The Research of Direct Torque Control Based on Space Vector Modulation

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Abstract. In order to solve the conventional direct torque control contradiction between the dynamic and static performance ,a permanent magnet synchronous motor system direct torque control architecture is proposed based on space vector modulation strategy . In this method flux and torque are controlled through stator voltage components in stator fluxlinkage coordinate axes and space vector modulation is used to control inverters.The simulation verifies that SVM-DTCis capable of effectively improving the steady state performance and keeping the excellent dynamic performance of theconventional DTC system simultaneously and remain the switching frequency constant.

Keywords: Simulation, Direct torque control, Space vector modulation.

1. Introduction

Direct torque control (DTC) has been widely used in the field of control of permanent magnet synchronous motor (PMSM), because it has the advantages of simple structure and fast dynamic response of the torque, which has been paid more and more attention in recent years [1-3].Conventional direct torque control is based on the torque, flux hysteresis controller output and a 60° stator flux linkage angle based on the signal, according to certain rules from the prefabricated switch table select the appropriate space voltage vector on the motorTorque, flux linkage for Bang-Bang control [4].However, according to this way of selecting the voltage vector can not meet the system of torque and flux linkage of the double request, will have a larger torque and flux ripple [5].In addition, the conventional DTC method can cause the output of the hysteresis controller and the position of the stator flux linkage signal to be constant over multiple sampling periods, resulting in the same switch state of the inverter during these sampling periods, and thus the switching frequency of the system is changedNot constant, the capacity of the power device can not be fully utilized [6].Space Vector Modulation (SVM) is used to obtain the desired arbitrary voltage vector by combining adjacent effective voltage vector and zero-voltage vector in one sampling period, and the voltage vector is linearly adjustable [7].

2. Space Vector Modulation Algorithm

There are eight switching states for three-phase voltage source inverters, corresponding to six active voltage vectors: U1 (100), U2 (110), U3 (010), U4 (011), U5 (001), U6 (101) And two zero-voltage vectors U7 (000), U8 (111). Space vector modulation is applied to the motor is based on three-phase symmetrical sinusoidal voltage supply AC motor generated by the ideal circular flux trajectory as the base, through the eight basic space voltage vector to the equivalent reference voltage vector so that the actual motor The air-gap trajectory approaches the ideal circle.

As shown in Fig. 1, in the coordinate system, the first sector is used as an example to synthesize the reference vector with two adjacent voltage vectors U1, U2 and zero vectors U0 (U7 and U8). According to the volt-second balance principle:

$$\mathbf{U}_1 T_1 + \mathbf{U}_2 T_2 + \mathbf{U}_0 T_0 = \mathbf{U}_s^* T_s \tag{1}$$

Where, T1, T2, respectively U1, U2 role of time, T0 is zero vector of time, T5 for the PWM cycle. The meaning of formula (1) is that the integral effect produced by the vector in T5 time is the same as the integration effect of U1, U2 and zero vector U0.

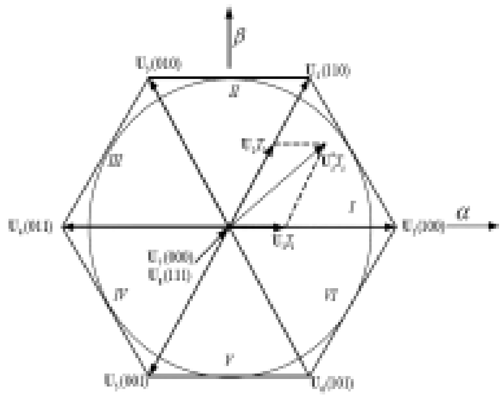


Figure.1 space voltage vector and sector

(1) U1, U2 and in axis decomposition obtained:

$$\begin{cases} T_1 = \dfrac{T_s}{2U_d}(3U_\alpha - \sqrt{3}U_\beta) \\ T_2 = \sqrt{3}\dfrac{T_s}{U_d}U_\beta \\ T_0 = T_s - T_1 - T_2 \end{cases} \tag{2}$$

The amplitude of the fundamental voltage of the output voltage increases linearly with time, and the time T0 of the zero vector U0 decreases gradually, but the following relationship should be satisfied:

$$\begin{cases} T_1 + T_2 \le T_s \\ T_0 \ge 0 \end{cases} \tag{3}$$

Similarly, in the remaining five sectors, the basic space voltage vector will change with the region of the corresponding changes. This allows SVM technology to synthesize any required space voltage vectors.

Space vector modulation is to use a certain frequency ($1/T_s$) and amplitude ($T_s/2$) of the equivalent time triangular wave to modulate A, B, C three-phase switching time T_{cm1} , T_{cm2} , T_{cm3} ,that is, the modulation signal. From the basic modulation principle of SVM, the maximum linear range of SVM is the inscribed circle shown in Fig.1, that is, the space vector modulation in the inscribed circle is linear modulation, while the over-inscribed circle is overmodulation . The following simulation and experimental analysis and comparison of different reference voltage vector in the case, SVM modulation signal and output line voltage waveform and the relationship between.

3. Dynamic Control of Stator Flux Linkage

Figure 2 depicts the relationship between the stator flux linkage and the space voltage vector in the motor operation and the relationship between the stator flux in a single sampling period T5Dynamic control process stator flux.

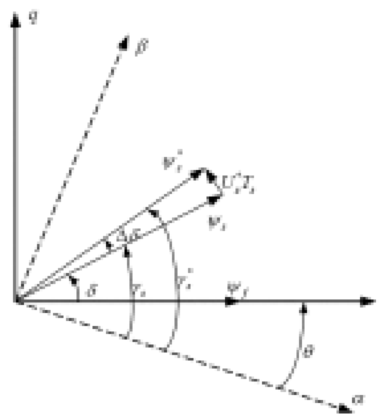


Figure.2 flux linkage diagram

In Fig. 2, the phase angle γ_s of the stator flux vector $\boldsymbol{\o}_s$ at the present moment can be estimated by the flux estimator in the stator two-phase stationary coordinate system $\alpha\beta$,If the control system gives the reference flux linkage $\boldsymbol{\o}^*_s$ with the phase angle γ^*_s , the stator flux linkage $\Delta\delta$ angle ahead of the current time, if the actual flux vector arrives at the reference flux linkage at the next sampling time, a space voltage vector $\mathbf{U}^*_s$ as shown in the figure should be applied in the time period of the sampling period T5, the reason for this is that the magnitude and phase angle of the applied space voltage vector U5 * can be calculated from equations (4) ~ (7) by moving the end points of the flux vector in the direction of the applied space voltage vector.

$$U^*_{s\alpha} = \frac{|\boldsymbol{\o}^*_s|\cos(\gamma_s+\Delta\delta) - |\ _s|\cos\gamma_s}{T_s} + R_s i_{s\alpha} \approx \frac{|\ ^*_s|\cos(\gamma_s+\Delta\delta) - |\ _s|\cos\gamma_s}{T_s} \quad (4)$$

$$U^*_{s\beta} = \frac{|\boldsymbol{\o}^*_s|\sin(\gamma_s+\Delta\delta) - |\ _s|\sin\gamma_s}{T_s} + R_s i_{s\beta} \approx \frac{|\ ^*_s|\sin(\gamma_s+\Delta\delta) - |\ _s|\sin\gamma_s}{T_s} \quad (5)$$

$$\left|\mathbf{U}^*_s\right| = \sqrt{{U^*_{s\alpha}}^2 + {U^*_{s\beta}}^2} \quad (6)$$

$$\varphi^*_s = \arctan(U^*_{s\beta} / U^*_{s\alpha}) \quad (7)$$

Where $U^*_{s\alpha}$ and $U^*_{s\beta}$ are the components of the reference voltage vector $\mathbf{U}^*_s$ in the two-phase stationary coordinate system $\alpha\beta$, respectively, $\left|\mathbf{U}^*_s\right|$ and φ^*_s , respectivelyis the amplitude and phase angle of $\mathbf{U}^*_s$. The stator flux vector magnitude and phase angle, torque can be calculated by the following formula:

$$\begin{cases} \psi_{s\alpha} = \int (u_{s\alpha} - R_s i_{s\alpha})dt \\ \psi_{s\beta} = \int (u_{s\beta} - R_s i_{s\beta})dt \end{cases} \quad (8)$$

$$|\psi_s| = \sqrt{\psi_{s\alpha}^2 + \psi_{s\beta}^2} \quad (9)$$

$$\gamma_s = \arctan(\psi_{s\beta} / \psi_{s\alpha}) \quad (10)$$

$$T_e = \frac{3}{2} N_p (\psi_{s\alpha} i_{s\beta} - \psi_{s\beta} i_{s\alpha}) \quad (11)$$

The subscripts α and β are the components of each physical quantity on the $\alpha\beta$ -axis of the stator two-phase stationary coordinate system.

4. Direct Torque Control of Space Vector Modulation

The structure diagram of the direct torque control system (SVM-DTC) of permanent magnet synchronous motor based on space vector modulation is shown in Fig.3, Where the reference flux calculation model element and the space voltage vector modulation element SVM replaces the flux linkage in a conventional DTCand a torque hysteresis controller and switch table.

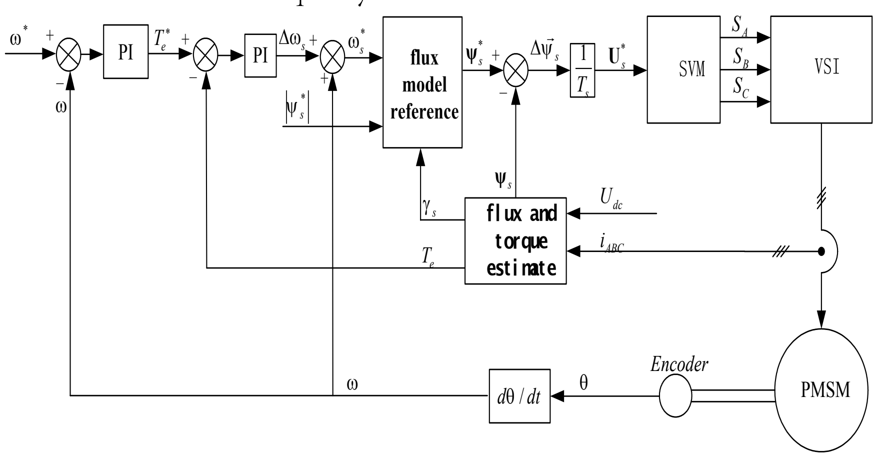


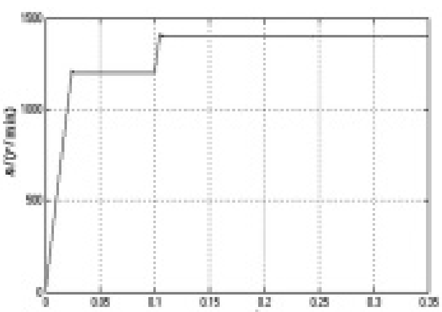
Figure.3 SVM-DTC block diagram of the structure

In Fig. 3, the difference between the reference angular velocity ω_s^* and the feedback angular velocity ω is output to the reference torque command T_e^* via a PI regulator.As the steady-state stator flux rotation speed and the rotor speed of rotation is the same, that is, synchronous speed ω , and when the reference torque or load torque in the dynamic process of mutation, the two speeds will be significantly inconsistent, the stator the flux rotation speed is significantly faster than the rotor rotation speed, there is a difference between the two rotational speed difference $\Delta\omega_s$ .Thus, the difference between the reference torque T_e^* and the estimated torque T_e can be output by a PI regulator, which is the stator flux rotational speed increment $\Delta\omega_s$,to reflect the dynamic change of the torque in real time.Thus, the total rotational speed ω_s^* of the flux linkage in one sampling period can be determined by the steady-state rotation speed ω and the rate of changeOf the rotational speed difference $\Delta\omega_s$, that is, the system should be in the next sampling period given the flux reference speed.After obtaining the total flux rotation speed ω_s^* , the reference flux vector ϕ_s^* given in the next sampling period can be obtained by referring to the flux linkage calculation model.The reference flux vector ϕ_s^* and the estimated flux vector ϕ_s of the current time can be calculated in the next sampling cycle should be applied to the space voltage vector $\mathbf{U}_s^*$, space voltage vector $\mathbf{U}_s^*$ and then through the space voltage vector modulation unit SVM to generate PWM pulse signal S_A , S_B and S_C , the final control voltage source inverter VSI drive permanent magnet synchronous motor.This new structure has the following advantages: PI regulator parameter adjustment is easy, and will not make the entire control system is running difficult.The product $\Delta\delta$ of the stator flux angle at the next time can be obtained by multiplying the flux rotation speed ω_s^* and the sampling period T5. Therefore, it is possible to adjust T5 todetermine $\Delta\delta$, which is easy to implement in the actual system.

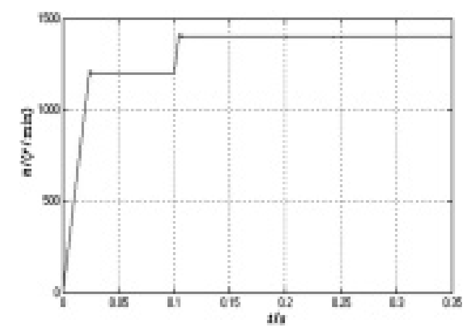
5. Simulation Analysis

The SVM-DTC control of permanent magnet synchronous motor (PMSM) based on the above-mentioned principle is established by Matlab / Simulink simulation softwareSystem model.The simulation motor parameters are: UN = 220v; NP = 4; Rs = 2.875 ohms; Ld = 8.5mH; Lq = 8.5mH;F = 0.175Wb.Specific simulation conditions are set to: no-load start, the initial speed 1200r / min, 0.1s step to 1400 r / min,The load was applied to the 2 N • m at 0.2 s.

Figures 4 to 6 show the performance comparison of the conventional DTC and SVM-DTC simulation results, respectively.As can be seen from the figure,The response time of this control system is very short, almost no overshoot, which is the direct torque control of the outstanding advantages.From the torqueWaveform, the control mode of dynamic response is very fast, steady-state SVM-DTC torque fluctuations more stable, which canIt is seen from the current waveform that the current waveform of the SVM-DTC is closer to the sine wave than the conventional DTC current waveform.These differences is that the conventional DTC can only be controlled by selecting six basic active space voltage vectors and a hysteresis controller and SVM-DTC can use SVM to arbitrarily linearly combine the required space voltage vector to by real-time sampling calculation can be more precise control of the stator flux linkage.

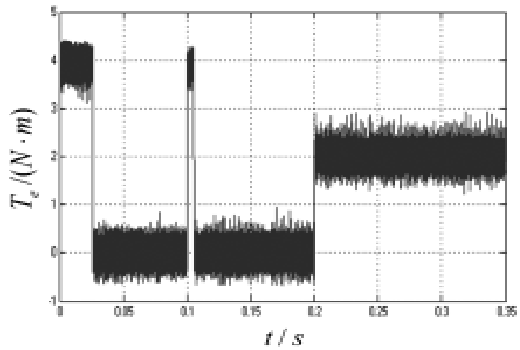


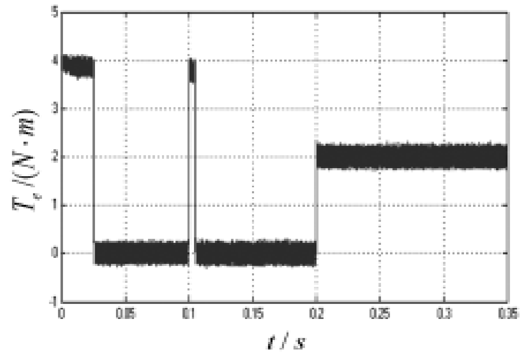
(a) Conventional DTC velocity response curve



(b) SVM-DTC velocity response curve

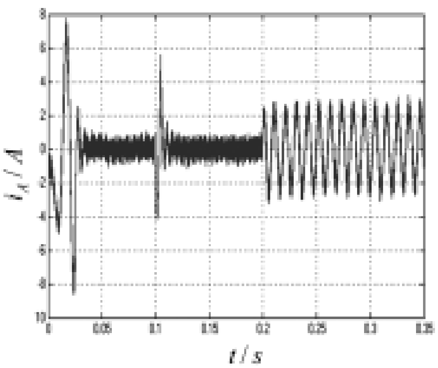
Figure .4 two kinds of control speed response curve

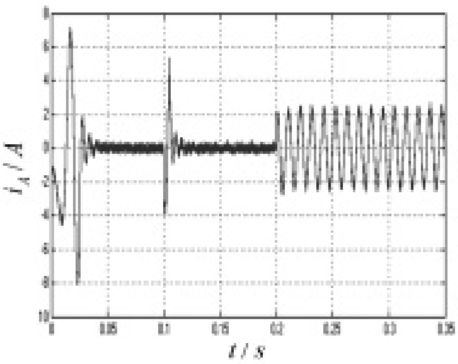




(a) Conventional DTC torque response curve (b)SVM-DTC torque response curve

Figure.5 two kinds of control torque response curve





(a)Conventional DTC Phase Current Curves (b)SVM-DTC phase current curve

Figure.6 two kinds of control phase current curve

Torque Figure 7 for the SVM-DTC control process of the motor torque angle δ waveform of the change, we can see that the torque angle is electromagnetic torque changes consistent.In most steady-state processes, the torque angle δ is in the vicinity of a fixed value to do a small wave and the torque angle also changes rapidly in the dynamic process of rapid torque change.

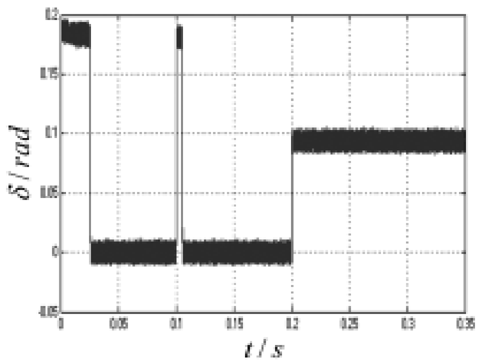


Figure.7 Torque angle δ curve

6. Conclusion

In order to solve the contradiction between dynamic and static performance of conventional direct torque control, that is, the contradiction between torque, fast response of flux linkage and torque, and large steady-state pulsation of flux linkage, this paper proposes a space vector based on space vector (PMSM) direct torque control (SVM-DTC), the principle and implementation of the scheme are discussed in detail. It is pointed out that the conventional DTC can only control the motor torque and flux linkage with a limited basic voltage vector, but none of the basic space voltage vectors can completely compensate the flux and torque errors in the system at the same time. Vector Modulation (SVM) is a promising solution. Secondly, the basic principle of SVM is expounded briefly. The SVM algorithm under different reference voltage vector input is analyzed, simulated and experimented. The SVM algorithm and its application are discussed in detail. Implementation has a clearer understanding. Finally, the SVM-DTC is discussed in detail, including the structure of the control system, the dynamic control process of the stator flux vector, the method of flux and torque estimation and the calculation model of the reference flux, etc. Theoretically, And the best compensation principle of flux error. Finally, the realization of SVM-DTC is studied, and compared with conventional DTC, the correctness of the control strategy is verified. Simulation results show that compared with conventional direct torque control, SVM-DTC has the advantages of faster dynamic response of conventional DTC and more stable steady-state operation while keeping the switching frequency of power devices constant. Because SVM-DTC has low hardware requirements and good control performance, it can effectively solve the contradiction between dynamic and static performance of conventional DTC, so it has good application prospects.

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