역기전력 및 무효전력에 의한 영구자석 동기전동기의 센서리스 속도제어 개선

논 문
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High-Performance Sensorless-Control of PMSM Using Back-EMF and Reactive Power

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Abstract - This paper investigates a high-performance strategy for speed sensorless control of a permanent magnet synchronous motor. Two speed sensorless controls using back-EMF and reactive power are analyzed in this paper, and these two speed estimations are appropriately applied according to the steady and transient states for a high-performance sensorless control. The proposed sensorless control algorithm has a better performance compared to the conventional control algorithms.

Key Words : Permanent Magnet Synchronous Motor, Sensorless Control, Back-EMF, Reactive Power

1. Introduction

The vector control in speed and torque controlled ac drives is widely used for high performance applications. The vector control of a permanent magnet synchronous motor is usually implemented through measuring the speed and position. However, speed and position sensors require the additional mounting space, reduce the reliability in harsh environments and increase the cost of a motor. Various control algorithms have been proposed for the elimination of speed and position sensors: estimators using state equations, Luenberger or Kalman observers, sliding mode control, reactive power, saliency effects, artificial intelligence, direct control of torque and flux, and so on[1]. Most sensorless control algorithms are based on the flux and speed estimations which are obtained from the motor equations, and therefore they are sensitive to the electrical and mechanical parameters. This paper analyzes two sensorless controls using back-EMF and reactive power which compensate the speed error due to parameter errors, and investigates the high-performance strategy in the sensorless control of a permanent magnet synchronous motor. A speed estimation obtained from the back-EMF algorithm shows better performance in the steady state, and a speed estimation obtained from the reactive power algorithm shows better performance in the transient state. These two speed estimations are appropriately applied according to the steady and transient states in the proposed high-performance sensorless-control scheme. The proposed algorithm is verified through the simulation and experimentation.

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2. Sensorless Control Using Back-EMF and Reactive Power

The α- and β- axis voltage equations in the stationary reference frame fixed to the stator may be expressed as

$$v_{\alpha s} = R_s i_{\alpha s} + L_s \frac{di_{\alpha s}}{dt} + e_{\alpha s} \quad (1)$$

$$v_{\beta s} = R_s i_{\beta s} + L_s \frac{di_{\beta s}}{dt} + e_{\beta s} \quad (2)$$

The back-EMFs in the stationary reference frame fixed to the stator may be expressed as

$$e_{\alpha s} = \frac{d\Psi_{\alpha f}}{dt} = -\omega_r K_e \sin\Theta_r \quad (3)$$

$$e_{\beta s} = \frac{d\Psi_{\beta f}}{dt} = \omega_r K_e \cos\Theta_r \quad (4)$$

From (3) and (4), the rotor angle and speed may be expressed as

$$\theta_r = \tan^{-1}(-\frac{e_{\alpha s}}{e_{\beta s}}) \quad (5)$$

$$\omega_r = \frac{1}{K_e}\sqrt{e_{\alpha s}^2 + e_{\beta s}^2}\ sgn(\omega_r) \quad (6)$$

The estimated rotor speed of (6) is seriously affected by error of the back-EMF constant. Some studies have been performed for a compensation of the parameter error [2]-[5].

Fig. 1 is the block diagrams of the back-EMF constant compensation which is analyzed in this paper[2].

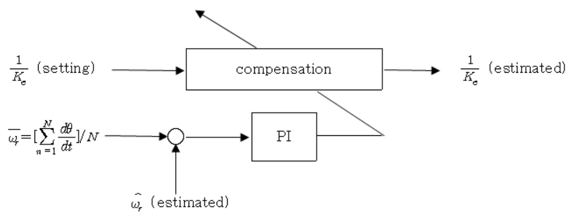


Fig. 1 Block diagram of back-EMF constant compensation

The compensation method of Fig. 2 uses a low pass filter for the rejection of a differential noise. Therefore, the transient state performance is poor.

The d- and q- axis voltage equations in the rotor reference frame with the rotating speed of ω_r may be expressed as

$$v_{ds} = R_s i_{ds} + L_s \frac{di_{ds}}{dt} - \omega_r L_s i_{qs} \quad (7)$$

$$v_{qs} = R_s i_{qs} + L_s \frac{di_{qs}}{dt} + \omega_r L_s i_{ds} + \omega_r K_e \quad (8)$$

From (8), the rotor speed estimation in the previous study using reactive power compensation is as follows[4].

$$\omega_r = \frac{v_{qs} - R_s i_{qs} - L_s \frac{di_{qs}}{dt}}{K_e + L_s i_{ds}} + C \quad (9)$$

In (9), a compensation value of C is determined by a compensation of the reactive power which may be expressed as

$$q_m = \boldsymbol{i_s} \times \boldsymbol{e_s} \quad (10)$$

where $\boldsymbol{i_s} = [i_{ds} i_{qs}]$, $\boldsymbol{e_s} = [e_{ds} e_{qs}]^T$, $e_{ds} = 0$, $e_{qs} = K_e \omega_r$.

From (10), the reactive power error due to the difference of the measured and estimated currents and may be expressed as

$$\triangle q_m = \hat{q}_m - q_m = (\hat{i}_{qs} - i_{qs}) K_e \omega_r \quad (11)$$

A compensation value of C may be expressed as

$$C = K_1 \triangle q_m + K_2 \int_0^t \triangle q_m d\tau \quad (12)$$

This compensation method may have a fast response in the transient state, but may have some steady state error due to a measured current error, and so on.

A new estimated speed, which is appropriately applied according to the steady and transient states, is proposed as follows

$$\omega_r = \frac{1}{T_s + 1} \omega_{CE} + \frac{T_s}{T_s + 1} \omega_{CR} \quad (13)$$

where ω_{CE} is the estimated speed in the back-EMF constant compensation, and ω_{CR} is the estimated speed in the reactive power compensation.

The overall system of the proposed sensorless control algorithm is shown in Fig. 2.

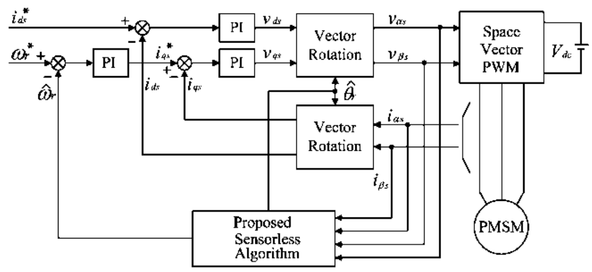


Fig. 2 Configuration of overall system

3. Simulation and Experimentation

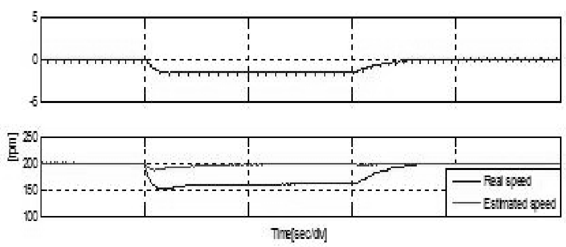
The simulation and experimentation have been performed to verify the proposed control algorithm applied to a sensorless permanent magnet synchronous motor.

Table 1 shows the specification of the permanent magnet synchronous motor used in the simulation and experimentation.

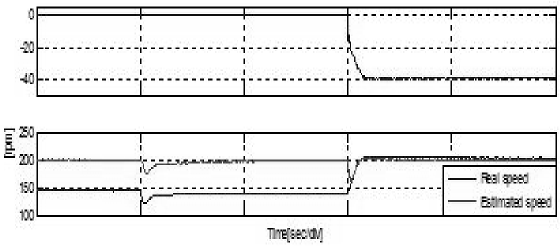
Table 1 Motor specification

Number of pole	8	Rs	1.5 Ω
Nominal current	5.3 A	Ls	4.17 mH
Nominal power	750 W	Ke	0.1 Vsec/rad

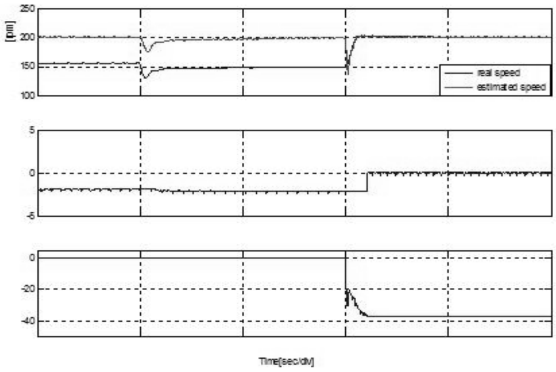
Fig. 3 and Fig. 4 are the simulation and experimental results obtained for the comparison with conventional algorithms in case that the back-EMF constant is decreased by 30% of the nominal value. The load torque of 2Nm is applied in the middle of the operation of the speed command 200rpm, and after that, the conventional and proposed control algorithms are applied.



(a) (top: K_e, bottom: $\hat{\omega}_r$ and ω_r)



(b) (top: C, bottom: $\widehat{\omega_r}$ and ω_r)



(c) (top: $\widehat{\omega_r}$ and ω_r, middle: K_e, bottom: C)

Fig. 3 Simulation response in the back-EMF constant decreased by 30% with the load variation (200rpm, 0→2Nm, $\widehat{K_e}=0.7K_e$)
(a) Back-EMF compensation
(b) Reactive power compensation
(c) Proposed compensation

4. Discussion and Conclusion

This paper proposed an improved speed sensorless control algorithm of a permanent magnet synchronous motor. A speed estimation obtained from the back-EMF compensation shows better performance in the steady state, and a speed estimation obtained from the reactive power compensation shows better performance in the transient state. These two speed estimations have been appropriately applied according to the steady and transient states in the proposed high-performance control scheme. As shown in the simulation and experimental results the proposed sensorless control algorithm has an improved performance, which has both a fast response and a small steady state error, compared to the conventional algorithms.

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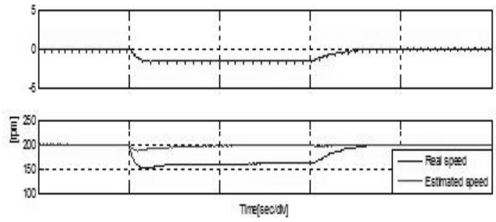
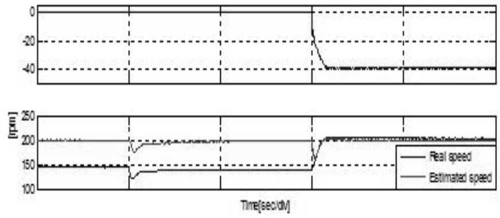
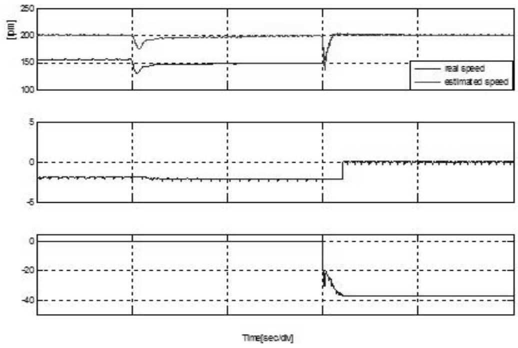


(a) (top: K_e, bottom: $\widehat{\omega_r}$ and ω_r)



(b) (top: C, bottom: $\widehat{\omega_r}$ and ω_r)



(c) (top: $\widehat{\omega_r}$ and ω_r, middle: K_e, bottom: C)

Fig. 4 Experimental responses in the back-EMF constant decreased by 30% with the load variation (200rpm, 0→2Nm, $\widehat{K_e}=0.7K_e$)
(a) Back-EMF compensation
(b) Reactive power compensation
(c) Proposed compensation

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