Rotor Position Detection and Driving Control Strategy of Permanent Magnet Synchronous Motor for Electric Vehicle

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Abstract: The key issue of permanent magnet synchronous motor control for electric vehicles is rotor position detection and drive control. Based on the physical and mathematical models of permanent magnet synchronous motors (PMSM), this paper proposes a method for detecting position-related electrical signals to estimate the rotor position of the motor, and a vector control technology drive control strategy for rotor position detection.

1. Introduction

Permanent magnet synchronous motors have become the first choice for major enterprises and research institutions to develop a new generation of electric vehicles because of their outstanding performance that many other types of motors cannot match. However, at this stage, some performance controls of permanent magnet synchronous motor systems still need to be improved and improved. Among them, the rotor position detection and drive control of sensorless permanent magnet motors are still the key that restricts its application as a vehicle drive motor and needs to be improved. Given below is the strategy of permanent magnet synchronous motor rotor position detection and starting control.

2. Permanent magnet synchronous motor physical and mathematical model

2.1 Physical model of permanent magnet synchronous motor

2.1.1 Physical model in XYZ axis system coordinates

In the space coordinates of the XYZ axis system, the three-phase stator windings of the permanent magnet synchronous motor differ in space by $2\pi/3$ phases. When a three-phase symmetrical current is applied to the stator side, a rotating magnetic field will be generated in the space of the three-phase stator winding. The permanent magnet acts as a rotor in the rotating magnetic field by electromagnetic force to produce synchronous motion[1].

In the XYZ axis system spatial coordinates, the physical model of the permanent magnet synchronous motor is shown in Figure 1. AA',BB',CC' are three-phase stator windings, and SN is the permanent magnet rotor[2]. $\vec{\psi}_f$ is the excitation space vector, which rotates with the rotor, $\vec{i}_s$ is the stator current space vector, θ_r is the electrical angle, and ω_r is the electrical angular velocity.

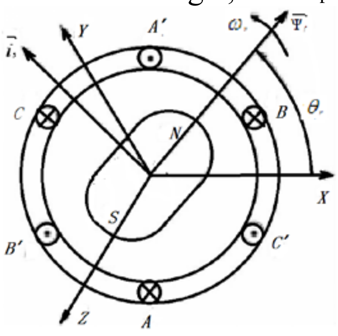

Fig.1 XYZ space coordinate system

2.1.2 Physical model in dq axis system coordinates

For the convenience of analysis and calculation, it is necessary to change the coordinates of the XYZ axis system to establish a coordinate that rotates with the rotor. The specific change is to set the permanent magnet's fundamental excitation field axis as the d axis, and start with the d axis, and rotate $\pi/2$ along the direction of the rotor as the q axis, where d represents the coordinate component of the stator's direct axis, q Represents the stator quadrature axis coordinate components, forming the dq axis coordinate system, as shown in the physical model of Figure 2.The spatial coordinates of the dq axis system are determined by the actual electrical angle θ_r between the d axis and the X axis, and the rotational angular velocity is equal to the electrical angular velocity ω_r .

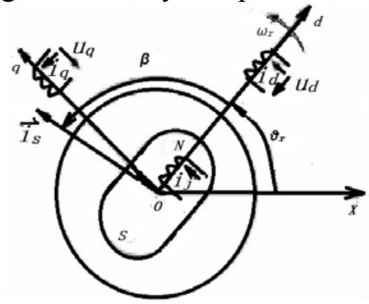

Fig.2 dq rotation coordinate system

2.2 Mathematical Model of PMSM

2.2.1 Mathematical model in XYZ axis system coordinates

According to the principle of permanent magnet synchronous motor, the mathematical model of the space vector of the stator current in the XYZ axis system is:

$$\vec{i}_s=\sqrt{\frac{2}{3}}(i_x+\lambda i_y+\lambda^2 i_z) \tag{1}$$

In formula (1): i_x,i_y,i_z are the currents of the three-phase stator respectively; $\lambda = e^{j2\pi/3}$ and $\lambda^2 = e^{j4\pi/3}$ are spatial operators.

According to the principle of permanent magnet synchronous motor, the mathematical model of the space vector of the stator voltage in the XYZ axis system is:

$$\vec{u}_s=(R_s\vec{i}_s+L_s\frac{d\vec{i}_s}{dt}+\frac{d}{dt}(\psi_f e^{j\vartheta_r}) \tag{2}$$

In formula (2):R_s is the stator winding phase resistance; L_s is the equivalent synchronous inductance of the stator winding; ψ_f rotor excitation space vector; θ_r is the actual electrical angle of the rotor[3].

2.2.2 Mathematical model in dq axis system coordinates

According to the principle of permanent magnet synchronous motor, through transformation, the space vector mathematical model of the stator voltage in the XYZ axis system is converted into a time phasor, and the voltage vector mathematical model in the dq axis system coordinates is obtained as:

$$\dot{U}_s=R_s\dot{I}_S+j\omega_S L_d\dot{I}_d+j\omega_S L_q\dot{I}_q+j\dot{E}_0 \tag{3}$$

In formula (3):ω_s is the rotor rotational angular velocity, which is equal to the electrical angular velocity ω_r; L_d is the component of the equivalent synchronous inductance of the stator winding on the d axis, L_q is the component of the stator winding equivalent synchronous inductance on the q axis; id is the component of the stator current on the d axis, i_q is the component of the stator current on the q axis; E_0 is the effective value of the no-load electromotive force induced by the permanent magnet excitation field in the phase winding.

According to formula (3), the current model in the dq axis system coordinates can be obtained:

$$\frac{d}{dt}i_d=-\frac{R_s}{L_d}i_d+\omega_s\frac{L_q}{L_d}i_q+\frac{1}{L_d}u_d \quad (4)$$

$$\frac{d}{dt}i_q=-\omega_s\frac{L_d}{L_q}i_d-\frac{R_s}{L_q}i_q-\omega_s\frac{\psi_f}{L_q}+\frac{1}{L_q}u_q \quad (5)$$

When the motor is running in a steady state, the rotor rotational angular speed ω_s is equal to the power synchronization angular frequency; in formula (4) and formula (5), each phasor uses the d axis as the time reference axis, and the back EMF vector leads the d axis by $\pi/2$ electrical angle , The initial phase of the stator current isβ, and the electrical angle at which the stator voltage leads the stator current isφ, that is, the phase difference between the stator voltage U_s and the current I_s is φ. The stator current I_s can be controlled by directly controlling the stator voltage U_s, so as to achieve the purpose of controlling the motor torque[4].

3. Rotor position detection and drive control strategy of PMSM for electric vehicle

The control of permanent magnet synchronous motor in electric vehicles is its core technology, and its control strategy directly determines the robustness and fast response performance of the permanent magnet synchronous motor drive system.Vector control technology, also called field-oriented control, is the mainstream control strategy of permanent magnet synchronous motors. Vector control involves a problem that must be solved, that is, how to accurately obtain the rotor position information of the permanent magnet synchronous motor.

3.1 Rotor position detection strategy of PMSM for electric vehicle

Rotor position detection technology determines the control accuracy of permanent magnet synchronous motors. In recent years, related research has attracted wide attention from experts and scholars at home and abroad. Generally, position sensors are used to collect rotor position information of permanent magnet synchronous motors.But the position sensor-based rotor position detection technology largely limits the development of permanent magnet synchronous motors for vehicles. Sensorless control technology overcomes the shortcomings of sensor systems and is the mainstream strategy for rotor position detection.

In order to obtain the rotor position information of the permanent magnet synchronous motor without a sensor, it can be realized by the strategy of online identification of the permanent magnet synchronous motor parameters. The specific method is to accurately obtain the four electrical parameters in the current model represented by formula (4) and formula (5) in the dq axis system coordinates: rotor flux ψ_f, stator resistance R_s and stator inductance L_d and L_q of the dq axis system, That is, by using the parallel structure of formula (4) and formula (5), the position and speed of the rotor of the permanent magnet synchronous motor are calculated.

3.2 Drive control strategy of PMSM for electric vehicle

In the electric vehicle motor drive system, the control strategy of the permanent magnet synchronous motor is its core part. The quality of the control strategy directly determines the robustness and fast response performance of the motor drive system. At present, the main control strategies for permanent magnet synchronous motor drive systems include: constant voltage-frequency ratio control technology, direct torque control technology and field-oriented vector control technology. Among them, vector control technology is a relatively good mainstream drive control strategy.

Vector control technology is also called field-oriented control. The basic idea is: try to simulate the control law of DC motor torque on permanent magnet synchronous motor, and simplify the permanent magnet synchronous motor to DC motor for control through coordinate transformation. That is, on the field-oriented coordinates, the stator current of the permanent magnet synchronous motor is decomposed into the excitation current component and the torque current component through vector transformation, and the two components are perpendicular to each other, independent of each other, and then adjusted separately. In this way, the torque control of the permanent magnet synchronous motor is similar to the DC motor in principle and characteristics. Aiming at the constant torque of the permanent magnet synchronous drive motor of electric vehicles below the base speed and the constant power output characteristics above the base speed: when the permanent magnet synchronous motor speed is below the base speed, use id equal to zero control; when the motor speed is above the base speed , use weak magnetic control.

In the i_d equal to zero control strategy, when the permanent magnet synchronous motor speed is below the base speed, the i_d equal to zero control is adopted. Since there is only i_q in the stator current, the output torque and speed of the permanent magnet synchronous motor can be controlled only by controlling the magnitude of i_q . In the field weakening control strategy, when the motor speed is above the base speed, since the permanent magnet synchronous motor uses permanent magnets for excitation, the excitation momentum cannot be adjusted, and weaken the air gap magnetic field in permanent magnet synchronous motor by controlling i_d, because when i_d is negative, the d-axis armature reaction in the permanent magnet synchronous motor will play the role of demagnetization, and the field weakening acceleration control is realized. When the stator voltage in a permanent magnet synchronous motor reaches the limit, the use of field weakening control will keep the voltage in the stator constant. When id is a negative value, the permanent magnet synchronous motor is controlled by field weakening. The greater the absolute value of i_d in the stator, the higher the rotor speed.

4. Summary

In short, the main advantages of the permanent magnet synchronous motor vector control strategy studied in this paper are: accurate torque control, fast dynamic response, good flexibility, wide speed range, simple control, high reliability, and high application value.

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