SPMSM No Sensor Rotor Pole Position Tracking Strategy Based on High Frequency Pulse Voltage Injection

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Abstract

In this paper, the rotor position detection and vector control technology of SPMSM without position sensor have been studied. Because of low speed, the calculation accuracy of the base wave model of the motor is not high, So， in low speed, the rotor position is detected by using the method based on pulse frequency voltage injection.The problem of starting failure of zero speed is solved by using the saturation convex effect principle.The operation characteristics of two cases without considering saturation effect and saturation effect are analyzed,The necessary derivation and simplification of the corresponding high frequency current response are made.In judging the rotor initial position, along the first discrimination position of the rotor magnetic pole, two opposite pulse voltages are injected, analyzes its current response, judge the magnetic polarity, get accurate rotor initial position.Then, a vector control system of permanent magnet synchronous motor based on the injection method of pulsating high frequency voltage signal is presented, Analyze and verify from multiple aspects. The results show that the proposed rotor position identification method is effective.

Keywords

Permanent magnet synchronous motor; Speed sensorless; High-frequency ripple; Speed identification.

1. Introduction

Permanent magnet synchronous motor (PMSM) has the synchronization of the stator magnetic field and the rotor magnetic field, and its the rotor is made by permanent magnet system. It has the higher electrical efficiency, the smaller moment of inertia, the higher power density, the high reliability, the simple structure, the smaller mechanical vibrations and lower noise advantages. So it's been widely used[1].PMSM that permanent magnet is pasted on the surface of the rotor is the SPMSM. This structure can be used to design the motor with a low inertia and a small diameter, which can be used to improve the dynamic performance[2]. In addition, permanent magnet magnetic permeability of the surface mounted permanent magnet synchronous motor is very close to the air, that makes the direct-axis inductance almost equal to the quadrature-axis inductance. Therefore, it can be regarded as an non-salient pole synchronous motors[3].

Variable voltage variable frequency, Direct torque control and Vector control are the three categories of permanent magnet synchronous motor Control system. In the Variable voltage variable frequency control system, through the controller given reference voltage and frequency, to produce alternating sine wave voltage in the stator winding for open loop control. This control mode can not accurately feed the motor running state, electromagnetic torque control accuracy is low. Direct torque control directly controls the motor stator flux and torque to stator magnetic chain orientation. This control method causes the torque ripple to be larger. Vector control is the ideal control method for permanent magnet synchronous motor. Include $i_d = 0$ control, maximum Output power control, Unit power factor control, Maximum torque current ratio control and Weak magnetic control, etc. Overall thought is through the control of the stator winding current amplitude and the control of the angle between rotor permanent magnet electromotive force and stator magnetic force[4]. to realize the decoupling of the magnetic potential variables by coordinate transformation of voltage and current, thus, the dc motor control mode is simulated to control AC motor.

2. High frequency pulse voltage injection position detection principle

The coordinate relationship of SPMSM is shown in fig.1. The high frequency pulse voltage signal $U_h \cos\omega_h t$ is injected into the estimated synchronous rotation coordinate system $\hat{d}$. the amplitude is U_h, the frequency is ω_h, the rotor position estimation error is defined $\Delta\theta_r = \hat{\theta}_r - \theta_r$, θ_r is the actual value of the rotor position, and $\hat{\theta}_r$ is the estimated value of the rotor position.

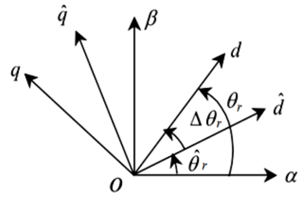

Fig.1 Relationship diagram of each coordinate system

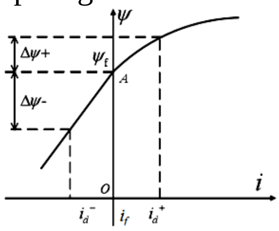

Fig.2 Direct axis magnetic circuit ψ-i characteristic curve

Fig.2 shows the ψ-i characteristic curve of the SPMSM direct axis magnetic circuit, which is affected by the saturation of the magnetic path. The electric inductance of the quadrature axis and the direct axis is different. Because the *q*-axis magnetic field is not affected by the excitation current, the *q*-axis magnetic circuit works at the origin, and the working point of the d-axis magnetic circuit is the point A on the axis. By type $L = \frac{d\psi}{di_d}$, When the positive d-axis current i_d^+ and the reverse d-axis current i_d^- which can produce the same magnetic chainare entered at A point, it can be made $L_d^+ < L_d^-$; At this time, the characteristic curve of the quadrature axis magnetic circuit and the direct axis magnetic circuit are roughly the same, there is no saturation phenomenon, and there is $L_q^+ = L_q^- = L_q$. It can be seen that, as long as the proper forward d-axis current is connected, makes $L_d < L_q$, the convex polarity of the motor will be shown in the permanent magnet synchronous motor air gap magnetic circuit.

3. No position sensor vector control system

3.1 The system structure

In MATLAB/simulink environment, build a simulation model as shown in fig.3, mainly including motor ontology modules, coordinate transformation module, inverter module, PI regulator module and demodulation module, etc.

The voltage injection module shown in fig.4. Fig.5 is an injection of voltage signal waveform for the detection process, and the time control of the signal is controlled by the method of multiplying the input signal and the step function. Initial estimation of rotor position in phase 1 (0-220ms); In the second phase, the positive voltage pulse and reverse voltage pulse is injected at 250ms and 300ms, and the positive direction of the magnetic pole is judged according to the current amplitude of the direct axial current in the two directions after the injection pulse.

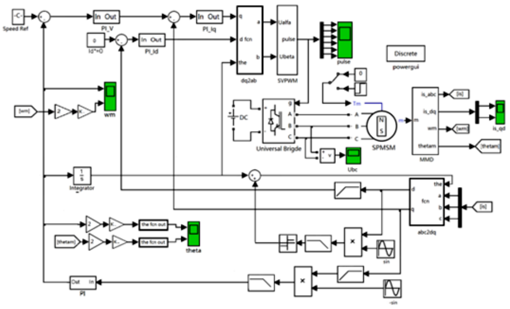

Fig.3 System simulation structure diagram

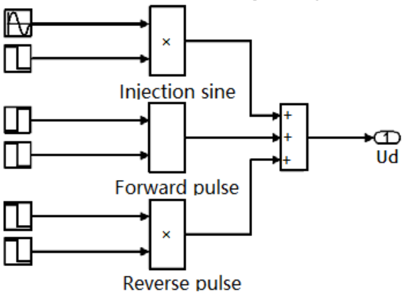

Fig.4 Voltage signal injection module

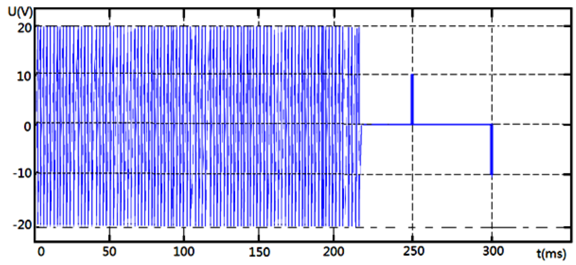

Fig.5 Injection voltage signal waveform

3.2 The simulation parameters

In the motor module, the SPMSM parameters are shown in table 1, and the PWM inverter adopts SVPWM modulation.

Table 1 SPMSM parameter list for simulation

SPMSM parameters	Numerical value	unit
The rated voltage	220	V
Rated current	8.6	A
Rated power	1500	W
Rated speed	3000	rpm
Number of pole-pairs	2	pair
Stator resistance	2.875	Ω
Direct axis inductance	7.96	mH
Quadrature axis inductance	7.96	mH
The moment of inertia	0.03	kg .m2
Permanent magnet flux linkage	0.275	Wb
The rated torque	16	N.m

3.3 Simulation results analysis

1. The influence of high-frequency pulse voltage amplitude on current error i_{Δ}

Due to coordinate system ($\hat{d}$-$\hat{q}$) with (d-q) almost synchronous rotation, so in the high-frequency voltage modulation link, the effect of motor magnetic circuit structural salient is tiny, the effect of saturability salient role is very big, and this effect is directly reflected in the high frequency direct axis current amplitude. Along with the constant change of position between $\hat{d}$-axis and d-axis, the amplitude of high-frequency current component on the axis of d-q is also corresponding, and its change directly reflects the modulation result.

When the motor speed is 15r/min, the injection amplitude of a high frequency pulse voltage is 10V, the actual position and the estimated position of the rotor, the corresponding stator current component $\hat{i}_d$ and the current error curve i_{Δ} shown in Fig.6. Therefore, the high frequency pulse voltage injection method can be used to track the rotor position well at low speed, and the error is not more than 5%. In addition, as the rotor position changes, the stator current $\hat{d}$ axis component is obviously modulated.

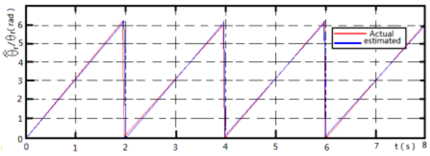

Fig.6 (a) Rotor position

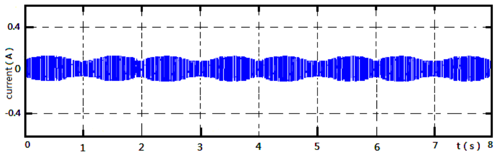

Fig.6 (b) $\hat{d}$ axis stator

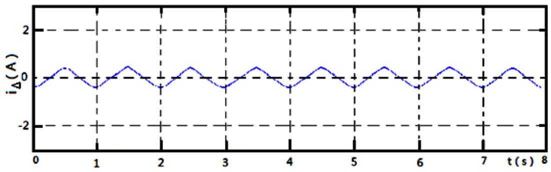

Fig.6 (c) Current error

Fig.6 Correspondence between rotor position, $\hat{d}$ axis stator current and current error（15rpm-10V）

When the motor speed is 30r/min, the injection amplitude of a high frequency pulse voltage is 10V, the actual position and the estimated position of the rotor, the corresponding stator current component $\hat{i}_d$ and the current error curve i_Δ shown in Fig.7. When the motor speed is 30r/min, the injection amplitude of a high frequency pulse voltage is 30V, the actual position and the estimated position of the rotor, the corresponding stator current component $\hat{i}_d$ and the current error curve i_Δ shown in Fig.8. As can be seen from the figure, the rotor estimation position can track the actual position well, and the error is no more than 4%. It can also be seen that, regardless of the pulse vibration signal, the stator current $\hat{d}$ axis component is obviously modulated, and the frequency of the modulation signal is consistent with the frequency of the current error.

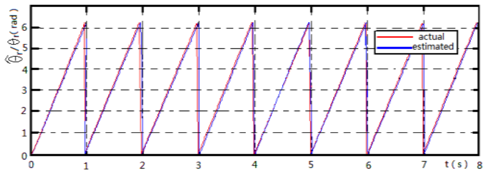

Fig.7 (a) Rotor position

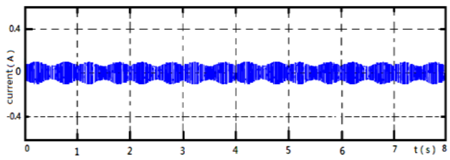

Fig.7 (b) $\hat{d}$ axis stator

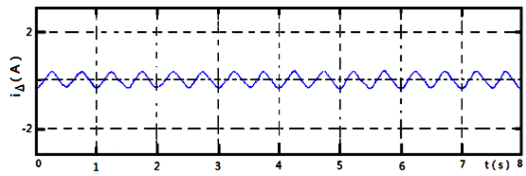

Fig.7 (c) Current error

Fig.17 Correspondence between rotor position, $\hat{d}$ axis stator current and current error（30rpm-10V）

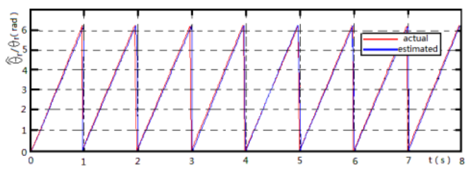

Fig.8 (a) Rotor position

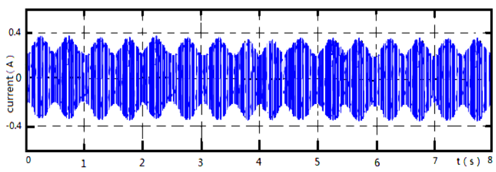

Fig.8 (b) $\hat{d}$ axis stator

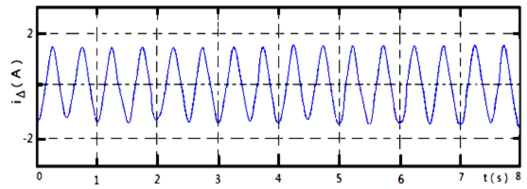

Fig.8 (c) Current error

Fig.8 Correspondence between rotor position, $\hat{d}$ axis stator current and current error（30rpm-30V）

As can be seen from Fig.6, Fig.7 and Fig.8, when the injected high-frequency voltage amplitude is reduced, the amplitude of the current error and the stator current amplitude are also reduced.That is: As long as the input voltage amplitude is within the allowable range, the stator current will be modulated, the rotor estimation position will track the actual position,and the frequency of high frequency current $\hat{i}_d$ and current error i_Δ must be consistent. Continue to increase the amplitude of high frequency pulse injection voltage will produce pulsating torque, affect the dynamic performance of the system. But the small amplitude can't inspire a required high frequency current, so the correct selection of high-frequency pulse voltage amplitude is very important.

2. Analysis of the initial position of the rotor at the Stationary state of the motor

(1) The position response curve of the magnetic pole is not detected

In order to verify effectiveness of the motor initial estimate position under stationary state, only injection of high frequency voltage on both ends of the motor, let the motor rotor initial position is different, choose rotor position respectively: 0° 、60° 、90° 、135° 、180° 、240. When the motor saturation effect is not considered and the rotor polarity is not detected, the corresponding rotor position estimate value and the actual value are shown in fig.9.

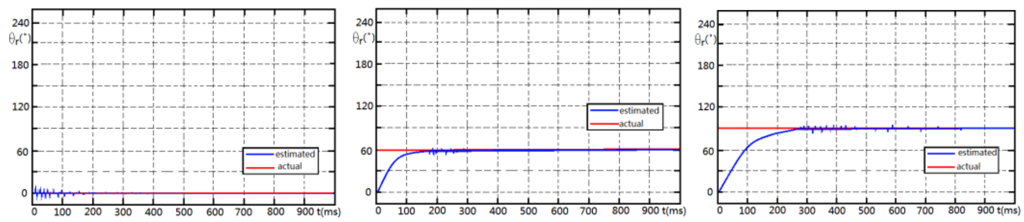

Fig.9 (a) 0。 Fig.9 (b) 60 。Fig.9 (c) 90

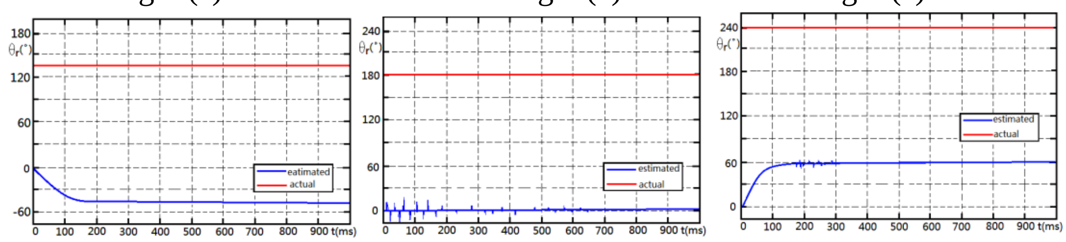

Fig.9 (d) 135 Fig.9 (e) 180 Fig.9 (f) 240

Fig.19 Response curves of different initial position of rotor in stationary state

As shown in fig.19, when the motor rotor position is: 0° 、60° 、90° , the rotor estimation Angle is the same as the actual value, it can converge after 200ms, and the error tends to zero. When the rotor position is 135° 、180° 、240° , because the saturation effect of the motor is not considered, so the polarity of the rotor cannot be discriminated, thus resulting in a 180° deviation between the estimated value of the rotor position and the real value.

4. Conclusion

In this paper, a SPMSM vector control system based on high frequency pulse voltage injection is established for the problem of the electric motor in low speed operation. When low speed control is performed on the sensorless SPMSM, the synchronous axial high pass filter is designed. At the same time using the salient pole motor saturation effect principle, injection two-way pulse to system, through the current amplitude change, judge the correct position of the rotor pole polarity, realize SPMSM accurate positioning of the initial position. Finally, the simulation verifies the feasibility of the algorithm and the performance of the vector control system based on this algorithm. The results show that the vector control system based on the high frequency pulse voltage injection method can realize the rotor position identification of SPMSM which running in low speed or at stationary state. And the design vector system can be high accuracy and smooth operation.

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