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TORQUE RESPONSE PERFORMANCE ANALYSIS OF PMSM DTC

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Abstract:-

In this paper, the basic principle of permanent magnet synchronous motor direct torque control, and the torque response performance of permanent magnet synchronous motor direct torque control are investigated. PMSM model is built and simulated on MATLAB / SIMULINK platform. The simulation results show that the permanent magnet synchronous motor direct torque control system have fast torque response, good dynamic performance and can quickly follow a variety changes of given torque. But in the full range of run-time, permanent magnet synchronous motor direct torque control system has relatively large torque ripple and rich harmonics, which is the traditional permanent magnet synchronous motor direct torque control's major defects.

Keywords:-*Permanent Magnet Synchronous Motor, Direct Torque Control, Torque Response, MATLAB/Simulink.*

1. INTRODUCTION

As a new motor, Permanent magnet synchronous motor removes the brush and commutator structure, have high operational reliability. Permanent magnet synchronous motor developed rapidly, coupled with its high efficiency, low loss, small size and a series of energy saving and environmental protection is of great significance for excellent performance. Therefore, the study has significant social and economic benefits [1-2].

This paper analyzes the operation principle of permanent magnet synchronous motor direct torque control. First, this paper states the basic concept of PMSM DTC, then detailed analysis of how it works. Including space vector voltage generation and space vector voltage control of the stator flux and torque. Finally, MATLAB / Simulink establishes permanent magnet synchronous motor system simulation model, and study it on DTC control simulation, then get the simulation results and analyse the torque response performance. The simulation results show that the theoretical analysis of the control is a manner that is consistent with good dynamic performance, but the torque ripple is relatively large, and harmonics is relatively rich.

2. PMSM-DTC Control Overview

2.1 Flux Control Principle

Stator flux for the armature back EMF integral [3-4]:

$$\psi_s(t)=\int_0^t (u_s - Ri_s)d\tau + \psi_0 \tag{1}$$

Among them, □$_0$ is the initial stator flux. When the motor running speed gets to a certain value (high-speed), stator resistance pressure drop should be ignored. In this case, in □t , from t_1 to t_2 , expression (1) under the space voltag vector u_s can be discretized as

$$\Delta\psi_s = \psi_s(t_2) - \psi_s(t_1) \approx u_s \Delta t \tag{2}$$

This equation shows two things: first, the direction of movement of the stator flux trajectory is consistent with the direction of the applied voltage vector space; size of the second velocity is proportional to the amplitude of the voltage space vector. Therefore, applying a suitable space voltage vector can control the stator flux trajectory range of motion. The space is divided into six sectors □$_1$, □$_2$, □$_3$, □$_4$, □$_5$ and □$_6$. Using sectors to select space voltage vector, as shown in **Figure 1:**

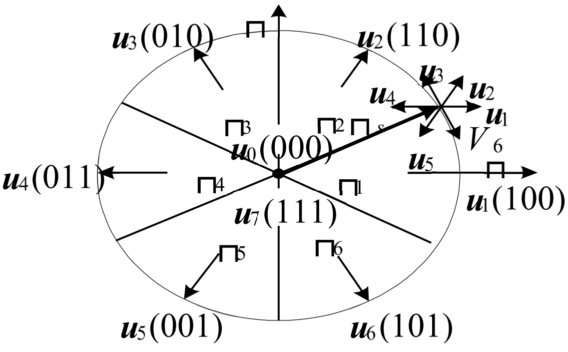

Fig. 1 space flux zoning diagram

In order to keep the amplitude of the stator flux approximately constant, according to flux bias current size and location flux, selecting the appropriate space voltage vector to control the flux amplitude purposes. If the current flux in the first sector, namely □$_1$ sector, when Flux is rotated counterclockwise, SVPWM u_3 reduces flux amplitude, u_2 increases the flux amplitude. According to this, choosing the appropriate space voltage vector to maintain a nearly constant flux amplitude. 2.2 PMSM-DTC System Control link The core issue of control is to generate the switch table, the switch table is mainly based on flux, torque and active sector decisions, as shown in figure 2 PMSM-DTC control includes the following aspects [5-7]：

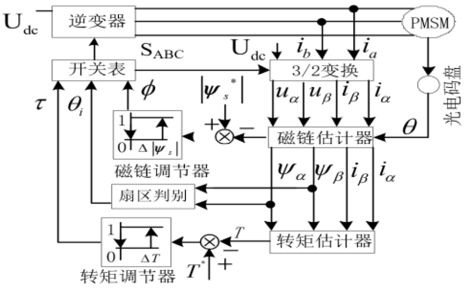

Fig. 2 PMSM-DTC system block diagram

(1) Detecting two-phase current i_a , i_b , through 3/2 transformation, to get a stationary two-phase coordinate system $i_{□}$, $i_{□}$ current; according to the bus voltage Udc and the inverter switch mode S_{ABC} may constitute a three-phase voltage, transformed by 3/2 to give a stationary two-phase coordinate system $u_{□}$, $u_{□}$ voltage;

(2) Calculated by the formula (1) to obtain the estimated stator flux $\boldsymbol{\psi}_s$ and the amplitude $|\boldsymbol{\psi}_s|$; by the formula (3) to obtain the estimated electromagnetic torque T;

Electromagnetic torque T in a rotating coordinate system is expressed as:

$$T = \frac{3}{2} P[\psi_f i_q - (L_q - L_d) i_d i_q] \tag{3}$$

(3)When the torque given $|\psi_s^*|$ and the difference between the actual torque $|\psi_s|$ greater than the torque regulator hysteresis band $\Delta|\psi_s|$, when that is $|\psi_s^*| - |\psi_s| > \Delta|\psi_s|$, so that the torque hysteresis regulator output $\phi = 1$, on behalf of the system requirements increase torque; if $|\psi_s| - |\psi_s^*| > \Delta|\psi_s|$ the transfer order moments hysteresis regulator output $\phi = 0$, indicates that the system is required to reduce torque;

(4) Also note the stator flux amplitude $|\psi_s|$, given $|\psi_s^*|$ and the actual flux amplitude difference of $\Delta|\psi_s|$, when the feedback flux less than flux amplitude given value, namely $|\psi_s^*| - |\psi_s| > \Delta|\psi_s|$, on behalf of the system requirements increase flux, flux hysteresis regulator output $\phi = 1$, indicates that the requested increase in flux; if $|\psi_s| - |\psi_s^*| > \Delta|\psi_s|$, then $\phi = 0$, on behalf of the system is required to reduce flux, said to reduce the flux;

(5) According to the torque regulator output τ , flux regulator output ϕ and the stator flux ψ_s in sector θ_i to select where the effective voltage vector effects. If the current stator flux vector ψ_s in the first sector, and the $\phi = 1$, $\tau = 1$, is said to increase the torque and flux, so choose the role of the effective voltage vector is $u_2(110)$, by analogy, the inverter switching table can be constituted. Above figure 1 for example, when the stator flux vector ψ_s falls on the boundary between the first and second sectors, namely in the 30 ° angle at the time, if $\phi = 1$, $\tau = 1$, can be seen at this time that the effective voltage vector $u_3(010)$ can increase the torque more quickly than $u_2(110)$, so it should choose $u_3(010)$, which can get the sector boundaries on the inverter switching table:

: Table 1 Inverter switching table

ϕ	τ	30°	90°	150°	210°	270°	330°
1	1	u_3	u_4	u_5	u_6	u_1	u_2
	0	u_6	u_1	u_2	u_3	u_4	u_5
0	1	u_4	u_5	u_6	u_1	u_2	u_3
	0	u_5	u_6	u_1	u_2	u_3	u_4

3. PMSM-DTC System’s MATLAB / Simulink Realization

3.1 System Simulation Chart

According to the figure 2, a block diagram of the control principle, carring out in MATLAB PMSM direct torque control system modeling, as shown in Figure 3:

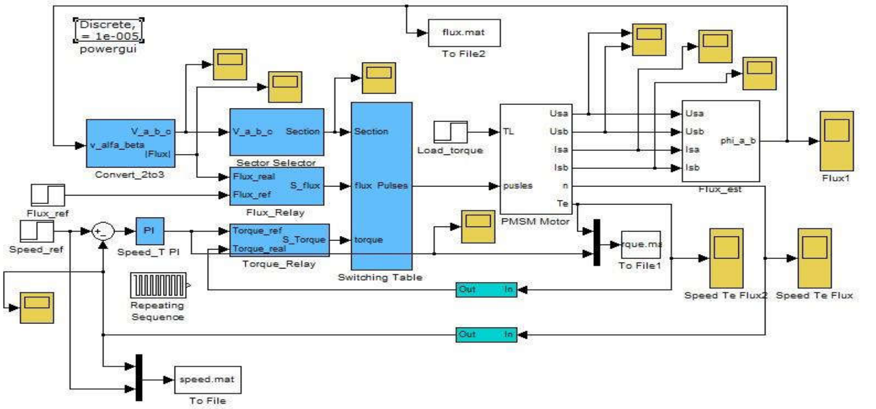

Fig.3 MATLAB simulation model of permanent magnet synchronous motor direct torque control system

The system is composed of several modules: the flux and torque hysteresis comparison and calculation module, sector selection, switch tables, inverter module, permanent magnet synchronous motor body module.

3.2 PMSM DTC’s Torque Response Performance Analysis

Setting the parameters correctly is a prerequisite for the success of the simulation, the electrical parameters of the system are set as follows:

Motor stator resistance R_s□1.11□ ; linear motor axis inductance L_d□ 0.0166H ; cross-axis motor inductance L_q□ 0.01645H; permanent magnet rotor flux amplitude $□_f$□ 0.5072Wb ; moment of inertia of the motor J□ 0.01kg m^2 ; motor pole pairs n_p □2; DC bus voltage U_{dc}=538V .

3.2.1 Simulation Analysis of Stable Operation

Load torque setting system for 3N•m, given the speed 1000r / min, given flux 0.5072Wb.

The simulation results are as follows:

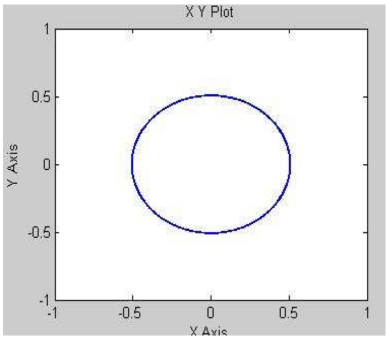

Figure 4: stator flux trajectory circles

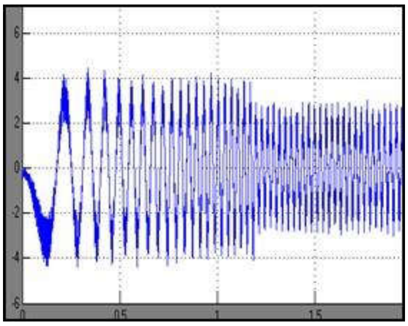

Figure 5: stator phase current

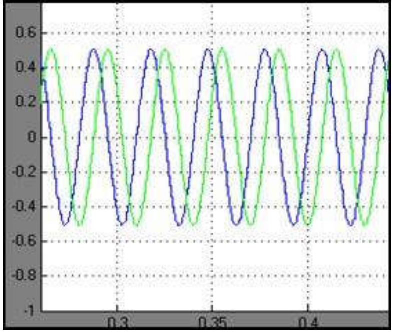

Figure 6: two-phase stationary stator flux

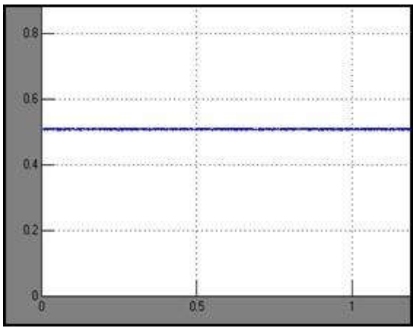

Figure 7: flux curve

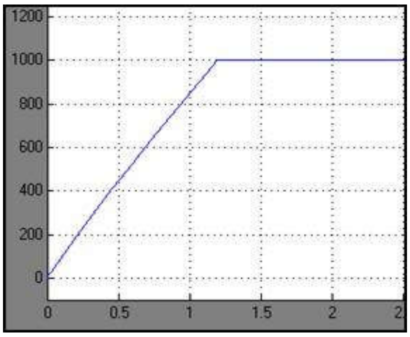

Figure 8: speed

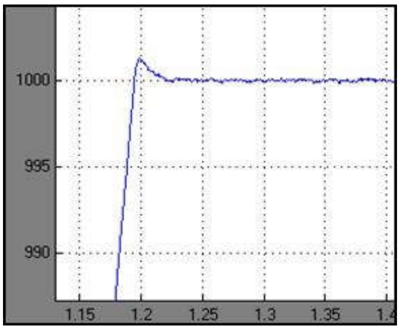

Figure 9: a partial enlarged speed

As can be seen from Figure 4, the stator flux trajectory is very close to a circle, in permanent magnet synchronous motor direct torque control, the stator flux control is more satisfactory, the stator flux circle has no serious distortion. It can be seen in Figure 5 stator current quickly restored sinusoidal, indicating that the current has good steady-state performance. Figs. 6 and 7 reflect the flux always runs at a constant value and it is very close to the reference value. Known from Figs. 8 and 9 in the vicinity of 1.2s, the speed increases from 0 to 1000 r/min into the ramp, and then it run at a constant speed 1000 r/min and stable operation, showing permanent magnet synchronous motors direct torque control can achieve faster, and has relatively high control accuracy.

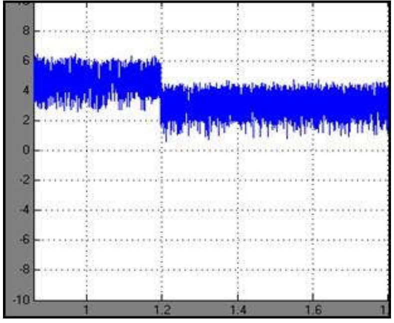

Figure 10: torque

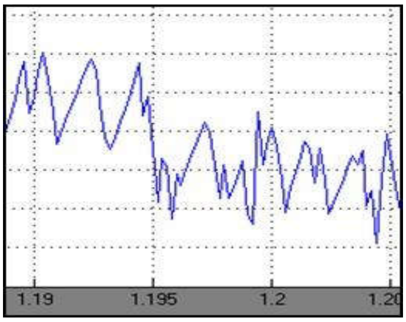

Figure 11: torque enlarged

As can be seen from Fig. 10, the motor electromagnetic torque soon rise to a maximum value when it just started, indicating that the permanent magnet synchronous motor starts with maximum torque. Before 1.2s, electromagnetic torque reached first a steady-state value 5N•m, after a short dump to settle down to reach the second steady state value 3N•m. Thus, the torque required 1.2s to reach a steady, relatively fast response, but another steady state values appear in 1.2s before this stage motor speed is relatively low, indicating that permanent magnet synchronous motor direct torque control at low speed control's effect is not satisfactory. It can be seen from Figure 11 there is a big torque ripple, this is the traditional PMSM DTC great deficiency.

3.2.2 Simulation and analysis of load mutation

This section simulation given speed 500r / min, PI controller parameters: Kp=1， Ki=100

(1)Rectangular pulse wave

Given the torque pulse wave is shown in Figure 12, the resulting simulation speed and torque is shown in Figure 13 and 14.

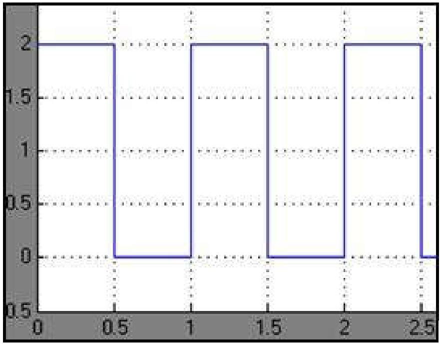

Figure 12: Given the torque

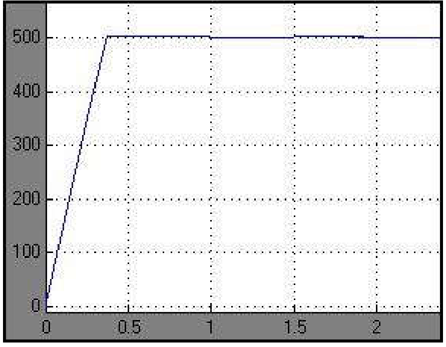

Figure 13: Speed

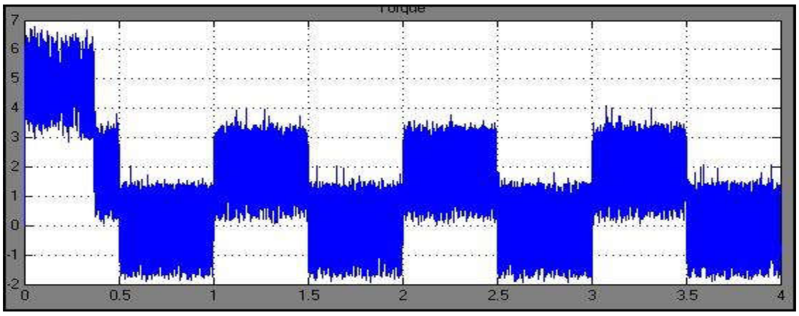

Figure 14: torque response when load torque mutation

As can be seen from Figure 14 in the vicinity of 0.4s torque reaches a steady state, beginning to follow the given torque variation, showing the amplitude of 2N•m, 50% duty cycle pulse change 1s, but pulsating is relatively huge. Speed control is precise.

(2) Sawtooth Triangle

Given torque is shown in Figure 15, is Sawtooth, the simulation results shown in Figure 16 and 17.

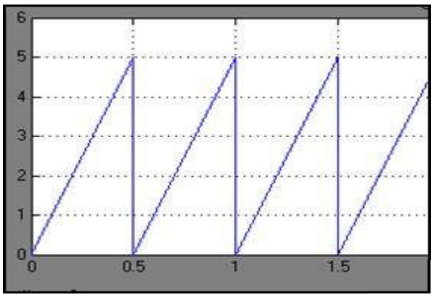

Figure 15: given the torque

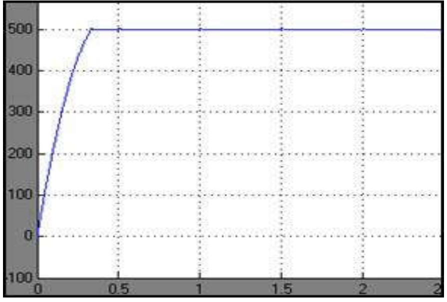

Figure 16: speed

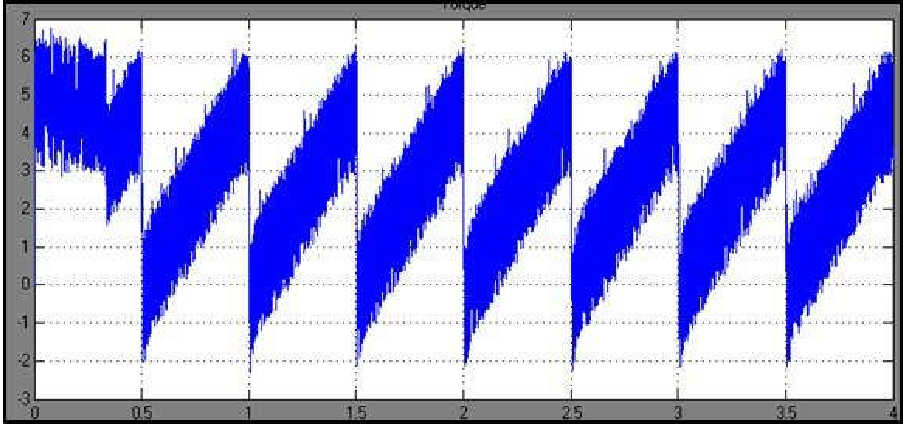

Figure 17: torque response when load torque mutation

As can be seen from Figure 17, the torque in the vicinity of 0.35s to reach steady state, begining to follow the given torque variation, showing the magnitude of 5N•m, cycle sawtooth change 0.5s, but pulsation is relatively large. Speed control is precise.

(3) sine wave

Given torque is shown in Figure 18, is the magnitude 2N•m, frequency 5rad / s sine wave.

Simulation results is shown in Figures 19 and 20.

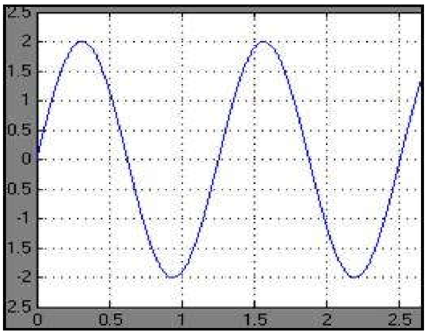

Figure 18: Given the torque

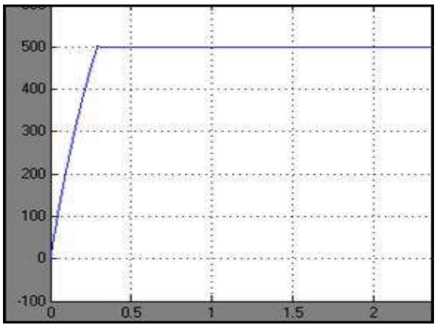

Figure 19: Speed

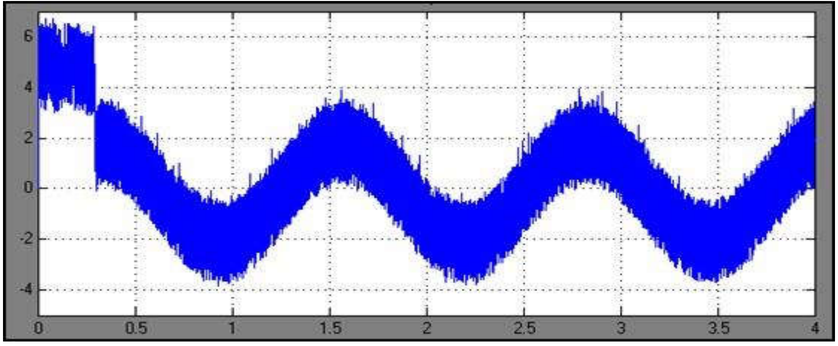

Figure 20: torque response when load torque mutation

As can be seen from Figure 20, the torque in the vicinity of 0.3s to reach steady state, beginning to follow the given torque variation, showing the amplitude of 2N•m sine wave cycle changes, but pulsation is relatively large. Speed control is precise.

The simulation results show that the permanent magnet synchronous motor direct torque control system have fast torque response, and can quickly follow a variety changes of given torque. But in the full range of run-time, permanent magnet synchronous motor direct torque control system has relatively large torque ripple and rich harmonics, which is the traditional permanent magnet synchronous motor direct torque control's major defects.

4. Conclusions

This paper gives PMSM DTC system configuration diagram and analyzes the realization process control system. For further analysis of the torque response performance of PMSM DTC, building the DTC model in the MATLAB / SIMULINK platform and simulate the system. Simulation results show that PMSM DTC has better dynamic response and faster response torque. But the current, flux and torque ripple is large, the inverter switching frequency is not constant, the control is not precise enough at low speed and torque ripple can easily cause high-frequency noise and so on.

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