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 Ud* and Up.
Fig. 1: PMSM sensorless vector control principle diagram

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

$$\delta = \arctan \left( \frac{\psi_q}{\psi_d} \right)$$  \hspace{1cm} (2)

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

$$\begin{align*}
\psi_d &= L_d i_d + \psi_i \\
\psi_q &= L_q i_q
\end{align*}$$  \hspace{1cm} (3)

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

$$\delta = \arctan \left( \frac{\psi_q}{\psi_d} \right)$$  \hspace{1cm} (4)

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

$$\arctan \left( \frac{\psi_q}{\psi_d} \right) = \delta + \theta$$  \hspace{1cm} (5)

The static flux linkage \( \alpha \beta \) can be expressed as:

$$|\psi_d|^2 = |\psi_q|^2 + |\psi_d|^2$$  \hspace{1cm} (6)

And we can get the rotor position angle:

$$\theta = \arctan \left( \frac{\psi_q}{\psi_d} \right) - \arctan \left( \frac{\psi_q}{\psi_d} \right)$$  \hspace{1cm} (7)

To derivate the rotor position angle:
\[ \omega_2 = \frac{(\psi_1 \psi_2 - \psi_1 \psi_0 - \psi_0 \psi_1 + \psi_1 \psi_0)}{\left| \psi_1 \right|^2} \]  

(8)

Substituting (3) in (8):

\[ \omega_2 = \frac{(\psi_1 \psi_2 - \psi_1 \psi_0 - L_d J_1 i_1 - L_q J_2 i_2 - \psi_1 \psi_1)}{\left| \psi_1 \right|^2} \]  

(9)

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

\[ \omega_2 = \frac{(\psi_1 \psi_2 - \psi_1 \psi_0 - L_q J_1 i_1)}{\left| \psi_1 \right|^2} \]  

(10)

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

\[ T_e = 1.5p(\psi_1 i_1 - \psi_1 i_2) \\
-1.5p(\psi_1 i_1 - \psi_1 i_2) \\
= 1.5p\psi_1 i_1 \]  

(11)

\[ i_1 = \frac{\psi_1 \psi_1 - \psi_1 i_1}{\psi_1} \]  

(12)

Substituting (12) in (10):

\[ \omega_2 = \frac{(\psi_1 \psi_1 - \psi_1 \psi_0 - (\psi_1 i_1 - \psi_1 i_1) J_2)}{\left| \psi_1 \right|^2} \]  

(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 \( R_s = 2.875 \, \Omega \), inductance \( L_s = 8.5 \, mH \), rotor inertia \( J = 0.8 \times 10^{-3} \, kg \, m^2 \), rotor flux linkage \( \psi_r = 0.175 \, Wb \). 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 rotor speed and actual rotor speed after load has a small cut. But soon back to steady
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.

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 rotorspeed 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, rotorspeed 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 rotorspeed 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 rotorspeed 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

<table>
<thead>
<tr>
<th>State</th>
<th>Mean position angle error (°)</th>
<th>Angle of deviation from the mean (%)</th>
<th>Rotor speed deviation from the mean (%)</th>
<th>Mean rotor speed error (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-load</td>
<td>0.041</td>
<td>0.011</td>
<td>2.978</td>
<td>14.8913</td>
</tr>
<tr>
<td>Loading</td>
<td>0.0516</td>
<td>0.0143</td>
<td>2.862</td>
<td>14.3114</td>
</tr>
<tr>
<td>Unload</td>
<td>0.0344</td>
<td>0.0095</td>
<td>2.508</td>
<td>12.5416</td>
</tr>
<tr>
<td>Change</td>
<td>0.0458</td>
<td>0.0127</td>
<td>1.762</td>
<td>17.6193</td>
</tr>
</tbody>
</table>

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.

REFERENCES