Research on Improving Direct Torque Control of Permanent Magnet Synchronous Motor by Sliding Mode Variable Structure Control

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Abstract

This paper starts with the problem of torque shake of direct torque control of permanent magnetic synchronous motor, and changes the Bang-Bang controller of traditional direct torque control into a sliding mode controller by introducing the control of the sliding mode structure, and improves the inverter by changing the structure control strategy to realize the stability of the torque output characteristics of the control system. The transfer function of slip-mode structure control is improved by induction method, which makes the gain of the controller change the feedback variable actively with the system conditions, so as to achieve the purpose of adaptive. Finally, the simulation experimental data of MATLAB/Simulink as the platform show that the improved system can reduce the speed jitter and torque fluctuation, and compare the output performance with the traditional direct torque control, and give the control advantages embodied in the control mode in this paper.

Keywords

Permanent magnet synchronous motor; Sliding mode control; Direct torque control; Robustness.

1. Introduction

Because PMSM has high electromechanical energy conversion efficiency, not only energy saving but also small size, light weight, simple structure, reliable operation and flexible shape and size under the same power. my country is also a big country with rare earth resources. The reserves of rare earth ore are about four times the total of other countries in the world, and the output of rare earth ore and rare earth permanent magnets are among the top in the world[1]. With the advancement of technology, the scientific research level of rare earth permanent magnet materials and rare earth permanent magnet motors have reached the international advanced level. The development cost and application range of permanent magnet materials are becoming wider and wider. Give full play to the rich advantages of rare earth resources, and vigorously research and promote the application of various permanent magnet motors represented by rare earth permanent magnet motors[2], which will help my country to realize the society as soon as possible. Socialist modernization has important practical significance.

2. Surface mount PMSM mathematical model

For the surface-mounted PMSM rotor structure, it belongs to the hidden pole rotor structure in terms of electromagnetic performance. In order to simplify the analysis, it must be assumed that SPMSM meets the following conditions:

(1) Ignore the saturation of the motor core;
(2) Excluding the eddy current and hysteresis loss in the motor;
(3) The current in the motor is a symmetrical three-phase sine wave current.

On the premise that the above three conditions are met, the mathematical model of the three-phase surface mount PMSM under the d-q axis system is:

$$\begin{cases} J\frac{d\omega_m}{dt} = \frac{3}{2}p_n\psi_f i_q - B_0\omega_m - T_{L0} \\ L\frac{di_q}{dt} = u_q - R_s i_q - p_n\omega_m\psi_f - p_n\omega_m L i_d \\ L\frac{di_d}{dt} = u_d - R_s i_d + p_n\omega_m L i_q \end{cases} \tag{1}$$

In the formula,$R_s$is the stator resistance;i_q,$i_d$and u_q,$u_d$are the stator winding $d{-}q$ axis current and $d{-}q$ axis voltage ;L is the stator inductance;$\psi_f$is permanent magnet rotor flux.

This mathematical model[3] adds the transformation of the internal parameters of the motor and the external load jitter, and the formula(1) can be rewritten as:

$$\begin{bmatrix} \dot{\omega_m} \\ \dot{i_q} \\ \dot{i_d} \end{bmatrix} = \begin{bmatrix} \frac{3p_n\psi_f}{2J} & 0 & 0 \\ 0 & \frac{1}{L} & 0 \\ 0 & 0 & \frac{1}{L} \end{bmatrix} \begin{bmatrix} i_q \\ u_q \\ u_d \end{bmatrix} + \begin{bmatrix} \frac{3p_n\Delta\psi_f i_q - 2(B_0\omega_m + T_{L0} + \Delta T_L)}{2J} \\ \frac{\Delta u_q - R_s i_q + p_n\omega_m\psi_f}{L} - p_n\omega_m i_d \\ \frac{\Delta u_d - R_s i_d}{L} + p_n\omega_m i_q \end{bmatrix} \tag{2}$$

In the formula, ΔT_L is the load torque change; $\Delta\psi_f$ is the change of permanent magnet flux linkage;Δu_q,$\Delta u_d$is the amount of change in the motor stator voltage under the shaft system caused by the change of motor parameters[4].

3. Analysis of the disadvantages of traditional PMSM direct torque control

Direct torque control can effectively judge the segment of the stator flux linkage based on the obtained flux linkage component, compare the difference between the stator flux linkage given value and the corresponding estimated value, and then send the signal through the hysteres is comparator. Enter the voltage vector lookup table. The appropriate switching state can be determined by setting the hysteresis state table for judgment, and then the control of PMSM can be completed by controlling the switching frequency of the inverter[5].The basic process is that the error between the set value of the flux linkage torque and the actual value of the flux linkage torque is transmitted to the hysteresis comparator, and the appropriate motor space vector is obtained through the offline operation switch table, so as to realize the speed control of the motor.

However, direct torque control also has some shortcomings, mainly due to the large torque ripple at low speed:

(1) Since the PWM control wave is generated by the hysteresis comparator, the inverter's switching frequency jitter is large, and the torque ripple is also relatively large.
(2) When the motor is running at low speed, the stator resistance voltage drop is large and the flux calculation error is large, which makes the PMSM-DTC speed control range narrow.
(3) Since both the torque and flux regulators use hysteresis comparators, torque pulsation is inevitably caused;
(4) The switching frequency of the inverter will also affect the magnitude of the torque ripple. The higher the switching frequency, the smaller the torque ripple. On the contrary, the lower the switching frequency, the greater the torque ripple[6].

4. Research on improvement of sliding mode variable structure control strategy

Sliding mode variable structure control improves the transfer function of sliding mode variable structure control through induction, so that the control function of the controller can be changed according to the current state of the system to achieve the purpose of self-adaptation[7].The advantages are that there is no need to perform accurate calculations on the system, and the control method is simple; and it has complete adaptability to parameter changes and external disturbances, fast recovery time after disturbance injection, and better system robustness. Aiming at the chattering problem of DTC, the improved system can better reduce speed jitter and torque fluctuation. In the SISO system, if there is an unknown complex structure, the original motor mathematical model can be improved with the help of the hyperlocal mathematical model:

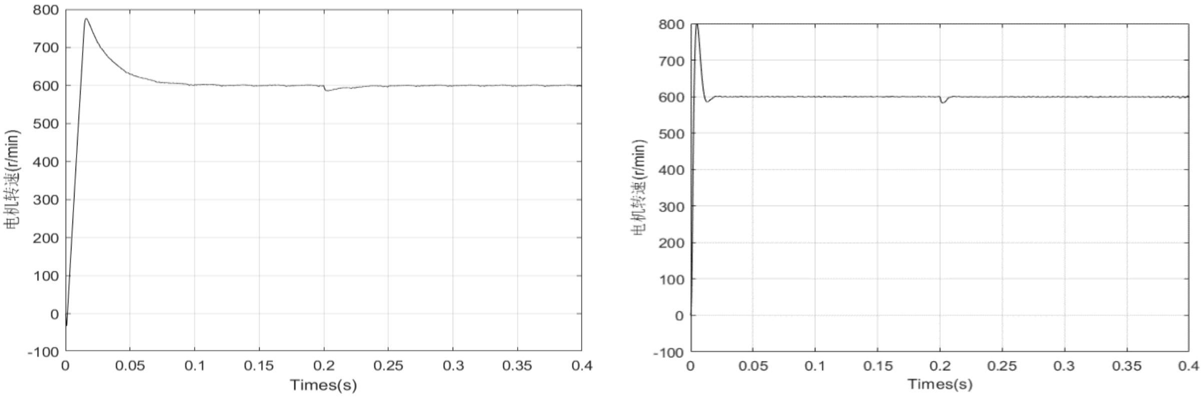
$$\boldsymbol{Y^{(w)} = N + aX} \tag{3}$$

In the formula: w is the order of the higher-order derivative of the system output Y, this simulation system takes w=1; a is a constant; N is the unknown quantity of the system. According to formula (9), the motor mathematical model can be improved into the following new mathematical model[8]:

$$\begin{bmatrix} \dot{\omega}_m \\ \dot{i}_q \\ \dot{i}_d \end{bmatrix} = \begin{bmatrix} N_w \\ N_q \\ N_d \end{bmatrix} + \begin{bmatrix} a_w & 0 & 0 \\ 0 & a_q & 0 \\ 0 & 0 & a_d \end{bmatrix} \begin{bmatrix} i_q \\ u_q \\ u_d \end{bmatrix} \tag{4}$$

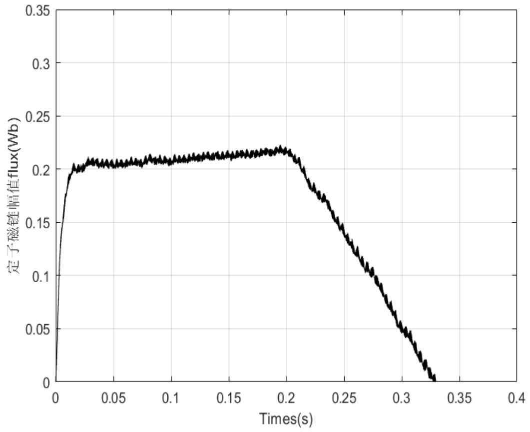
In the formula: $\begin{cases} \boldsymbol{a_w = \frac{3p_n\psi_f}{2J}} \\ \boldsymbol{a_q = a_d = \frac{1}{L}} \end{cases}$,N_w,N_q,N_d For unknown variables, the structure of the improved mathematical model is greatly simplified, enabling the system to exhibit faster response speed and anti-interference performance.

Compare the two control methods described in this article before and after, as shown in Figure 1, Figure 2 and Figure 3. According to the simulation results, it can be seen that compared with the traditional direct torque control, the PMSM-DTC sliding mode variable structure control strategy given in this paper can effectively improve the response speed of the traditional DTC, the speed response speed and torque chattering problems, and enhance the system robustness. Great and reduced torque ripple[9].

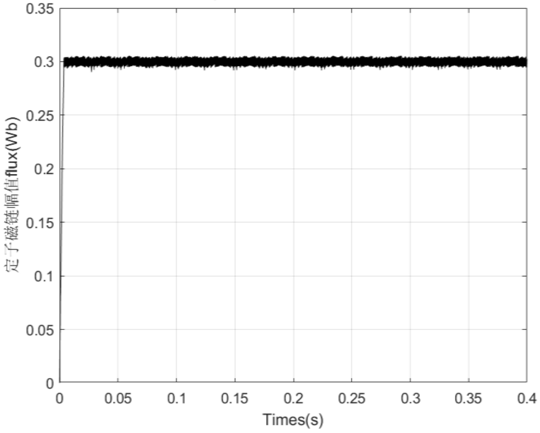


(a) Motor speed under traditional DTC(b) The motor speed under the improved PMSM DTC

Fig.1 The motor speed under the improved PMSM DTC

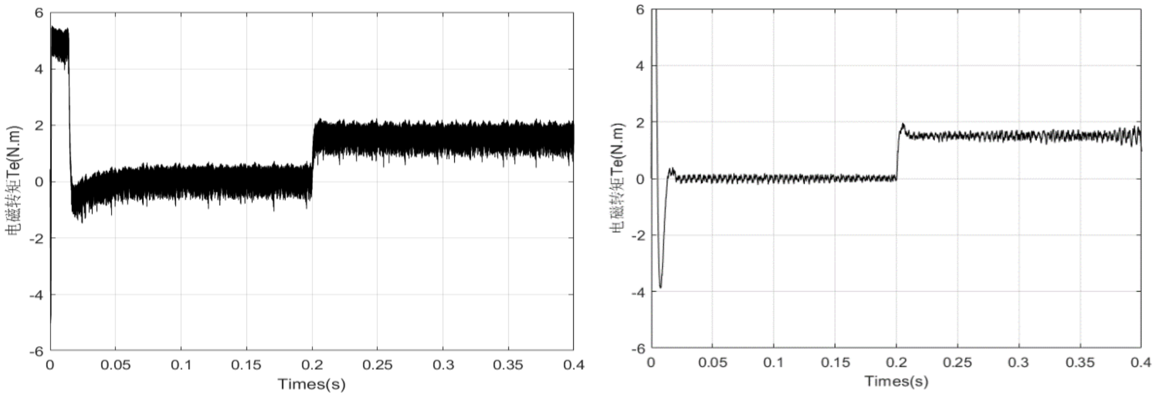


(a) Motor stator flux linkage amplitude under traditional DTC



(b) Improved PMSM DTC motor flux linkage amplitude

Fig.2 Motor stator flux linkage amplitude under traditional DTC



(a) (b)

Fig.3 Motor torque under improved PMSM DTC

5. Conclusion

Aiming at the shortcomings of traditional direct torque control systems, this paper proposes an improved scheme of PMSM-DTC system based on sliding mode variable structure control, and designs new sliding mode controllers and speed PI controllers. Aiming at the chattering of the sliding mode controller, a new hyperlocal mathematical model algorithm is used to eliminate the chattering problem; the improved PMSM-DTC can significantly accelerate the initial state response speed of the motor, from the original 0.1s to 0.02s.The improved system not only meets the given requirements, but also reduces the torque ripple; under the premise of accelerating the response speed, the sudden increase is improved to a fluctuating increase, which reduces the unstable factors of the motor;

improves the robustness of the system and eliminates The jitter problem in the control process greatly improves the control performance of SPMSM.

References

[1] Tang Renyuan. Modern permanent magnet motor theory and design [M]. Beijing: Machinery Industry Press, 2002.

[2] Wang Xiuhe. Permanent magnet motor [M]. Beijing: China Electric Power Press, 2007.

[3] Yuan Lei, etc. Modern permanent magnet synchronous motor control principle and MATLAB simulation [M]. Beijing: Beijing University of Aeronautics and Astronautics Press, 2016.

[4] Wang Chengyuan, etc. Modern motor control technology [M]. Beijing: Machinery Industry Press, 2017.

[5] Cui Hong, Li Yandong. Overview of Permanent Magnet Synchronous Motor Control Strategy[J]. Explosion-proof Motor, 2021, 56(03): 3-7.

[6] Li Qingguo. Ship electric propulsion system with improved direct torque control technology[J]. Ship Science and Technology, 2021, 43(06): 97-99.

[7] Xiao Xiong, Wang Haocheng, Wu Yujuan, Zhang Yongjun, Zhou Yanli, Li Jing. Master-slave structure coaxial dual-motor model prediction based on dual sliding mode estimation direct torque control speed sensorless control strategy[J]. Journal of Electrotechnical Engineering, 2021,36(05):1014-1026.

[8] Fan Yuanhui. Sensorless control and experimental research of permanent magnet motor based on a new sliding mode observer [D]. Shenyang University of Technology, 2020.

[9] Chen Shihu, Li Yinong. An improved torque predictive control method to reduce the torque ripple of permanent magnet synchronous motors[J]. Chinese Science and Technology Papers Online Boutique Paper, 2018, 14(11): 1461-1467.

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