Parameters adaptive backstepping control of PMSM using DTC method

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Abstract. The torque and flux ripple of traditional DTC control of PMSM is large, and due to the lack of adaptive control system, the change of the system parameters has a great impact on the steady and transient control performance of the motor speed. Based on the traditional DTC control algorithm, a parameter identification adaptive backstepping DTC control algorithm is proposed in this paper. Because the backstepping controller is used to replace PI controller and flux hysteresis controller, the steady-state and transient performance of the system is obviously improved. At the same time, a parameter identification adaptive controller is designed, which can effectively suppress the influence of parameter changes on the speed control performance. The simulation results verify the correctness and effectiveness of the control algorithm. The control algorithm can significantly improve the steady-state and transient performance of the system under the condition of parameter mutation.

1 Introduction

The traditional direct torque control (DTC) of permanent magnet synchronous motor (PMSM)^[1,2] has the advantages of less parameter dependence and faster response speed. However, due to the hysteresis controller used in the torque and flux control, the flux and torque ripple is too large^[3]. At the same time, the PI controller is used in the speed loop, resulting in a slow speed response. The backstepping control is a kind of nonlinear system control strategy and the decoupling and order reduction of control system are realized by Lyapunov function. In reference [4], a multi-stage hysteresis controller is proposed to improve the torque and flux ripple of traditional DTC. In reference [5], a novel sliding mode controller is designed, which combined with space vector modulation, can effectively reduce the torque and flux ripple of traditional DTC. Based on the backstepping control algorithm^[6-7], reference [8] proposed a control strategy based on space vector modulation, which has the same response speed as the traditional DTC, while significantly reducing the torque and flux ripple.

However, the above control methods do not consider the system response optimization under the condition of system parameter mutation. In high precision control system, the influence of these parameters should be considered. In this paper, the backstepping control of PMSM using DTC method is proposed by combining the backstepping control with adaptive control algorithm. This method can not only improve the performance of traditional DTC, but also suppress the influence of

parameter deviation and improve the robustness of the system.

2 System Description

2.1 Mathematical model of PMSM

$$\varphi_{\mu} = \varphi_v^2 + \varphi_o^2, \quad i = \frac{1}{J}, \quad \kappa = \frac{B}{J}, \quad v = \frac{1}{L_d}, \quad o = \frac{L_d}{L_d - L_q} \quad (1)$$

$$T_e = 1.5n_p (\varphi_v i_o + \varphi_o i_v), \quad \frac{d\omega}{dt} = \eta n_p (T_e - T_L) - \kappa \omega \quad (2)$$

$$\begin{cases} \frac{di_v}{dt} = -vRi_v - o\omega i_o - vE_v + vu_v \\ \frac{di_o}{dt} = -o\omega i_v - vRi_o - vE_o + vu_o \end{cases} \quad (3)$$

Where φ_{μ} is the stator flux linkage, φ_v, φ_o are the α axis and β axis flux linkage, J is the inertia, B is the viscous friction coefficient, i_v and i_o are the components of stator current in α axis and β axis, R is the phase resistance, ω is mechanical angular velocity, L_v and L_o are the equivalent inductances in d axis and q axis, E_v and E_o are the EMF in d axis and q axis, T_e is the electromagnetic torque, n_p is the number of rotor pole pairs.

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2.2 Control strategy design

$$\xi_\omega = \omega - \omega_{ref}, \xi_T = T_e - T_{ref}, \xi_\varphi = \varphi_s - \varphi_{ref} \quad (4)$$

$$\eta_1 = \frac{1}{2}\xi_\omega^2 + \frac{1}{2}\xi_T^2 + \frac{1}{2}\xi_\varphi^2 \quad (5)$$

$$T_L = T_L^* - \Delta T_L, R = R^* - \Delta R \quad (6)$$

$$u_v^* = \frac{2\varphi_o}{3n_p \left[\varphi_o(i_o - \varphi_o v) + \varphi_v(i_v - \varphi_o v) \right]} \cdot \left[1.5n_p(\varphi_v v i_o + \varphi_o v i_v) R^* - 1.5n_p(\omega o i_v - v E_o) \varphi_v \right. \\ \left. - m_p \xi_\omega - 1.5n_p(\varphi_o v - i_v) \left(\frac{R^* \varphi_v i_v}{\varphi_o} + R^* i_o - \frac{k_\varphi \xi_\varphi}{2\varphi_o} \right) - 1.5n_p(\omega o i_o + v E_v) + (\kappa - k_\omega) T_e \right. \\ \left. + (\kappa - k_\omega) T_L^* + \frac{\kappa \omega (\kappa - k_\omega)}{m_p} + \frac{\ddot{\omega}^*}{m_p} + \frac{k_\omega \dot{\omega}^*}{m_p} + \dot{T}_L^* - k_T \xi_T \right] \quad (7)$$

$$u_o^* = \frac{2\varphi_v}{3n_p \left[\varphi_o(v - i_o) + \varphi_v(\varphi_o v - i_v) \right]} \cdot \left[1.5n_p(\varphi_v v i_o + \varphi_o v i_v) R^* - 1.5n_p(\omega o i_v - v E_o) \varphi_v \right. \\ \left. - m_p \xi_\omega - 1.5n_p(i_o - \varphi_o v) \left(\frac{R^* \varphi_v i_v}{\varphi_o} + R^* i_v - \frac{k_\varphi \xi_\varphi}{2\varphi_v} \right) - 1.5n_p(\omega o i_o + v E_v) \varphi_\beta + (\kappa - k_\omega) T_e \right. \\ \left. + (\kappa - k_\omega) T_L^* + \frac{\kappa \omega (\kappa - k_\omega)}{m_p} + \frac{\ddot{\omega}^*}{m_p} + \frac{k_\omega \dot{\omega}^*}{m_p} + \dot{T}_L^* - k_T \xi_T \right] \quad (8)$$

By substitution of (6), (7) and (8) into the derivative of (5), we can obtain

$$\eta_2 = -k_\omega \xi_\omega^2 - k_T \xi_T^2 - k_\varphi \xi_\varphi^2 + m_p e_\omega \Delta T_L + (\kappa - k_\omega) \Delta T_L \\ + 1.5n_p(\varphi_v v i_o + \varphi_o v i_v) \Delta R + \xi_\varphi (2\Delta R \varphi_v i_v + 2\Delta R \varphi_o i_o) \quad (9)$$

Lyapunov function is chosen as follows

$$\eta_2 = \eta_1 + \frac{\Delta R^2}{2\lambda_1} + \frac{\Delta T_L^2}{2\lambda_2} \quad (10)$$

Where λ_1, λ_2 represents positive adaptive gains. Adaptive law is obtained:

$$\Delta \dot{T}_L = \lambda_2 (k_\omega - \kappa - m_p \xi_\omega) \quad (11)$$

$$\Delta \dot{R} = -1.5n_p(\varphi_v v i_o + \varphi_o v i_v) - 2\xi_\varphi \lambda_1(\varphi_v i_v + \varphi_o i_o) \quad (12)$$

By substitution of (11), (12) into the derivative of (10), we can obtain

The $\xi_\omega, \xi_T, \xi_\varphi$ are assumed that the tracking error of $\omega, T_e, \varphi_s, \Delta T_L, \Delta R$ are assumed that the estimations errors. The α and β axis voltage can be chosen as (7) and (8)

$$\frac{d\eta_2}{dt} = -k_\omega \xi_\omega^2 - k_T \xi_T^2 - k_\varphi \xi_\varphi^2 \leq 0 \quad (13)$$

$$\lim_{t \rightarrow \infty} \xi_\omega = \lim_{t \rightarrow \infty} \xi_T = \lim_{t \rightarrow \infty} \xi_\varphi = 0 \quad (14)$$

Selection of suitable controller gains k_ω, k_T, k_φ and

adaptive law gains r_1, r_2 can ensure the tracking error signals of system are asymptotically stable. That is to say, the control method proposed in this paper can quickly track the given reference signals and restrain the influence of outside interference at the same time.

3 Simulation Results

The controller gains value are $k_\omega = 0.02, k_T = 100, k_\varphi = 1000$. The adaptive identification parameters are $t_1 = 4.12, t_2 = 5.58$. The results of comparative experiments with reference speed $\omega = 20$ rad/s and load torque $T_L = 28 \text{ N}\cdot\text{m}$ are shown below.

Fig 1. Speed wave of the general DTC algorithm.

Fig 2. Speed wave of the algorithm in this paper.

Fig 3. Torque wave of the general DTC algorithm.

Fig 4. Torque wave of the algorithm in this paper.

From the above comparison, it can be seen that through the algorithm optimization, the speed and torque

ripple are significantly improved, and the response time is also significantly improved.

Fig 5. Speed wave of backstepping the general DTC without adaptive law

Fig 6. Speed wave of the algorithm in this paper with adaptive law

In order to verify the suppression of stator resistance and load mutation, comparative experiments are carried out. The stator resistance R_s is increased to 0.4Ω in $0.15s$, and the load torque T_L is increased to $42N \cdot m$ in $0.3s$. The speed change of PMSM is analyzed under the condition of parameter mutation.

The simulation results show that in the traditional algorithm, the speed deviates from the reference value about $1rad/s$ in $0.15s$, and there is an obvious jitter peak at $0.3s$. The control algorithm in this paper only has a small amplitude peak at $0.15s$ and $0.3s$, which can quickly recover to the reference value.

4 Conclusion

The traditional DTC control has large torque and speed ripple, and the steady state value of speed will shift when the parameter changes suddenly, which will affect the accuracy and robustness of the control system. The control algorithm proposed in this paper can solve the above problems. From the simulation results, it can be seen that the proposed control algorithm not only significantly reduces the torque and speed ripple, but also significantly shortens the response time. At the same time, there is no

static error in the speed tracking under the condition of parameter drift, which significantly improves the accuracy and robustness of the control system. The proposed control algorithm in this paper is of great significance to the precise control of the PMSM.

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