Research on vector control technology for permanent magnet synchronous motor

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Abstract. This paper summarizes the development history of permanent magnet synchronous motor, introduces the mathe- matical model of permanent magnet synchronous motor, selects permanent magnet synchronous motor as the research object, expounds the important ideas and basic principles of vector control, and finally prospects its future development trend, so as to clarify the development direction of vector control and sort out a clearer development context.

Keywords: Permanent magnet synchronous motor, Math- ematical model, Vector control, Basic principles, Development trend.

1. Introduction

Compared with asynchronous motor, synchronous motor has the advantages of measurable rotor parameters, high power factor and good control performance. The permanent magnet synchronous motor excited by permanent magnet material omits the devices such as brush and slip ring, which reduces the volume of the motor and the loss of the motor at the same time. Therefore, permanent magnet synchronous motor is gradually favored because of its small volume, light weight, high efficiency and energy saving.

The permanent magnet synchronous motor based on FOC aims to control the size and direction of the magnetic field accurately, so that the motor has stable motion torque, low noise, high efficiency and high-speed dynamic response. FOC allows us to control the brushless motor at the" pixel level", which can achieve many effects that cannot be achieved by traditional motor control methods. Therefore, its prospect and development trend should not be underestimated.

2. Research and development of pmsm control technology

2.1 Development history of permanent magnet synchronous motor

The earliest invention of the motor is the use of natural magnets to establish a magnetic field. In 1821, Faraday found

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that the electrified conductor can rotate around the permanent magnet, successfully realized the conversion from electrical energy to mechanical energy for the first time, and established the laboratory model of the motor, which is considered to be the first permanent magnet motor in the world. In 1822, Joseph Louis Gay-Lussac of France invented the electromagnet, that is, to generate a magnetic field by winding a coil around the iron core. This is an important invention, but it was not valued and applied at that time. In 1831, shortly after the discovery of electromagnetic induction, Faraday invented the world's first real motor Faraday disk generator using the principle of electromagnetic induction. In 1832, William Sturgeon invented the commutator and made the world's first rotating motor that can produce continuous motion. In 1834, Jacobi in Germany manufactured the first practical motor. At the same time, Thomas Davenport of the United States has also successfully developed a motor for printing press drive.

In the mid-20th century, with the emergence of alnico and ferrite permanent magnets and the continuous improvement of performance, various new permanent magnet motors continue to appear and are widely used. With the improvement of high temperature resistance and the reduction of price of Nd-Fe- B materials, Nd-Fe-B permanent magnet motors have been more and more widely used in fire protection, industrial and agricultural production and daily life, and the varieties and application fields of permanent magnet motors are expanding.

2.2 Permanent magnet synchronous motor control technology

According to the multivariable and strong coupling char- acteristics of permanent magnet synchronous motor, adopting appropriate control strategy can make it have good dynamic and static performance, so as to improve the rapidity and stability of the system. At present, the control strategies of permanent magnet synchronous motor mainly include the following three ways: constant voltage frequency ratio control (V / F), vector control (FOC) and direct torque control (DTC).

V/F control is a relatively simple control method of PMSM, which has the characteristics of strong universality, good economy and simple control. This method controls the output voltage of the frequency converter to change with the change of frequency, ensures that the magnetic flux of the motor remains unchanged, and maintains the ratio of voltage and frequency as a constant, so that the stator flux is constant. Because the V / F control does not control the phase of voltage, the speed drop is obvious under sudden load, which is easy to produce instantaneous out of step, resulting in torque and speed oscillation. In view of its simple control process and low cost, this method is widely used in fan and water pump, which have slightly lower requirements for control accuracy and less load change.

Vector control, also known as field oriented control, is controlled by German F.Balschk first proposed it in 1971. When using vector control, the stator current is decomposed into excitation current and torque current components by co- ordinate transformation, so that they can be decoupled and in- dependent without affecting each other. PMSM is simulated as the control of DC motor through decoupling control strategy. The permanent magnet synchronous motor with vector control has the advantages of small torque ripple and high control accuracy. It is suitable for occasions with strict requirements for control performance and accuracy. However, vector control also has some defects, the calculation is slightly complex, and the change of motor parameters will greatly affect the control effect, so its application scope is limited.

DTC uses hysteresis control to select the optimal switching state of the inverter, so as to obtain high-performance dynamic torque. The system has the characteristics of less torque depen- dence, less rotation parameters and faster response. However, because the torque is not easy to observe and the torque ripple is large when the motor is at low speed, it cannot be applied to the servo system with wide speed regulation range.

With the continuous exploration and research in the field of motor control by experts and scholars at home and abroad, vector control has reached a mature stage in theory. Therefore, vector control method is used to control permanent magnet synchronous motor.

3. Vector control technology of pmsm

3.1 Physical model of permanent magnet synchronous motor

Permanent magnet synchronous motor is a nonlinear system, which has the characteristics of multivariable and strong coupling. Due to its complex electromagnetic relationship, it is difficult to establish an accurate mathematical model. There- fore, the following assumptions are made when analyzing it:

Ignore core saturation, eddy current and hysteresis losses.

Ignore the armature reaction during commutation.

The rotor has no damping winding and the permanent magnet has no damping effect.

The stator winding current only produces sinusoidal magnetic potential in the air gap without high-order harmonics.

In the control process of PMSM, there are three ways to establish coordinate system in space, namely three-phase static (ABC) and two-phase static (αβ). And two-phase synchronous rotation (d-

q) coordinate system, as shown in the figure 1. When the rotating speed of the stator is the same as that of the three-phase stator winding, the magnetic field around the rotor will be transmitted into the sine wave mode with the rotation speed of the stator winding being 120 degrees, which will be synchronous with the three-phase stator winding.

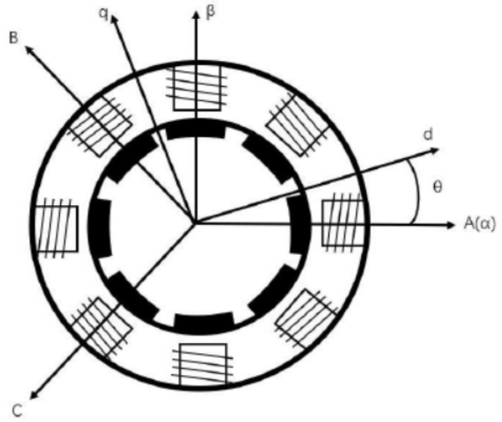

Fig. 1 Structure diagram of permanent magnet synchronous motor.

Stator voltage equation of PMSM in three-phase static coordinate system:

$$\begin{cases} U_a = R_s i_a + \frac{\mathrm{d}\Psi_a}{\mathrm{d}t} \\ U_b = R_s i_b + \frac{\mathrm{d}\Psi_b}{\mathrm{d}t} \\ U_c = R_s i_c + \frac{\mathrm{d}\Psi_c}{\mathrm{d}t} \end{cases} \tag{1}$$

And, U_a、U_b、U_c is the three-phase stator voltage; i_a、i_b、i_c is the three-phase stator current; Ψ_a、Ψ_b、Ψ_c is a three-phase stator flux linkage; R_s is the winding of each phase stator.

Flux linkage equation in three-phase stationary coordinate system:

$$\begin{cases} \Psi_a = L_{AA} i_A + L_{AB} i_B + L_{AC} i_C + \psi_f \cos\theta_a \\ \Psi_b = L_{AB} i_A + L_{BB} i_B + L_{BC} i_C + \psi_f \cos\theta_b \\ \Psi_c = L_{AC} i_A + L_{BC} i_B + L_{CC} i_C + \psi_f \cos\theta_c \end{cases} \tag{2}$$

And, L_{AA}、L_{BB}、L_{CC} is the stator inductance; L_{AB}、L_{BC}、L_{AC} is the stator mutual inductance; ψ_f is the rotor flux linkage; θ_a、θ_b、θ_c is the rotor position angle.

Voltage equation in d-q coordinate system:

And, U_d、U_q is the d-axis and q-axis components of the stator voltage; i_d、i_d is the It is the d-axis and q-axis components of the stator current; ψ_d、ψ_q is the d-axis and q-axis components of the flux linkage.

Flux linkage equation in dq coordinate system:

$$\begin{cases} \psi_d = L_d i_d + \psi_f \\ \psi_q = L_q i_q \end{cases} \tag{3}$$

Torque equation:

$$\mathrm{T} = \frac{3}{2}\mathrm{P_n}\left[\psi_f i_q + \left(L_d - L_q\right) i_d i_q\right] \tag{4}$$

It can be seen from the torque equation that the electromagnetic torque is composed of two parts. The first term is generated by the interaction between the permanent magnet and the stator winding flux linkage, and the second term is generated by the change of magnetoresistance.

The mathematical model of permanent magnet synchronous motor explains its internal composition and helps to design control strategy. The mathematical model needs to be analyzed in coordinate transformation and PI parameter setting, so the mathematical model is very important for the control system.

4. Vector control system of pmsm

Vector control is one of the best methods for efficient control of Brushless DC motor and permanent magnet synchronous motor. Vector control aims to control the size and direction of the magnetic field accurately, so that the motor has stable torque, low noise, high efficiency and high-speed dynamic response. In short, vector control is a driving control method for brushless motor. It allows us to control the brushless motor at the "pixel level", which can achieve many effects that cannot be achieved by traditional motor control methods.

4.1 Vector control

The FOC control system designed in this paper adopts the architecture strategy of current closed-loop control and adopts fast observer to collect feedback parameters. System utilization id = 0, MTPA and flux weakening control, calculate the required current and voltage vector, generate three-phase PWM control signal, control the two-level inverter to synthesize the space vector in the form of SVPWM, so as to generate vector voltage and provide it to the permanent magnet synchronous motor to control the motor. The vector system designed in this paper is shown in Figure 2.

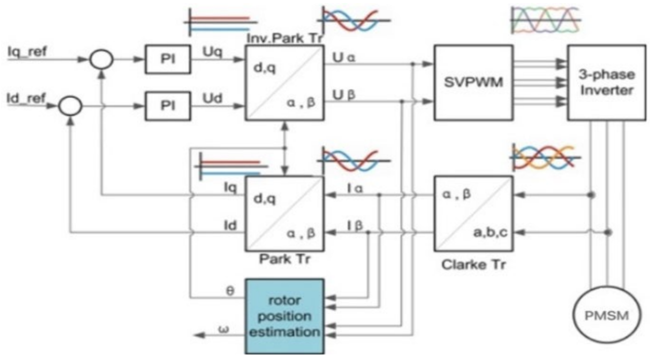

Fig. 2 Vector control flow chart.

4.2 Principle of space vector pulse width modulation

The theoretical basis of space vector pulse width modulation (SVPWM) is the principle of average value equivalence, that is, the average value is equal to the given voltage vector by combining the basic voltage vectors in a switching cycle.

Since the vector that the inverter can form cannot meet the requirements of continuous angle change, the SVPWM module uses six basic spatial effective voltage vectors $V_1(001)$、$V_2(010)$、$V_3(011)$、$V_4(100)$、$V_5(101)$、$V_6(110)$ and two zero vectors $V_0(000)$、$V_7(111)$. The 360-degree voltage space is evenly divided into six sectors, so that any vector within 360 degrees can be synthesized, as shown in Figure 3.

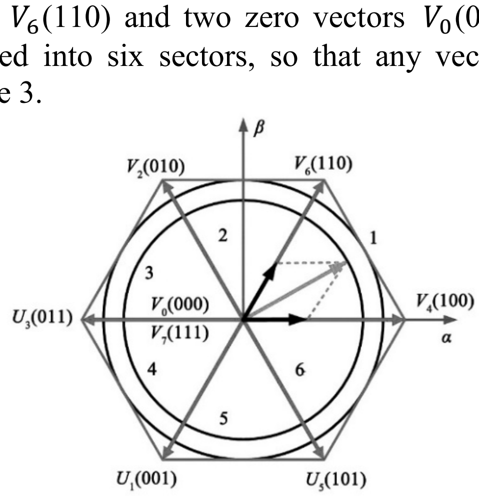

Fig. 3 Space voltage vector diagram.

When it is necessary to synthesize a vector, first determine the sector of the vector through the sector calculation module, and use the nearest two basic vectors to represent the required vector.

Because the action size of each basic vector is determined by the action time, then determine the action time of the two basic vectors through the time calculation module, and finally generate the required vector to form a PWM control signal.

5. Latest research progress of vector control of pmsm

According to the structure, specific application and control purpose of permanent magnet synchronous motor, vector control has many specific control methods, such as id = 0 control, maximum torque / current control, flux weakening control and maximum output power control. In order to further improve the control performance and reduce the cost, people are also constantly exploring the application of advanced control theory in permanent magnet synchronous motor, such as:

Rotor position estimation and sensorless control. Reducing sensors is an important way to reduce the cost of control system. In the absence of rotor position sensors, it is necessary to obtain the "rotor position" by observer method. Permanent magnet synchronous motor requires high accuracy of rotor position, which is also the difficulty of the problem. There are many achievements in this field, mainly using stator terminal voltage and terminal current to calculate rotor position and speed.

Intelligent control. Including neural network control, fuzzy control and other intelligent control methods, which can significantly improve the response performance and adaptive ability of the control system. The application in motor control is also very meaningful. In recent years, with the new development of control theory, especially the continuous maturity of intelligent control, coupled with the rapid development of computer technology and microelectronics technology, the "integration" of advanced control strategy based on intelligent control theory and traditional control strategy based on traditional control theory can be realized, and the corresponding material foundation has been laid for its practical application.

Fully digital control. With the development of microelectronics and computer technology, the control system of permanent magnet synchronous motor has experienced from the initial analog control to semi analog and semi digital hybrid control, and then to full digital control. At the same time, the rapid development of single chip microcomputer, microcomputer and DSP control chip, as well as the combination of modern control theory and new control ideas, have laid the foundation for permanent magnet synchronous motor in the servo control system with higher precision requirements. The improvement of digital chip calculation speed and the optimization of software algorithm ensure the stability and dynamic response ability of permanent magnet synchronous motor control system.

6. Conclusion

With the rapid development of power electronics technology and modern control theory technology, the vector control technology of permanent magnet synchronous motor has developed rapidly and gradually been widely used, which is conducive to promote the technical extension of electromechanical combination and control automation in the industrial field. This paper introduces and expounds the development history of permanent magnet synchronous motor, motor control method, vector control principle and other key application technologies and cutting-edge technologies in detail, which provides some guidance and reference for grasping the development direction of vector control of permanent magnet synchronous motor.

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