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Research on Torque Ripple Suppression of Permanent Magnet Synchronous Motor

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Abstract. With the increasing application of the permanent magnet synchronous motor, the requirements for the stability of the motor control system are improved, and the torque ripple play an important role on the system performance.This paper studies the generation and main suppression methods of torque pulsation of permanent magnet synchronous motor.

1. Introduction

In the society, electric energy is the most commonly used and the most common secondary energy, and as the electromechanical energy conversion device, the motor's electricity consumption accounts for 70% of the total power consumption.As the rational use of limited resources becomes more and more important, how to more effectively reduce energy consumption and improve the efficiency of the motor is around the corner, higher requirements for stability and reliability of the motor are put forward, and at present Permanent Magnet Synchronous Motor(PMSM) has the most advantages. The advencement of the power electronic technology, microcomputer control technology and control theories promoted the development of the motor adjustable speed control technology, but the most obvious shortcoming of PMSM is the existence of torque ripple. Due to the motor body design, deviation or negative potential of distortion of the controller, the resulting torque pulsation of the motor affects the stability of the speed and efficiency of the motor, so the study of torque ripple has important meaning.

2. Mathematical model of the PMSM

PMSM stator is similar with the general three-phase synchronous motor stator. Some assumptions is done in the modelling and analysis process: the distribution in the air gap of rotor permanent magnetic field is ignored; magnetic circuit is Linear. Inductance parameter is fixed. The core eddy current and hysteresis losses is excluded. No damper winding in the rotor.

Under the above assumption, model of PMSM in the d、q coordinates can be written as：

Voltage equation is:

$$\begin{cases} u_d = ri_d - \omega L_q i_q + \dfrac{d\psi_d}{dt} \\ u_q = ri_q + \omega L_d i_d + \dfrac{d\psi_q}{dt} \end{cases} \tag{1}$$

Flux equation is:

$$\begin{cases} \psi_d = L_d i_d + \psi_f \\ \psi_q = L_q i_q \end{cases} \tag{2}$$

For surface PMSM, $L_d = L_q = L$,torque equation is:

$$T_e = \frac{3}{2} p \left[\psi_f i_q + (L_d - L_q) i_d i_q \right] = \frac{3}{2} p \psi_f i_q \tag{3}$$

Mechanical equations of motion is:

$$T_e - T_L = \frac{J}{p} \frac{d\omega}{dt} \tag{4}$$

In the above equation, u_d , u_q , i_d , i_q , L_d , L_q are the voltage and current of axis d and axis q; r is the stator resistance is the pole pairs of motor; ψ_f is the flux of PMSM and the stator cross chain; T_e is electromagnetic torque; T_L is load torque; J is moment of inertia; ω is rotor electrical angular velocity.

3. Methods of torque ripple suppression

Torque ripple in motor operation is mainly caused by the following factors:

①Motor body aspect, processing reasons such as: Magnetic circuit asymmetry, the rotor is not coaxial, and saturation of the magnetic circuit. The magnetic field generated by the permanent magnet interacts with the armature slot and generates tooth groove torque.

②Current harmonic aspect, due to the existence of non-ideal factors such as the dead zone time of the inverter and the pressure drop of the switch tube, the speed regulating system introduces a large number of high current harmonic components.

③Load change aspect, the compressor works in a mechanical cycle including compression, smooth, exhaust, and causes load disturbance during different states.

According to these reasons, domestic and foreign experts and scholars have studied for many years and obtained some research results. There are several main types:

3.1. Space voltage vector modulation technology

Its theoretical basis is the principle of average equivalence, which is to combine the basic voltage vector in a switch cycle to make its average value equal to the given voltage vector. According to the requirements of motor torque and flux control, an optimal space vector is obtained, which can compensate the magnetic chain and torque error accurately and reduce the torque ripple. This method is no longer confined to the basic space voltage vector number of 8, but rather the whole space voltage vector, theoretically there is no limit. This method reduces the torque ripple through the number of vectors, but the more the number of vectors, the subdivision of the vector table, the more complex the control method is, and the control performance cannot be guaranteed.

3.2. Programmed current method

It is the most commonly useful method to suppress the torque ripple of PMSM. This control method needs to know the information of the torque and ripple torque of a specific PMSM in advance, so as to calculate the instruction current waveform needed to suppress the torque ripple. The calculation of the phase current instruction waveform can be obtained by the torque equation of the given torque and rotor position angle through the rotating coordinate system. The off-line computing motor torque

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ripple waveform is stored in the processor in advance, and the compensation is realized according to the rotor position.

3.3. Speed ring output compensation

In the synchronous rotation coordinate system, periodic pulsation suppression is achieved by tracking the periodicity, the method is suitable for industrial processes with repetitive motion properties. It is effective to suppress the periodic pulsation, however, considering the processing power of the hardware circuit in the practical application and the calculation of the iterative learning algorithm, it has not achieved the ideal effect in practice.

3.4. Dead zone compensation method

①Software compensation method. The dead zone effect is compensated by voltage error signal and current polarity. The method only needs to design the dead zone compensation algorithm to write the motor control system and save the inverter output voltage pulse width detection circuit without the additional design of the corresponding hardware circuit.

②Hardware compensation method. Increase the actual output voltage detection circuit on the three-phase bridge arm and inverter output PWM wave Pulse Width. Compare with the ideal reference PWM pulse width, and time error between them is obtained, and the actual output pulse width of the inverter is compensated.

3.5. Torque feedback method

The electric moment of the motor is directly controlled, the actual value of output torque is used as the feedback signal, and then design torque regulator to directly control instantaneous output torque. The focus of this method is to obtain accurate feedback value of output torque. In the real application, the torque feedback can be obtained by direct torque meter or indirect state calculation.

4. Conclusion

This paper introduces the main causes of torque pulsation, and enumerates several key techniques to suppress pulsation, but there are still disadvantages.

①The method of modern control theory involves a large amount of computation, and the operation speed and storage capacity of DSP control chip are higher.

②Due to the limitations of existing technology, the estimation of rotor position cannot be completely accurate.

③It is difficult to realize the nonlinear complete compensation of permanent magnet synchronous motor.

④The algorithm lacks the learning ability to adapt to the complex changes in the dynamic system.

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