Design of Permanent Magnet Synchronous Motor Control System for Electric Vehicle Air Conditioning Compressor Based on Vector Control

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Abstract

Permanent magnet synchronous motor (PMSM) has the advantages of small size, light weight, simple structure, reliable operation, high power factor, easy heat dissipation and easy maintenance. It has become the best choice for electric vehicle air conditioner compressors, but in actual working conditions, the air conditioner compressor has the problem of excessive noise and serious system turbulence, which makes the air conditioner compressor unable to work normally, which has serious consequences. The method of using the field oriented control can overcome the problems existing under actual working conditions, so it proposed the design of permanent magnet synchronous motor control system for electric vehicle air conditioner compressor.

Subject Areas

Electric Engineering

Keywords

Air Conditioning Compressor, Permanent Magnet Synchronous Motor, Electric Vehicle, Vector Control

1. Introduction

Permanent magnet synchronous motors are increasingly being applied to machine tool servo systems, elevator drives, electric vehicle propulsion, and air conditioning compressors. Automotive air conditioning compressors are the

core part of electric vehicle air conditioners, solving the problem of excessive noise and serious system oscillation [1].

Permanent magnet synchronous motor (PMSM) has the characteristics of small size, simple structure, high power factor, reliable operation, easy heat dissipation and easy maintenance. It has been widely used in machine tool servo system, elevator drive, electric vehicle propulsion, air conditioner compressor, etc. [2]. Compared with ordinary air conditioner compressors, PMSM has significant advantages in the application of electric vehicle air conditioner compressors. PMSM has the characteristics of wide speed regulation range, high control precision and small torque ripple [3]. With the development of high-speed microprocessors, advances in power electronics, and continuous improvement of control algorithms, the application of PMSM technology has become more mature and extensive. Based on the actual working conditions of electric vehicle air conditioner compressor, based on the analysis of PMSM vector control working principle, the design of permanent magnet synchronous motor control system for electric vehicle air conditioner compressor is completed. With dsPIC30F4011 as the core, electric vehicle air conditioner compressor is constructed, PMSM control system.

In the traditional automotive system, the compressor and the car-driven engine need to be used together, and the car must be started before the car air-conditioning compressor can work normally. In the electric vehicle system, the whole system is electric, and the compression system does not need to rely on the driving of the automobile wheel engine. Up to now, the air conditioning system has become an independent part, as a separate unit, with independent power supply system and vehicle main system. The signal transmission through communication enables individual control and variable frequency control functions. The efficiency ratios of the compressor's traditional mechanical mode and electric mode are shown in Table 1.

2. The principle of PMSM Work

2.1. The Mathematical Model of PMSM

To simplify the analysis, assume that the magnetic path of the PMSM is not saturated and the spatial magnetic field is sinusoidal, ignoring hysteresis and eddy current losses [4].

The direction of the PMSM rotor permanent magnet magnetic field is defined as the d-axis, and the d-axis is orthogonal to the q-axis. The dq coordinate

Table 1. Comparison of the efficiency of the traditional mechanical mode and electric mode of the compressor.

Model mode	Volumetric efficiency	Transmission efficiency	Others	Comprehensive
Motor drive	0.9	0.65	0.75	0.44
Mechanical drive	0.4	0.95	0.75	0.29

system is fixed on the rotor, rotates synchronously with the rotor, and the angle between the d-axis and the A-axis is a variable, physical model [5].

The mathematical model of the PMSM in the synchronously rotated d-q coordinate system is established as follows.

Motor flux linkage equation:

$$\begin{cases} \psi_d = L_d i_d + \psi_f \\ \psi_q = L_q i_q \end{cases} \tag{1}$$

Torque equation:

$$T_e = \frac{3}{2} P_n \left(\psi_d i_q - \psi_q i_d \right) \tag{2}$$

Stator voltage equation:

$$\begin{cases} u_d = R_s i_d + \dfrac{\mathrm{d}\psi_d}{\mathrm{d}t} - \omega_e \psi_q \\ u_q = R_s i_q + \dfrac{\mathrm{d}\psi_q}{\mathrm{d}t} + \omega_e \psi_d \end{cases} \tag{3}$$

Equation of motion:

$$T_e - T_L = J \frac{\mathrm{d}\omega_m}{\mathrm{d}t} + B\omega_m \tag{4}$$

L_d, L_q —d, q-axis equivalent inductance;

ψ_f —Permanent magnet flux linkage;

R_s —Stator resistance;

ω_e, ω_m —Electrical angular velocity and mechanical angular velocity;

T_e —Electromagnetic torque;

p_n —Magnetic pole pair;

T_L —Load torque;

J —Moment of inertia;

B —Coefficient of friction.

According to formula (3), it can be concluded:

$$T_e = \frac{3}{2} p_n \psi_d i_q = \frac{3}{2} p_n \left(L_d i_d + \psi_f \right) i_q = \frac{3}{2} p_n \psi_f i_q \tag{5}$$

as follows:

$$T_e = \frac{3}{2} p_n \psi_f i_q \tag{6}$$

It can be known from the above equation that the electromagnetic torque of the motor is determined only by the q-axis current, which realizes the decoupling of the electromagnetic torque of the motor. Therefore, it can be seen that after the control strategy of $i_d = 0$, the permanent magnet synchronous motor is equivalent to a single-excitation DC motor, and only the torque current i_q can be controlled to control the electromagnetic torque, thereby realizing the speed control. The schematic diagram of PMSM vector control is shown in **Figure 1**.
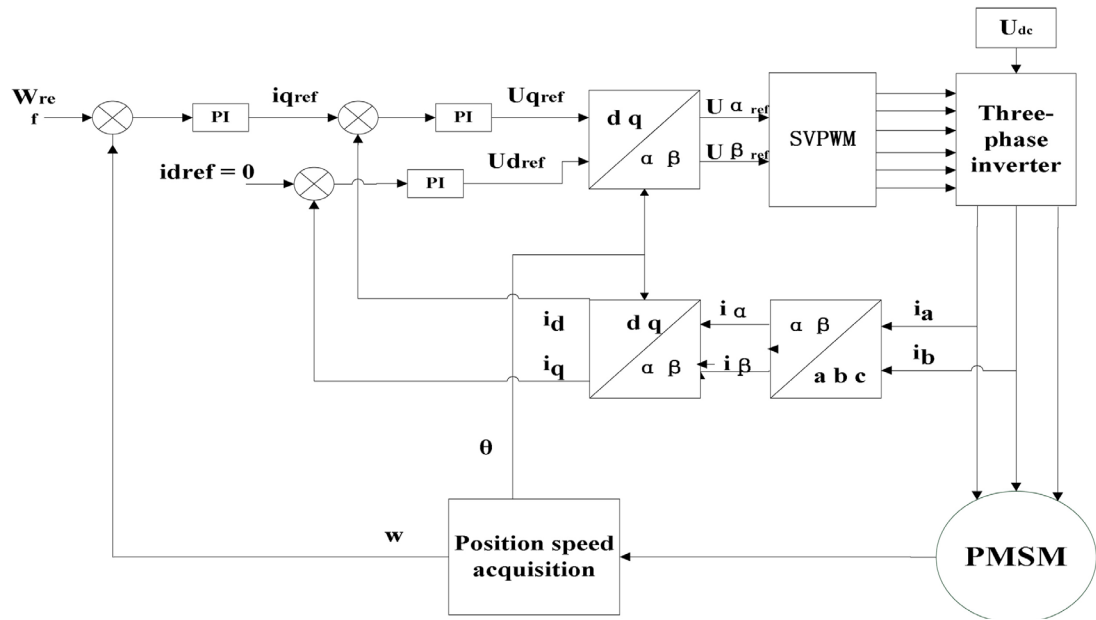
Figure 1. PMSM vector control schematic.

2.2. Principle of PMSM Control

SVPWM refers to outputting different pulse sequences according to different combinations of three switching tubes of the upper arm of the three-phase inverter bridge for controlling the inverter output three-phase sinusoidal voltage or three-phase sinusoidal current [6].

The six switching devices are controlled by six control signals. Each group of upper and lower bridge switching devices can only be turned on and the other is turned off. Therefore, the inverter has eight working states, corresponding to eight voltage vectors. Set the upper bridge to conduct, the lower bridge is marked as 1, the lower bridge is turned on, and the upper bridge is closed as 0. The formula for the phase voltage can be derived:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \frac{1}{3} U_{dc} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \tag{7}$$

u_a, u_b, u_c —Three-phase stator phase voltage in A-B-C coordinate system.

Using the Clark transform, u_α, u_β in the α-β coordinate system can be obtained.

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{8}$$

The eight voltage vector distributions are shown in **Figure 2**.

From the above figure, there are 6 non-zero vector amplitudes in the 8 basic space voltage vectors, the phase difference is 60°, the vector space is divided into 6 sectors, and the other 2 are zero vectors. According to the parallelogram rule,
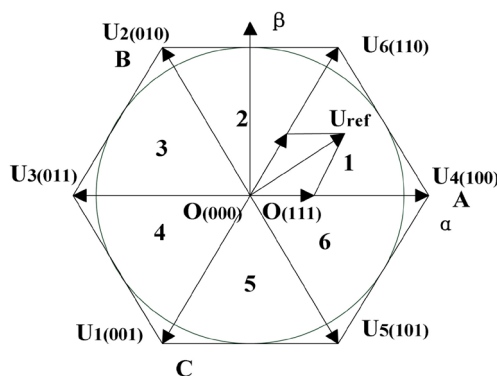
Figure 2. Basic space vector.

these 8 basic space vectors can be used to synthesize any voltage vector that does not exceed the maximum amplitude [7]. SVPWM technology uses these 8 basic space vectors to approximate a given reference voltage vector U_{ref}.

3. Design of PMSM Control System

3.1. Hardware Design of PMSM Control System

The hardware structure of the permanent magnet synchronous motor control system for electric vehicle air conditioner compressor is shown in **Figure 3**. It can be seen from **Figure 3** that the hardware structure of the control system consists of three parts: control module, communication module and power module.

Among them, the control chip is dsPIC30F4011, which is a high-performance 16-bit digital signal controller with low-power high-speed flash technology, wide operating voltage range and efficient and fast working speed. It can be reprogrammed under software control, power management mode to meet system requirements.

The power module input terminal is connected to 230 V high-voltage DC power to supply power to the power module and the control module. The step-down is achieved by using a high frequency transformer. The DC-DC Converter UC2843 is used to control the switching of the MOS tube, and the direct current is converted into a high-frequency oscillation pulse waveform, and a low-voltage alternating current is generated by the transformer. After low-voltage AC rectification, the output voltage of the control chip is output via the three-terminal regulator LM117.

Communication circuit uses optocoupler isolation, which can be abnormal in the input signal. The protection chip is not burned out intelligent power module. Barrier protection function, when there are temperature, current, voltage and other faults, the FO pin of the module will output a fault signal to stop the motor, thereby playing a protective role.

3.2. Software Design of PMSM Control System

In addition to the hardware system, the control system requires software to
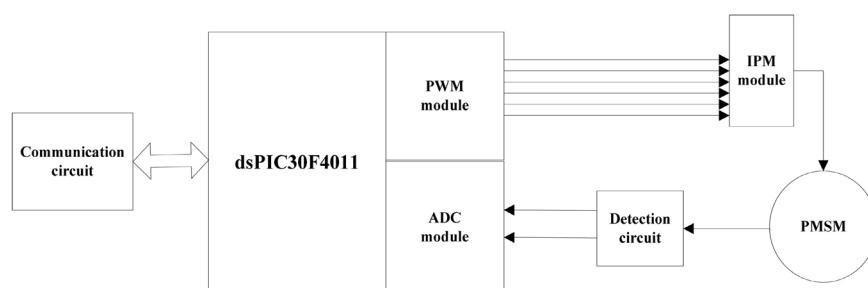
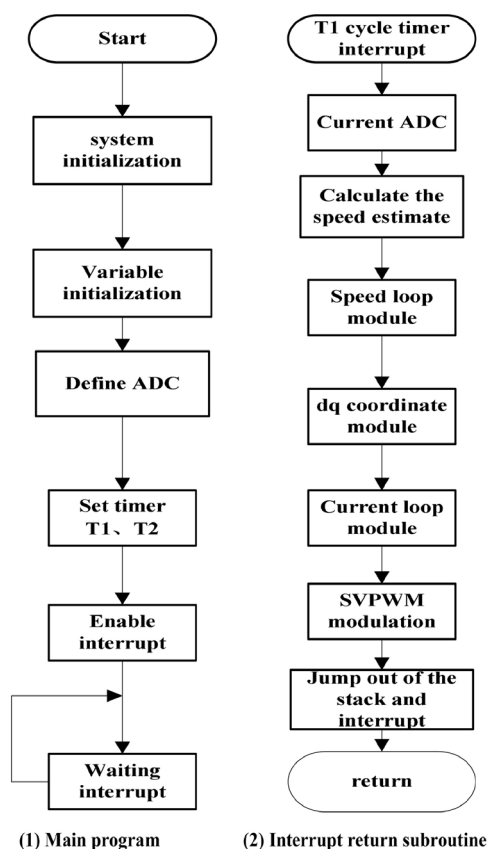Figure 3. Control system hardware structure.

Figure 4. Block diagram.

implement the functions of the system. The main function of this software is to realize the FOC and subroutine modules of permanent magnet synchronous motor, making full use of dsPIC30F4011 chip computing function and software filtering. The whole program is developed in the chip-specific development environment MPLAB with C language. The software system has good real-time and reliability, which is convenient for modification and debugging.

The control program consists of a main program and an interrupt service subroutine. The specific process block diagram is shown in **Figure 4**.

4. Experimental Results and Analysis

The structure of the body, rotor and stator of the motor used in the drive system

are shown in **Figure 5** and **Figure 6**.

The technical specifications of the motor used in this control system are shown in **Table 2**.

Figures 7-9 are waveform diagrams of the respective phase currents measured at $n = 1570 \, \text{r/min}$, $n = 2370 \, \text{r/min}$, and $n = 3350 \, \text{r/min}$.

5. Conclusion

The permanent magnet synchronous motor control system of electric vehicle air

Figure 5. Structure diagram of motor body.

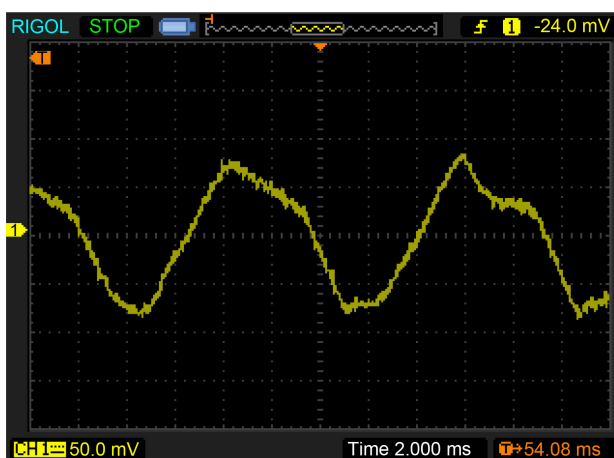**Figure 6.** Structure diagram of rotor and stator.

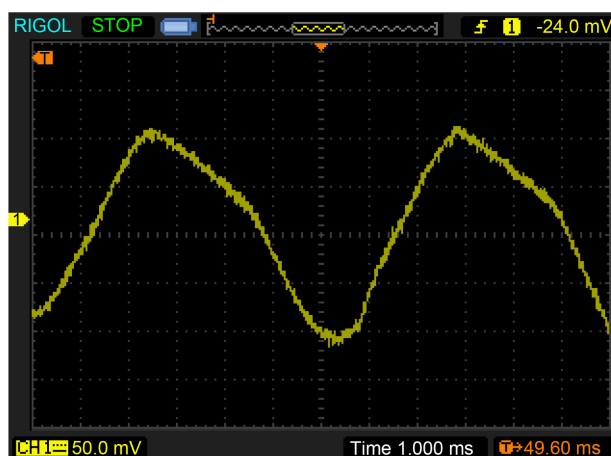**Figure 7.** n = 1570 r/min , Phase current waveform.

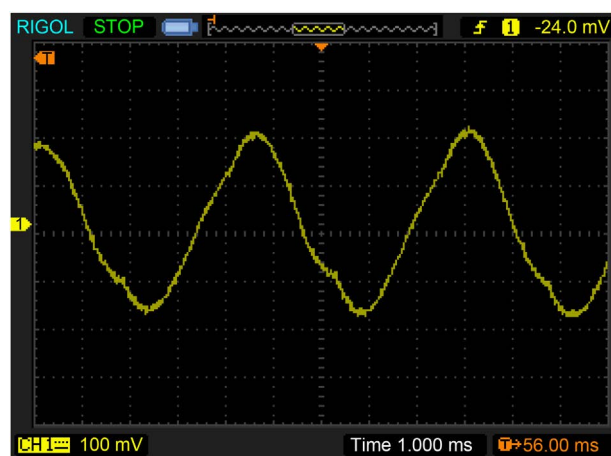**Figure 8.** $n = 2370 \text{r/min}$, Phase current waveform.

Figure 9. $n = 3350 \text{r/min}$, Phase current waveform.

Table 2. Motor technical indicators.

Rated speed	3000 r/min	Stator resistance	0.0187 Ω
Rated power	4430 w	Straight axis self-inductance	0.02547 H
Rated Voltage	230 V	Cross-axis self-inductance	0.02816 H
Rated torque	3 N·m	Permanent magnet flux linkage	0.1717 Wb
Magnetic pole logarithm	4	Moment of inertia	2.26×10^{-5} kg·m^2

conditioner compressor designed in this paper has been tested several times to analyze the control performance of the motor. The results show that the control system can significantly improve the normal operation of the drive motor in the environment of excessive noise and severe system oscillation, and the working ability to meet the actual working conditions of electric vehicle air conditioning compressors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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