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PMSM Sensorless Vector Control Based on Instantaneous Power Angle Detection

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Abstract: Nowadays, with the rapid development of high-performance servo system, As the newly rich of servo motor, Permanent magnet synchronous motor (PMSM) control requirements also become higher and higher. It is worth noting that the sensorless PMSM control system has gradually become the research hot spot. The key reason is there is a lot of inconvenience in many industrial fields to install motor speed encoder to measure the speed of PMSM (Casadei *et al*., 2000). For the purpose of realizing the sensorless vector control of PMSM, this study proposed a rotor speed and position estimation method based on the instantaneous power angle detection, targeted on the most common vector control method-id = 0 control algorithm. The study discussed the basic principles of the sensorless control of PMSM technology, established a PMSM sensorless vector control system simulation model. The simulation results showed that rotor speed sensorless vector control system has good dynamic and static performance and robustness characteristics. The sensorless control algorithm is simple and easy to implement.

Key words: Permanent magnet synchronous motor, simulation, sensorless, vector control

INTRODUCTION

Permanent magnet synchronous motor control needs reliable rotor position signal, however, the installation of photoelectric encoder brings many defects to the system, such as high cost, difficult installation and maintenance, decline in anti-interference ability and reliability. Sensorless technology has become one of research hotspots in the field of motor control technology.

So far, PMSM vector control system has many methods to estimate the motor rotor position and rotor speed. Lei *et al*. (2007) proposed a model reference adaptive method. This method can guarantee the estimated parameters gradual convergence, but is more sensitive to the parameters of the reference model and is poor robustness. Li and Elbuluk (2001) and Bolognani *et al*. (2003) used the sliding mode variable structure and Extended Kalman Filter (EKF) method to achieve sensorless vector control for PMSM, compared with other algorithm, it can get good position and rotor speed estimation results, but the algorithm is too complicated. Especially need to calculate Jacobean matrix, brought difficulties to the practical application. Li *et al*. (2010) used artificial intelligence estimate method to estimate position and rotor speed. Estimation method is relatively complex, is not conducive to the adjustment of the structure and parameters design. Jia and He (2007) proposed a method to estimate the rotor speed based on the stator flux linkage, however, this method is based on variable structure system to estimate the position. The defects are implement complicated, response rotor speed is slow and poor robustness. In this study, the rotor speed estimation method based on instantaneous power angle detection is been further derivation. Get the position estimation method. Under the common vector control system which can get very good results. Thus, the sensorless control of permanent magnet synchronous motor vector control system is proposed.

SENSORLESS VECTOR CONTROL OF PMSM CONTROL PRINCIPLE

In the PMSM control system, In order to get maximum torque of motor, commonly used control strategy of id = 0. The id = 0 of the rotor field oriented vector control of PMSM drive system principle diagram shown in Fig. 1.

Control procedure: The given rotor speed signal is compared with the detected rotor speed signal, after the rotor speed PI controller, the output current component as a given signal iq* for quadratic axis current PI controller. After coordinate transformation, Feedback current is stator id, iq. The given direct axis current id* = 0. Compared with the transformed current id, iq and sent the results to the PI controller, respectively. The output of the PI controller are ud* and uq*. After Parke transformation we got U^*_α and U^*_β.

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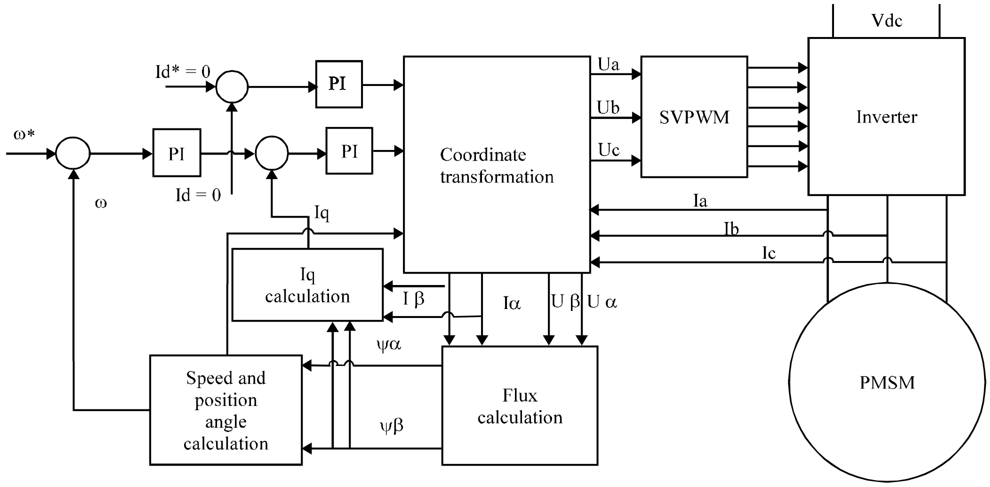

Fig. 1: PMSM sensorless vector control principle diagram

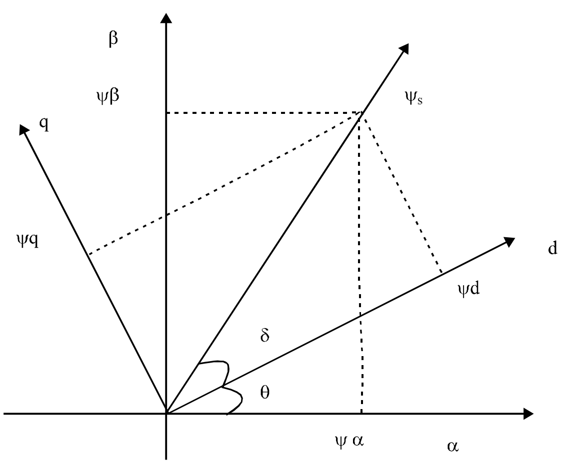

Fig. 2: PMSM coordinate system

Finally, through the six-way SVPWM module output control signal to drive the inverter.

Rotor speed/position estimation based on instantaneous power angle detection: The component of PMSM static linkage ψs under different coordinate system is shown in Fig. 2.

U_α, U_β are the component of ψs in αβ coordinate system. ψd*, ψq* are the component of ψ_s in dq coordinate system. δ is power angle. θ is the rotor flux linkage angle.

The flux linkage of PMSM in stastic αβ coordinate system are:

$$\begin{cases}\psi_\alpha = \int (U_\alpha - L_s i_\alpha)dt \\ \psi_\beta = \int (U_\beta - L_s i_\beta)dt\end{cases} \tag{1}$$

According to Fig. 2, the instantaneous power angle can show as below:

$$\delta = \arctan(\psi_q/\psi_d) \tag{2}$$

The flux linkage of PMSM in stastic dq coordinate system are:

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

And because the control algorithm of the control system is the id = 0, so the power angle expression can be simplified as:

$$\delta = \arctan(L_s i_q/\psi_f) \tag{4}$$

The static flux linkage angle expression (4) can be expressed as:

$$\arctan(\psi_\beta/\psi_\alpha) = \delta+\theta \tag{5}$$

The static flux linkage øs can be expressed as:

$$|\psi_s|^2 = \psi^2_\alpha+\psi^2_\beta \tag{6}$$

And we can get the rotor position angle:

$$\theta = \arctan(\psi_\beta/\psi_\alpha)-\arctan(\psi_q/\psi_d) \tag{7}$$

To derivate the rotor position angle:

$$\omega_r = (\dot{\psi}_\beta \psi_\alpha - \dot{\psi}_\alpha \psi_\beta - \dot{\psi}_q \psi_d + \dot{\psi}_d \psi_q)/|\psi_s|^2 \quad (8)$$

Substituting (3) in (8):

$$\omega_r = (\dot{\psi}_\beta \psi_\alpha - \dot{\psi}_\alpha \psi_\beta - L_d L_q \dot{i}_q i_d + L_d L_q \dot{i}_d i_q - \psi_f L_q \dot{i}_q)/|\psi_s|^2 \quad (9)$$

Because id = 0, so the rotor speed can expressed as:

$$\omega_r = (\dot{\psi}_\beta \psi_\alpha - \dot{\psi}_\alpha \psi_\beta - \psi_f L_q \dot{i}_q)/|\psi_s|^2 \quad (10)$$

The expression of electromagnetic torque of PMSM is shown as below:

$$\begin{aligned} T_e &= 1.5p(\psi_\alpha i_\beta - \psi_\beta i_\alpha) \\ &= 1.5p(\psi_d i_q - \psi_q i_d) \\ &= 1.5p\psi_d i_q \end{aligned} \quad (11)$$

$$i_q = \frac{(\psi_\alpha i_\beta - \psi_\beta i_\alpha)}{\psi_f} \quad (12)$$

Substituting (12) in (10):

$$\omega_r = (\dot{\psi}_\beta \psi_\alpha - \dot{\psi}_\alpha \psi_\beta - (\psi_\alpha i_\beta - \psi_\beta i_\alpha)L_q)/|\psi_s|^2 \quad (13)$$

SIMULAITON ANALYSIS

In order to verify the feasibility of design scheme, according to the above analysis of the theory, the simulation of PMSM vector control system is performed in MATLAB/Simulink (Ge, 2008). Motor parameter: number of poles: P = 4, stator resistance R_s = 2.875 Ω, inductance Ls = 8.5 mH, rotor inertia J = 0.8×10-3 kg m^{-2}, rotor flux linkage ψ_f = 0.175 Wb. Chosen algorithm ode23 tb where relative error is 1e-3 and the simulation time is 0.1 sec.

The system no-load waveform is shown in Fig. 3-6. From Fig. 3, we can find that after 0.015 sec system is in steady state, the estimated rotor speed and the measured rotor speed is very close. From Fig. 4, we can find that the estimated rotor position angle and the measured angle are almost completely overlapped. Figure 5 and 6 is the error of actual and estimated rotor speed in no-load and the error of actual and estimated position angle in no-load, respectively.

The system loading waveform is shown in Fig. 7-10. At the time of 0.04 sec, apply load of 3 N m^{-1}. From Fig. 5, we can find that the estimated rotorspeed and actual rotor speed after load has a small cut. But soon back to steady

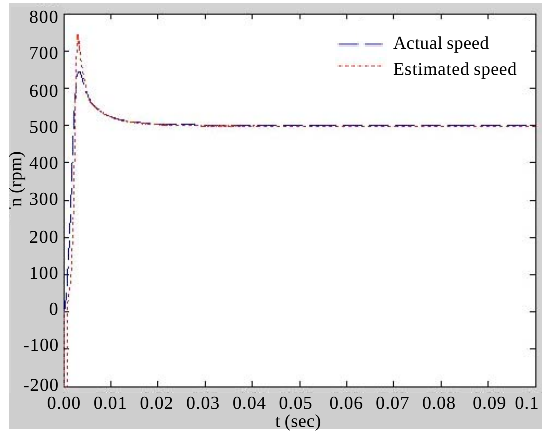

Fig. 3: Actual and estimated rotor speed in no-load

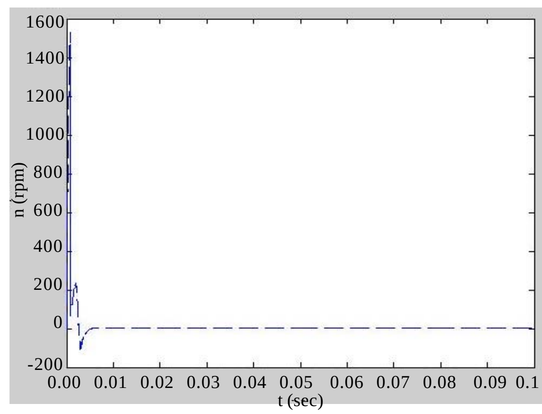

Fig. 4: Actual and estimated position angle in no-load

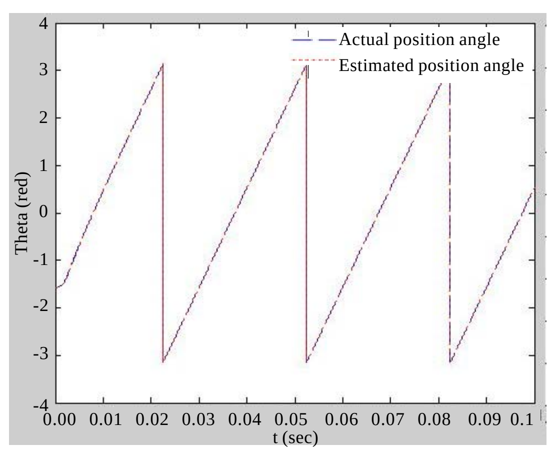

Fig. 5: Error of actual and estimated rotor speed in no-load

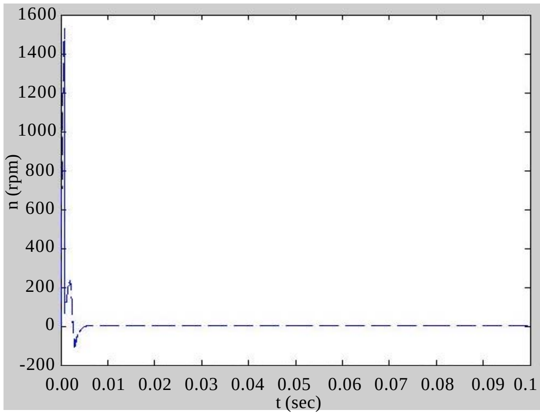

Fig. 6: Error of actual and estimated position angle in no-load

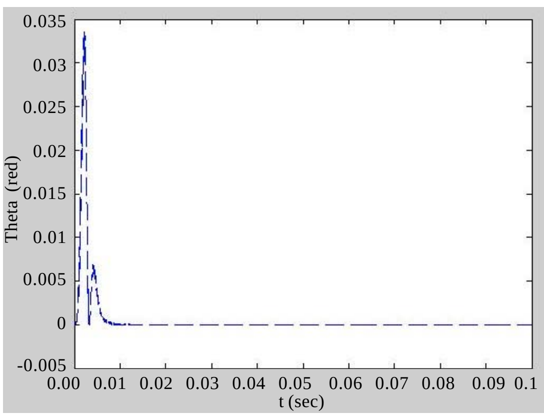

Fig. 7: Actual and estimated rotor speed in loading

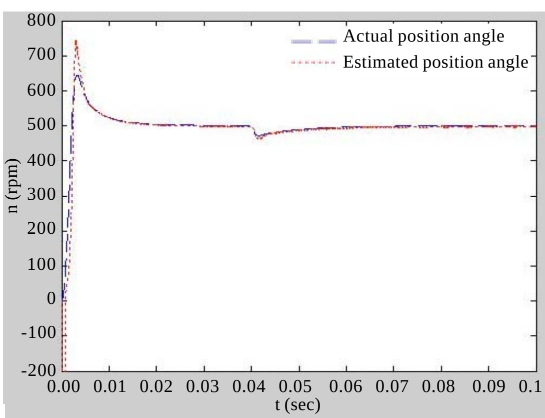

Fig. 8: Actual and estimated position angle in loading

state and the rotorspeed is still 500 rpm. The position angle is relatively precise and the error of rotorspeed and position angle is shown in Fig. 9 and 10.

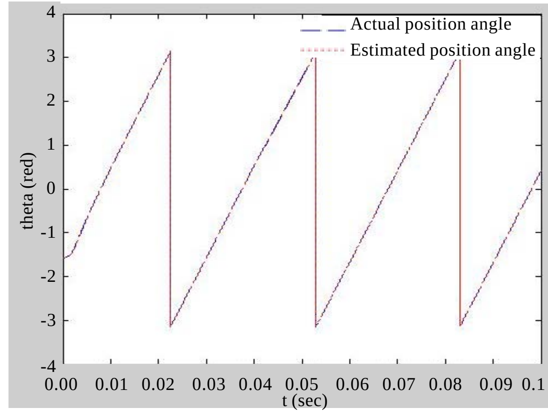

Fig. 9: Error of actual and estimated rotor speed in loading

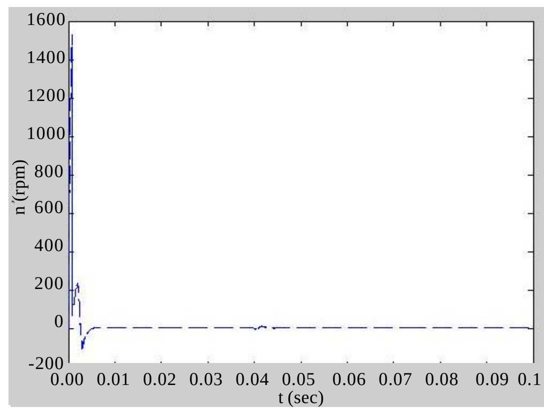

Fig. 10: Error of actual and estimated position angle in loading

The system unloading waveform is shown in Fig. 7-10. The motor started with the load of 3 N m^{-1} and the given rotorspeed is 500 rpm, At the time of 0.04 sec, unload to 0 N m^{-1}. From Fig. 11, we can find that the estimated rotorspeed and actual rotor speed after load has a small rise. But soon back to steady state and the rotorspeed is still 500 rpm. The position angle is relatively precise and the error of rotorspeed and position angle is shown in Fig. 13 and 14, respectively.

While the torque keeps 3 N m^{-1}, rotor speed rise from 500-1000 rpm in 0.04, the waveform is shown in Fig. 15-18.

The picture above shows that the algorithm to estimate the rotor position angle precision is relatively high. When the load mutates, the estimated motor position and rotor speed and the actual signal is very close. It is proved that the algorithm has high tracking accuracy. Load torque changes has little influence on the rotor speed and rotor position, illustrate the strong

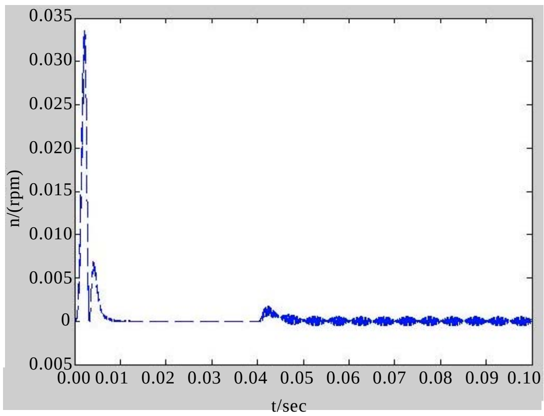

Fig. 11: Actual and estimated rotor speed in unload

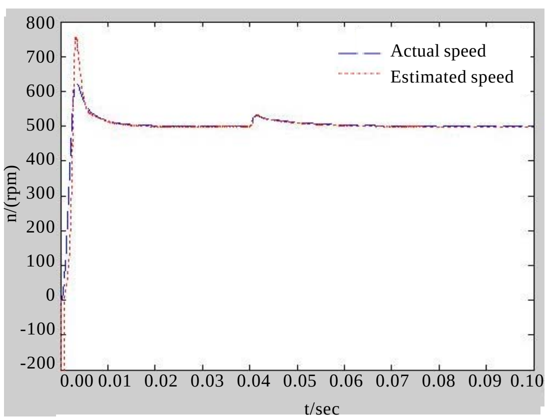

Fig. 12: Actual and estimated position angle in unload

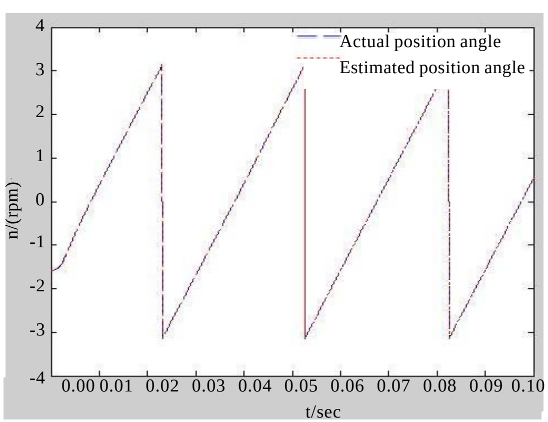

Fig. 13: Error of actual and estimated rotor speed in unload

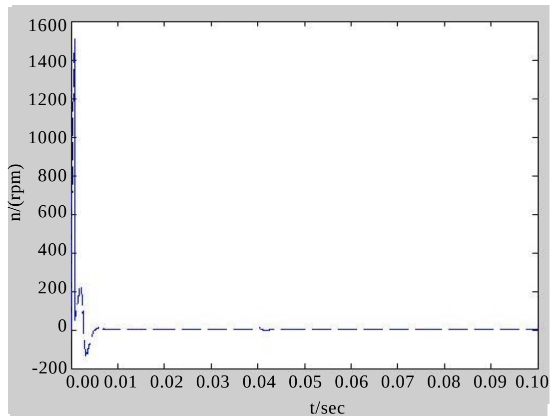

Fig. 14: Error of actual and estimated position angle in unload

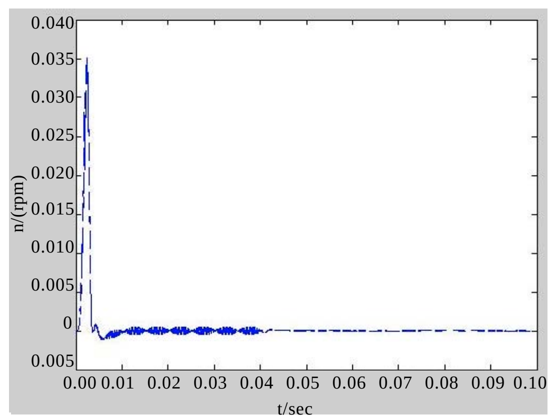

Fig. 15: Actual and estimated rotor speed in changing given rotor speed

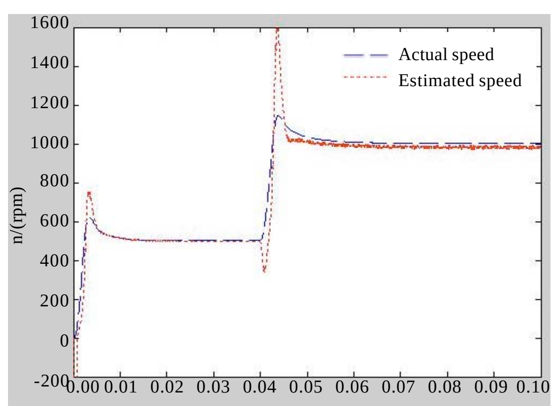

Fig. 16: Actual and estimated position angle in changing given rotor speed

Table 1: Errors in different states

State	Mean position angle error (°)	Angle of deviation from the mean (%)	Rotor speed deviation from the mean (%)	Mean rotor speed error (rpm)
No-load	0.0401	0.0111	2.978	14.8913
loading	0.0516	0.0143	2.862	14.3114
Unload	0.0344	0.0095	2.508	12.5416
Change given speed	0.0458	0.0127	1.762	17.6193

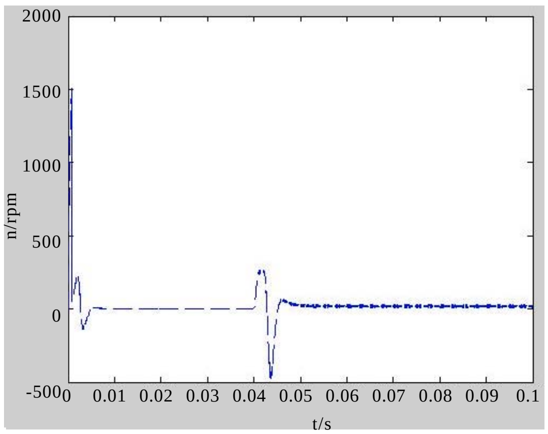

Fig. 17: Error of actual and estimated rotor speed in changing given rotor speed

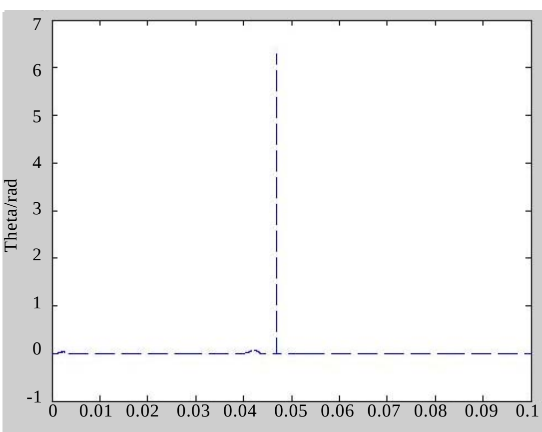

Fig. 18: Error of actual and estimated position angle in changing given rotor speed

robustness and rotor speed closed loop system has played a very good regulatory role. Verify the feasibility and correctness by using this algorithm to replace the mechanical position sensor. Table 1 lists the mean error between rotor position, rotor speed and actual signal values in the no-load, loading, unloading and the rotor speed changes as well as torque constant state. From the data can be more intuitive to see the algorithm estimates of effect in different condition.

CONCLUSION

Based on PMSM as control object, the rotor speed and position estimation based on stator flux were studied, proposed a novel rotor speed and position estimated algorithm. The simulation of PMSM vector control system is performed in MATLAB/Simulink and has carried on the simulation demonstration. The simulation result shows that the proposed scheme can accurately detect rotor space position and rotor speed in no-load, loading, unloading and the rotor speed changes as well as torque constant state, has a wide rotor speed range and good static and dynamic performance and the calculation is not complex, has good industrial application prospect.

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