SENSORLESS CONTROL OF SURFACE-MOUNT PERMANENT-MAGNET SYNCHRONOUS MOTORS

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ABSTRACT

Because of the characteristics of the surface mounted permanent magnet synchronous motor (SPMSM) is gaining popularity in all fields of engineering (like industrial applications, robotics and automobiles etc.). But the exact controlling of the position and speed of motor is still a challenging task because attachments of sophisticated sensors causes increase in cost and reduces the operational ruggedness of the motor which it the key requirement in many applications. In this paper we are presenting a sensor less controlling method for SPMSM involves space vector modulation (SVM) with measurement vector insertion, voltage by frequency (V/F) control and model reference adaptive system (MRAS). The simulation result shows that the proposed method can effectively control the SPMSM.

Keywords: Sensor less motor control, surface mounted permanent magnet synchronous motor (SPMSM), Space vector modulation, voltage by frequency (V/F) controlling, model reference adaptive system (MRAS).

1. INTRODUCTION

The surface mounted permanent magnet synchronous motor (SPMSM) have large power density in comparison of induction motor hence it can produce greater power even at much lower size it also have the higher efficiency and greater torque to current ratio. With all these advantages it has difficult to control because the controlling system needs to know the position of the rotor and for this it require special sensors (Hall Effect sensors) to sense the position of the rotor exactly and additional wiring is also required to connects the sensors with control circuits. The involvement of sensor increases the cost of the motor and the wiring increases the complexity and because the sensors are not so strong hence it overall reduces the durability and the ruggedness of the motor. Because of these problems it is required to avoid the sensors and develop some other methods which can sense the rotor
position by just the observations of the stator voltage and currents and these methods are classified as sensor less controlling methods. Although it is always difficult to estimate the rotor position by just stator voltage and current observations because the observations are corrupted by the transients of the motor characteristics and the switching activities there are many more problems associated to this hence in this paper we are proposing a techniques that can overcome these problems.

2. LITERATURE REVIEW

The proposed work involves combination of many theories and this section presents a brief review of the literature helps in developing the concepts of this paper. Chalermpon Pewmaikam et al [1] presented presents a torque control system with an adaptive fuzzy logic compensator for torque control and torque estimation simultaneously. Peter B. Schmidt et al [3] presents a technique that will calculate the absolute angular position of a permanent magnet (PM) rotor within a pole pair at standstill. The algorithm works with non-salient pole motors. By choosing an appropriate voltage pulse width and applying it to each phase winding, the stator currents will partially saturate the stator iron, enabling the algorithm to discern between a north pole and a south pole, and subsequently, the absolute position. The scheme is computationally simple and does not rely on the knowledge of any of the motor parameters. Rotor Position and Velocity Estimation at Standstill and High Speeds is presented in [4] the proposal addresses self-sensing (“sensor less”) control of salient pole permanent magnet synchronous motors (PMSM’s). The major contribution of this work is the introduction of a simple-to-implement estimation technique that operates over a wide speed range, including zero speed. In the proposed technique the motor acts as the electromagnetic resolver and the power converter applies carrier frequency voltages to the stator which produce high frequency currents that vary with position. The sensed currents are then processed with a heterodyning technique that produces a signal that is approximately proportional to the difference between the actual rotor position and an estimated rotor position. This position error signal and a torque estimate are then used as inputs to a Luenberger style observer to produce parameter insensitive, zero lag, position and velocity estimates. Nur Bekiroglu, Selin Ozcira [6] presents the Direct Torque Control Method with Low Pass (LP) Filter in this article direct torque control (DTC) of a permanent magnet synchronous motor is realized with a sensor less speed control technique without using an observer. Space vector pulse width modulation (SVPWM) technique is applied in order to determine the switching sequence of the voltage source inverter. Torque and flux, the main variables of the DTC, are estimated by using the mathematical model of the motor. Estimated torque and flux values are compared with their references in every control cycle. Then, according to the torque and flux demand, the voltage vector is constituted. In the proposed control scheme, speed is estimated by using flux calculations and a PI controller is used to process the torque and flux errors. Furthermore, a low-pass (LP) filter is implemented within the proposed system for voltage and current harmonics suppression.

3. SPACE VECTORS

During normal state, there are eight switching states of inverter which can be expressed as space voltage vector \( S_{A, B} \) and \( C \) such as \((0,0,0), (0,0,1), (0,1,0), (0,1,1), (1,0,0), (1,0,1), (1,1,0) \) and \((1,1,1)\). \( S_A = 1 \) means upper switch of leg A is on while the lower
one is off, and vice versa. The same logic is applicable to \( S_B \) and \( S_C \) also. Amongst above eight voltage vectors, \((0, 0, 0)\) and \((1, 1, 1)\) are termed as zero vectors while the other six as active vectors [5]. The switching vectors describe the inverter output voltages as shown in Figure 2.

**Figure 1:** Voltage source inverter-induction motor drive.

**Figure 2:** Voltage vectors and space sectors [5].

### 4. MEASUREMENT VECTOR INSERTION METHOD (MVIM)

A new single current sensing algorithm is proposed in [1] for achieving high-quality phase current reconstruction and regulation using a dc link current sensor. The proposed method effectively overcomes the problem created by the un-measurable intervals figure 3.

**Figure 3:** Un-measurable areas (shaded) in the inverter output voltage space vector plane along sector boundaries.
The new concept introduces a special switching sequence whenever the reference voltage vector falls into one of the un-measurable regions to insure that all three phase currents are measurable. In the first switching interval, the PWM algorithm generates a reference voltage vector according to basic SVPWM operation. During the second switching interval the new method introduces three special measurement vectors as shown in Fig. 4 and 54, so that all three phase currents can be sequentially measured during this interval.

![Diagram](image)

**Figure 4:** Basic concept of MVIM.

![Diagram](image)

**Figure 5:** Example of PWM timing waveforms for basic MVIM algorithm for reference vector in vicinity of (100) active voltage vector with $T_{s1} = T_{s2}$.

A group of three active space vectors consisting of [100], [010], and [001] can be utilized for the measurement vectors, or, alternatively, a second group of active space vectors [110], [011], and [101] can be applied. This new algorithm will be referred to as the measurement vector insertion method (MVIM).

5. SCALAR CONTROL V/F OF PMSM

Constant volt per hertz control in an open loop is used more often in the squirrel cage IM applications. Using this technique for synchronous motors with permanent magnets offers a big advantage of sensor less control. Information about the angular speed can be estimated indirectly from the frequency of the supply voltage. The angular speed calculated from the supply voltage frequency according to (1) can be considered as the value of the rotor angular
speed if the external load torque is not higher than the breakdown torque. The mechanical synchronous angular speed $\omega_s$ is proportional to the frequency $f_s$ of the supply voltage

$$\omega_s = \frac{2\pi f_s}{p} \ldots \ldots \ldots \ldots (1)$$

Where $p$ is the number of pole pairs, the RMS value of the induced voltage of AC motors is given as

$$E_f = \sqrt{2}\pi f_s N_s k_w \phi \ldots \ldots \ldots (2)$$

By neglecting the stator resistive voltage drop and assuming steady state conditions, the stator voltage is identical to the induced one and the expression of magnetic flux can be written as

$$\phi = \frac{V_{sph}}{\sqrt{2}\pi f_s N_s k_w} = c \frac{V_{sph}}{f_s} \ldots \ldots (3)$$

To maintain the stator flux constant at its nominal value in the base speed range, the voltage-to-frequency ratio is kept constant, hence the name $V/f$ control.

6. MODEL REFERENCE ADAPTIVE SYSTEM (MRAS)

Many articles have used MRAS approach to estimate rotor position. It makes use of the redundancy of two machine models of different structures that estimate the same state variable (rotor speed) of different set of input variables. The estimator that does not involve the quantity to be estimated is chosen as the reference model, and the other estimator may be regarded as the adjustable model. The error between the estimated quantities obtained by the two models is proportional to the angular displacement between the two estimated flux vectors. A PI adaptive mechanism is used to give the estimated speed. As the error signal gets minimized by the PI, the tuning signal $\omega$ approaches the actual speed $\omega$ of the motor. Based on MRAS principle, paper [15] uses voltage model and current model to calculate stator flux, the error between the two results is used to estimate rotor speed. Though simple for application, the estimated result depends greatly on motor parameter accuracy. In order to overcome this problem, in [16] [17] a combined method is suggested (Figure 6). The idea comes from HF injection method. In the proposed method a calibration signal $\epsilon$ containing estimated angle error is used for the calculation of stator flux using the voltage model. The author claims that the proposed combination of the two methods results in an observer having good steady-state accuracy and excellent dynamic properties over a wide speed range.

![Figure 6: MRAS based on stator flux estimation](image_url)
Paper [18] presents a MRAS method based on stator current. Using PM motor itself as a reference model, another adaptive mechanism is established (Figure 7).

![Figure 7: MRAS based on stator current](image)

This method is easy for application. The stability of the system is guaranteed by the Popov super stability theory. It is somewhat robust to parameter inaccuracy. Yet in the calculation, only PI integration is used to calculate the estimated speed from current difference between the two models. The convergence speed and the steady estimation accuracy cannot be properly assured.

7. SIMULATED MODEL

The proposed system is modeled and simulated using the MATLAB/Simulink. Figure 8 and 9 shows the block diagram and Simulink model of the simulated system respectively.

![Figure 8: Block Diagram of the Proposed System](image)
Finally the proposed method is tested for three different scenarios. In first scenario the motor speed is regulated for constant load.

![Figure 9](image.png)

**Figure 9:** the figure shows that the controller quickly responds to achieve the desired speed of 1500 RPM and only small overshoot is detected.

In second scenario the motor speed is regulated for step changing load (Increasing).

![Figure 10](image.png)

**Figure 10:** the load is changed from 1Nm to 2Nm at 0.2 second and the speed of the motor remains locked with negligible dip for very short time. It is also not showing any overshoot.

In second scenario the motor speed is regulated for step changing load (Decreasing).

![Figure 11](image.png)

**Figure 11:** the load is changed from 2Nm to 1Nm at 0.2 second and the speed of the motor remains locked with negligible surge for very short time. It is also not showing any overshoot.

In third scenario the load is maintained to constant while the required speed is step changed.

![Figure 12](image.png)

**Figure 12:** the load is maintained constant 1Nm and the required speed is changed from 1500 RMS to 1700 RMS at 0.2 second. The simulation result shows that the motor catches the new speed in just 0.02 seconds and with negligible overshoot. The result also shows that no oscillation occurs.
Table 1: Summarized Results for all scenarios discussed above.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Max Overshoot (In %)</th>
<th>Settling Time (In Sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.33</td>
<td>0.06</td>
</tr>
<tr>
<td>2(a)</td>
<td>-0.66</td>
<td>0.01</td>
</tr>
<tr>
<td>2(b)</td>
<td>0.66</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>1.11</td>
<td>0.02</td>
</tr>
</tbody>
</table>

8. CONCLUSION

In this paper, a sensorless controlling method is presented for the speed regulation of the surface mounted permanent magnet synchronous motors (SPMSM). The proposed method involves many theories as SVPWM with Measurement Vectors, V/F controlling and MRAS, and finally, the model is simulated using MATLAB/Simulink. The simulation results show that the proposed method not only accurately regulates the speed under steady state conditions but also regulates the speeds for changing loads and variable speed regulation without overshoot and oscillations.

REFERENCES
