THE INTELLIGENT DRIVE FOR PERMANENT MAGNET AC MOTORS

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Abstract: This paper describes novel rotor position estimation for permanent magnet AC motors. The algorithm developed relies on the phase voltages and the currents of the motor drive, which are both reconstructed from the DC link current and the switching control signals of the inverter. The work presents an intelligent control scheme for magnet AC motors with a minimum number of sensors. The scheme includes two principal sections: the rotor position *estimation algorithm and the current and voltage reconstruction. In the scheme, only one current sensor is required to measure the DC link current of the inverter.*

1. INTRODUCTION

The permanent magnet AC motors have a wide range of applications because of their high efficiency, high power density and easy controllability. In order to control such motors, however, their rotor position must be known and the accuracy of motor data primarily depends upon the type of the motor used. The permanent magnet AC motors belong to the family of the synchronous AC machines and so that the constant torque can be produced only when the winding currents are precisely synchronized with the induced voltages, which can be determined from the instantaneous rotor position.

The motors are powered via the three-phase inverters that ensure the synchronization of the current, which generates switching states from the rotor position data. The conventional way of measuring the rotor position data involves some form shaft-mounted sensing devices, such Hall-Effect devices, and resolves, absolute or incremental encoders. However, these mechanical shaft-mounted position sensors have many drawbacks and therefore, their applications could be restricted.

A number of indirect rotor position detection schemes for permanent magnet AC motors have been suggested in the recent years. The expected benefits of these indirect techniques are: elimination of the electrical connections of sensors, reduced size, no maintenance, unsusceptible to the environmental factors, increased reliability and above all these, operating at zero, low and higher speeds. However, most of the indirect position detection techniques have problems when they are used in real-time system, especially at the low and zero speed range. Moreover, in order to extract the rotor position information, the earlier schemes require at least four or more voltage and current sensors in total. The current information in the drive is used to accomplish the current control loop. However, the voltage and current sensors are expensive mainly due the requirements for the isolation. Therefore, employing minimum number of sensors, which also increase the reliability of the system.

The work presents an intelligent control scheme for magnet AC motors with a minimum number of sensors. The scheme includes two principal sections: the rotor position estimation algorithm and the current and voltage reconstruction. In the scheme, only one current sensor is required to measure the DC link current of the inverter.

2. POSITION ESTIMATION

In the permanent magnet AC motors with trapezoidal back electromotive force (emf), the rotor position information is needed every 60^0 electrical interval to achieve the current commutation and hence the self-synchronization. Several rotor position estimation methods for such motors have been proposed in the references [1-4], which are based on the back emf sensing or the conducting states of the freewheeling inverter diodes. However, all of the methods proposed so far ultimately fail at low and zero speed due to the absence of the measurable signal, back emf.

In the permanent magnet AC motors with sinusoidal back emf however, the continuous rotor position data is required. Furthermore, the continuous rotor potion information can be used to eliminate the torque ripple, which occur in the practical motor drives. A number of rotor position elimination techniques have also been reported for such motors. Some of the rotor position estimate techniques are based on the vector principle of AC motors. However, the accuracy of the measured voltages and the currents and the accurate knowledge of the motor parameters are necessary in these algorithms. Moreover, the reported methods suffer at low speeds require extensive computational power.

Other rotor position estimation techniques are based on the flux linkages, which can be obtained from the stator voltages and the currents of the motors. The flux linkage based methods operate accurately over a wide speed range and can be applied to the permanent magnet AC motors with trapezoidal and the sinusoidal back e.m.fs. However, the performance of the position estimation depends very much on the quality and the accuracy of the estimated flux linkages. The motor parameter variation also affects the accuracy of the estimated rotor position in these methods.

From the mathematical model of the permanent magnet AC motors, on can be observed that that the back emf. or flux linkage varies as a function of the rotor position only. Therefore, if these quantities are measured or estimated, the rotor position information can be determined. However, it is difficult to measure the back emfs, specifically at low operating speeds, or the flux linkages directly because of the integration shift in the calculations. On solve the above problems; instead of direct calculation of the back emfs or the flux linkages, this work presents an incremental estimation method for the rotor position.

From the mathematical model of the permanent magnet AC motors, the per-phase voltage equation of the star-connected the permanent magnet AC motor can be given by:

$$v = Ri + L\frac{di}{dt} + e, \tag{1}$$

where v is the phase voltage; R is the winding resistance, i is the line current; L is the equivalent winding inductance and e is the back emf. The back emf, e is a function of the rotor's angular speed and the position, can be expressed as:

$$e = k_e\,\omega_r\,e(\theta_e) = \frac{k_e\;e(\theta_e)}{p}\cdot\frac{d\theta_e}{dt}, \tag{2}$$

where k_e is the back emf constant; ω_r is the rotor's angular speed; $e(\theta_e)$ is the back emf function varies with rotor position; (θ_e) is the electrical rotor position and p is the number of pole pairs in the motor. Substituting equation (2) in (1), the increment of the rotor position within each time step can be calculated by

$$\Delta\theta_e = \frac{(V - Ri)\Delta t - L\Delta i}{k_e \cdot e(\theta_e)} \cdot p \,. \tag{3}$$

Hence, an incremental algorithm as given below can estimate the rotor position.

$$\theta_e(k) = \theta_e(k-1) + \Delta\theta_e \,. \tag{4}$$

If the parameters p, R, L, k_e and the function $e(\theta_e)$ are known, the rotor position θ_e can be calculated by using the data of the voltage and the current of the motor.
The algorithm is simple and easy to implement in real-time, due the less mathematical computations. The method can operate at very low operating speeds and even at zero speed. If the initial value of the rotor position has in error, it can be corrected within a short time and accurate rotor position information can be obtained. Finally, the method does not dependent upon the shape of the back emfs and hence can be applied to the types of the permanent magnet AC motors.

3. THE VOLTAGE AND THE CURRENT RECONSTRUCTION IN THE DRIVE

In order to control the permanent magnet AC motor, it is necessary to know all of the three line currents for the current control and/or the rotor position rotor estimation. The conventional method of obtaining the line currents in the practical drive is to measure them directly. Depending upon the winding connections of the motor, at least two current sensors are needed, as in the star connected motor. However, the current sensors are usually expensive due to the requirements of the high frequency bandwidths and the electrical isolation. Measuring can reduce the number of current sensors only the DC link current of the inverter and reconstructing the three-phase line currents from the measurement. Two current reconstruction methods have already been reported in the literature [1], [2], [3].

The current and the voltage reconstruction method are based on the model of the permanent magnet AC motor drive. The switching controls signals (a three-phase inverter consisting six switching devices and six diodes can create seventy-two possible switching states), the rotor position and the speed of the motor are used in the state observer that estimates not only the three-phase currents but also the three-phase voltages of the motor. (The observer can reconstruct the DC link current under all of the seventy-two states). The output of the observer is the estimated DC link current, which is reconstructed from the switching control signals and the estimated three-phase currents. The estimated DC link current and the measured DC link current are subtracted to generate an error term that can be used to correct the estimated voltages and the currents. Hence the observer can not only estimate the voltages and the currents accurately at any operation condition but also compensate the parameter variations in the motor.

4. THE COMPLETE INTELLIGENT DRIVE SYSTEM

The complete motor drive consists of the rotor position estimator and the current/voltage reconstruction sections. Figure 1 shows the block diagram of the drive system. If the DC link voltage of the inverter is constant, the drive requires only one current sensor that is used to measure the DC link. As explained above, the state observer estimates the phase currents of the motor from the switching control signals, the rotor position and the speed. The estimated three-phase currents reconstruct the DC link current by using the switching control signals. Then the error between the reconstructed DC links current is used to correct the estimated voltages and the currents in the drive.

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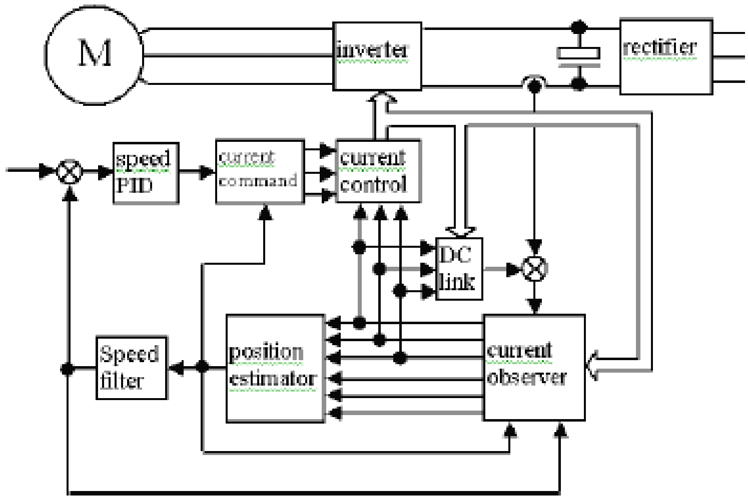
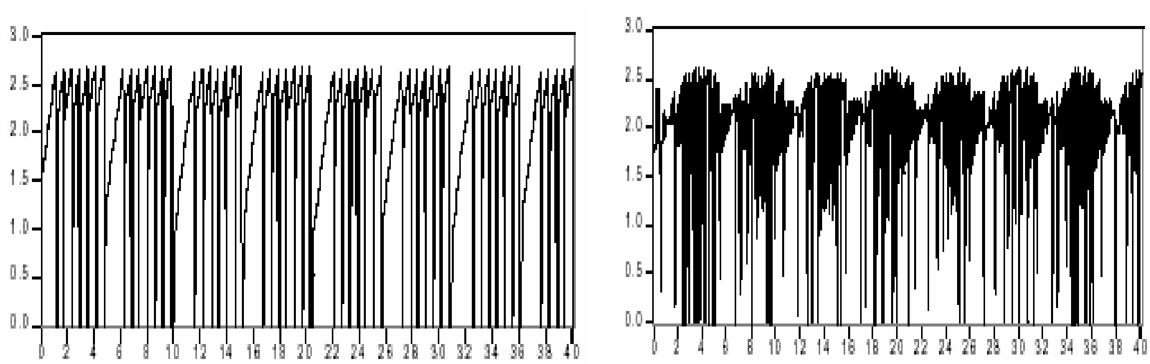


Figure 1. The complete block diagram of the intelligent motor drive system.



a) b)

Figure 2. The estimated steady-state current waveforms in the drive with a current control: DC link, reconstructed current of Phase 1, actual current of Phase 1 a) BTPM motor, b) BSPM motor.

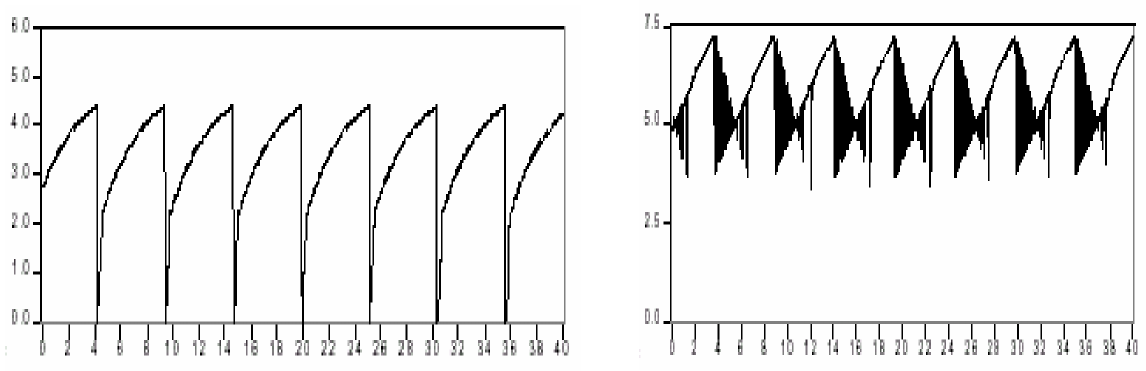


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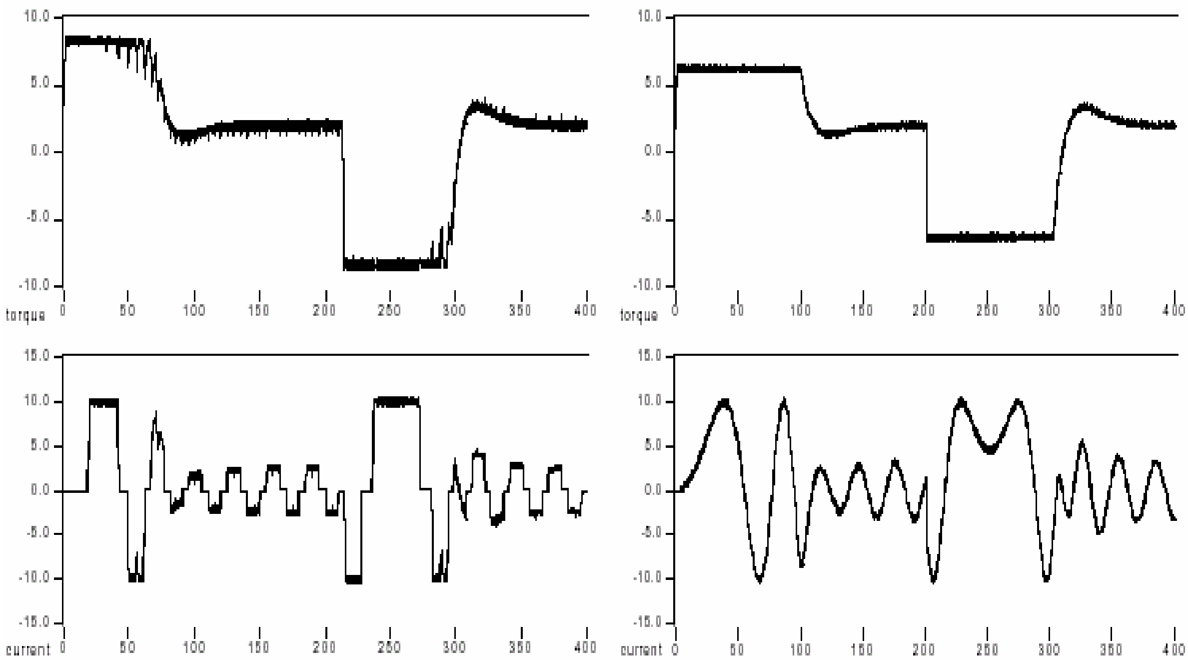
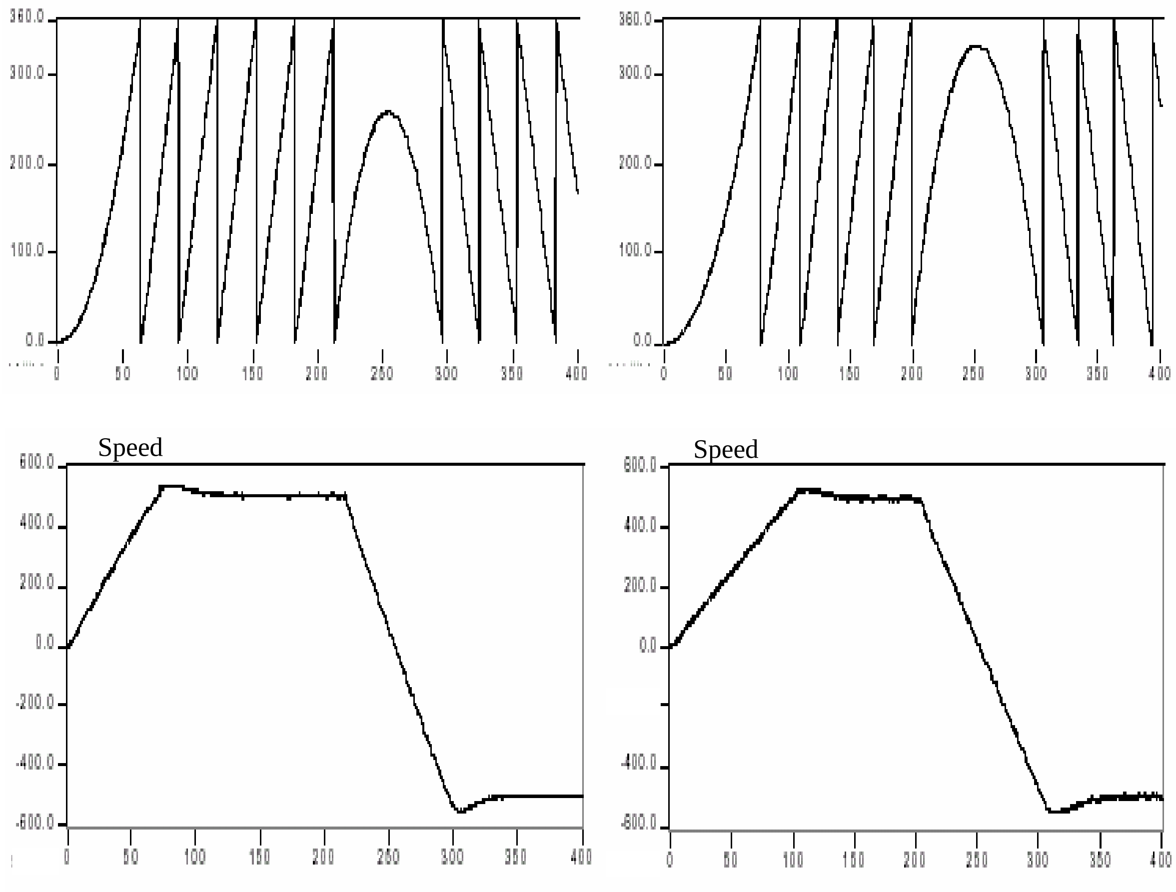
Figure 3. The estimated steady-state current waveforms in the drive without a current control: DC link, reconstructed current of Phase 1, actual current of Phase 1 a) BTPM motor, b) BSPM motor.

On observe the electromagnetic torque, the phase current, the predicted rotor position and the speed waveform, in figure 4.1 and 4.2. The identical motor parameters are used in both BSPM and BTPM motors. In the above results, the both motors are accelerated from standstill until a steady-state speed of 500 rpm is reached and then the speed is reduced down to zero and the rotation is reversed. The negative speed in the graphs illustrates the reversed rotation of the motor.



a) b)

Figure 4.1. The estimated waveforms of the torque and the phase 1 current: a) the results of the BTPM motor drive, b) the results of the BSPM motor drive.



a) b)

Figure 4.2. The estimated waveforms of the rotor position and the speed respectively a) the results of the BTPM motor drive, b) the results of the BSPM motor drive.

5. CONCLUSIONS

The algorithm relies on the phase voltages and the currents of the motor drive, which both are reconstructed from the measured DC link current and the switching control signals of the inverter. The state observer does not require any modification in the algorithm even if the motor type or the excitation mode is altered. The identical algorithms are used in the state observer controlling the motors with trapezoidal or sinusoidal back emfs.

Permanent magnet AC motors have a wide range of applications because of their high efficiency, high power density and easy controllability. In order to control such motors, however, their rotor position must be known and the accuracy of the rotor position data primarily depend upon the type of the motor.

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