# Pseudo-sensorless Control of Permanent-magnet Synchronous Motor Based on Linear Hall-effect Sensor Signal

Seung-Tae Lee[1], and Jin Hur[1], *Senior Member IEEE*

[1] Dept. of Electrical Engineering, Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon 406-772, Korea
Jinhur@inu.ac.kr

**Generally, position and current sensors are used for the precise control of electric motors, but these sensors are expensive and inadequate in some applications considering cost. Thus, this study proposes a pseud-sensorless driver using only two linear hall sensors. The hall sensors are located in the shadow of permanent-magnet and detect a rotor position by measuring the magnetic flux changed by rotating rotor. Here, to obtain accurate rotor position, the harmonic components of the hall signals are eliminated through adaptive notch filter and phase-locked loop. Then, the hall signals are again synchronized with the fundamental wave of current in stationary reference frame, which is used for vector control of permanent-magnet synchronous motors. The proposed driver has the benefits including low cost and proper controllability in wide speed range.**

***Index Terms*—Adaptive filters, Hall effect, Phase locked loops, Permanent magnet machines, Sensorless control.**

## I. Introduction

To achieve precise operation of permanent-magnet (PM) synchronous motors (PMSMs), conventional drivers generally require the accurate monitoring of rotor position using encoder or resolver mounted on a motor shaft [1]. However, these sensors are expensive and the size of system is increased by mechanical coupling structure. For these reason, many researchers have studied the sensorless drives which can be representatively grouped into two approaches: the back electromotive force (EMF) and signal injection-based methods [2], [3]. The methods based on back EMF are easy to operate symmetric PMSMs, but are inappropriate in low speed range owing to magnitude reduction of the back EMF. In the case of the signal injection-based methods, they appear as a necessary solution at low speed, but suffer cross-saturation and secondary saliency problems.

To overcome above mentioned problems, this study proposes a pseudo-sensorless driver based on synchronization of estimated phase currents with linear hall signals. First of all, the hall sensors are utilized for rotor position information by measuring the edge-field of PM, but measured hall signals include third-harmonic components which cause estimation error. Thus, to eliminate the third-harmonic components, their signals are processed by adaptive notch filter (ANF) and phase-locked loop (PLL). Then, the processing hall signals are again synchronized to the fundamental wave of estimated phase currents in $\alpha\beta$-axes of stationary reference frame. The synchronized signals are applied to the feedback control in a current controller, which can substitute current sensors. Consequently, the linear hall sensors perform both the sensing of rotor position and the role of current sensor. The proposed driver is verified by simulation, and has the benefits that are low cost and accurate operation at low speed in comparison to other drivers.

## II. The Detection of Rotor Position

### A. Rotor Position Estimated by Linear Hall Sensors

To detect rotor position, two linear hall sensors are installed in the edge of PM in *dq*-axes, as shown in Fig. 1. When the rotor turns, the output signals of sine and cosine waveforms are generated by the sensors, and the magnitude and shape of the signals are affected by the distance from the PM to the hall sensor. To obtain a sinusoidal wave, the distance should be chosen in the light of magnetic saturation in the edge of the PM. Fig. 2 (a) shows the hall signals with harmonic components. Fig. 2 (b)–(d) shows the waveform and estimation error between real angle and angle estimated by hall signals without any compensation, and the maximum of error is around 10°. The main reasons of the estimation error caused by the harmonic components are the dispersion of edge-field and the shape of PM.

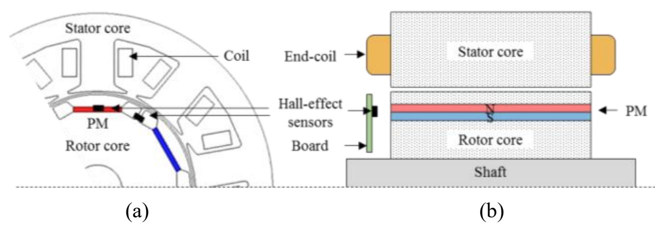


Fig. 1. Schematic diagram of PMSM for proposed driver. (a) Cross-section. (b) Longitudinal section.

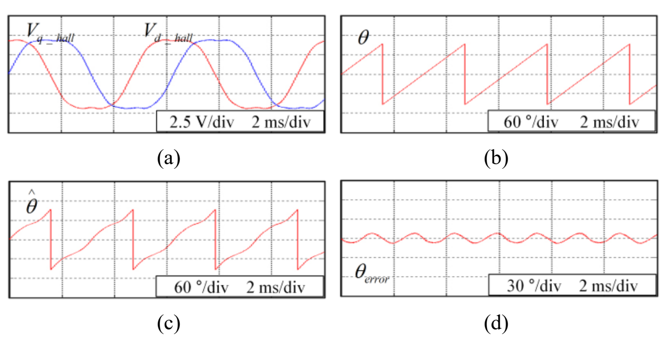


Fig. 2. A comparison of rotor position estimated by linear hall sensors. (a) Hall signals. (b) Real rotor position. (c) Estimated rotor position. (d) Rotor position error.

### B. Compensation of Rotor Position Error

The hall signals are compensated to reduce the estimation error. The orthogonal PLL is applied to rotor position estimation, as shown in Fig. 3. Here, the input signals of the orthogonal PLL are the hall signals $h_\alpha(t)$ and $h_\beta(t)$, as in (1) and (2). The phase difference $x(t)$ of the signals is determined by phase detector, as in (3). The second-harmonic component caused by multiplying sine and cosine functions is filtered out by the loop filter.

$$h_\alpha(t) = \sum_{n=1}^{\infty} A_n \sin\left[n\left(\omega_0 t + \frac{\pi}{2}\right)\right] \approx A_1 \cos(\omega_0 t) - A_3 \cos(3\omega_0 t) \quad (1)$$

$$h_\beta(t) = \sum_{n=1}^{\infty} A_n \sin(n\omega_0 t) \approx A_1 \sin(\omega_0 t) + A_3 \sin(3\omega_0 t) \quad (2)$$

$$x(t) = A_1 \sin[(\omega_0 - \hat{\omega})t] + A_3 \sin[(3\omega_0 + \hat{\omega})t] \quad (3)$$

where $\omega_0$ is the fundamental frequency of input signal. $A_1$ and $A_3$ is amplitudes of the fundamental and third-harmonic component, respectively.

Although hall signals are compensated through the orthogonal PLL, the third-harmonic components still remain. The third-harmonics are eliminated by using feedback of harmonic calculated from estimated angle in ANF, as shown in Fig. 4. As a result, estimated angle is shown in Fig. 5.

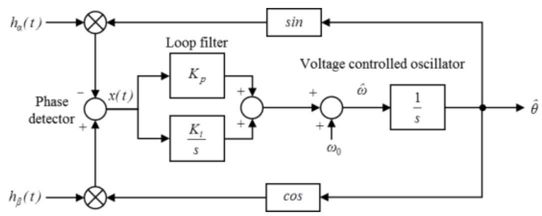


Fig. 3. Block diagram of orthogonal PLL.

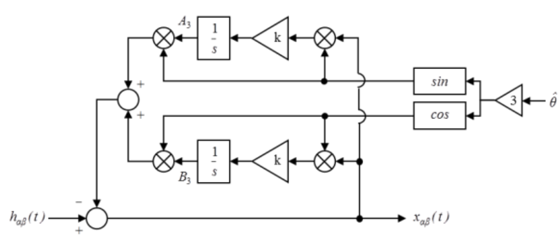


Fig. 4. Block diagram of ANF.

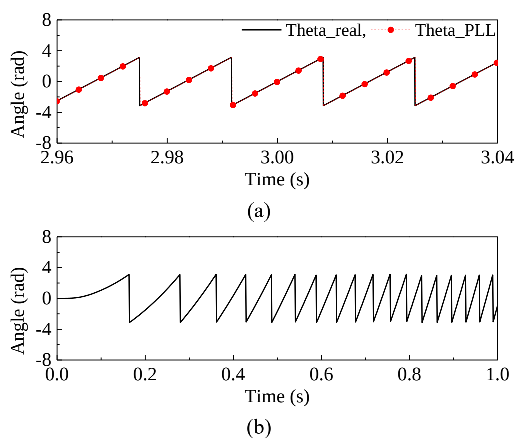


Fig. 5. Estimated rotor position through PLL and ANF. (a) A comparison between real and estimated angle. (b) Estimated angle in transient state.

## III. The Synchronization of Phase Currents with Linear Hall Signals

A proportional integral current controller is constructed by voltage equations on *dq*-axes in rotating reference frame, as in (4) and (5). Here, the reference value of the current in *dq*-axes is compared with the practical value. The proceeding hall signal is synchronized with the current by using an inverse operation and $\alpha\beta$ to *dq* transformation. Fig. 6 shows the overall block diagram of proposed drive. When the speed increases, synchronized hall signals in transient state are shown in Fig. 7.

$$v_{ds} = R_s i_{ds} + L_{ds}\frac{di_{ds}}{dt} - \omega_r L_{qs} i_{qs} \quad (4)$$

$$v_{qs} = R_s i_{qs} + L_{qs}\frac{di_{qs}}{dt} - \omega_r L_{ds} i_{ds} + \omega_r \phi_f \quad (5)$$

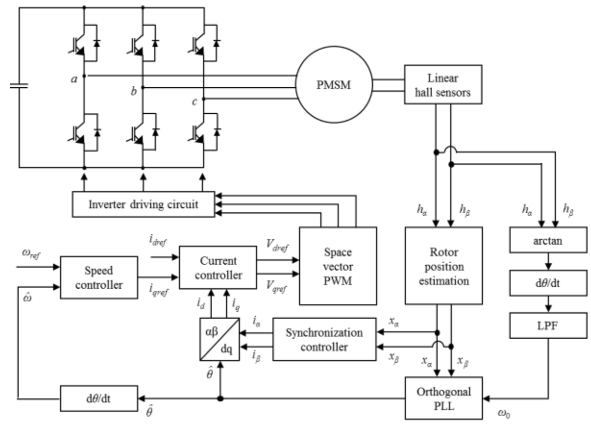


Fig. 6. Block diagram of proposed pseudo-sensorless driver.

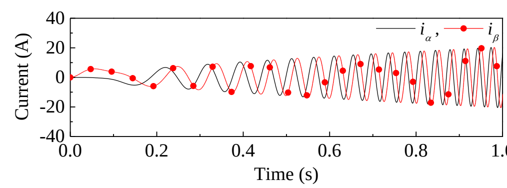


Fig. 7. Synchronized hall signals in stationary reference frame.

## IV. Conclusion

The estimated rotor position in a proposed driver well followed the real rotor position of a PMSM, but calculated phase current still has estimation error because fundamental wave of the current is considered except for pulse-width modulation. The error is not critical for generating a targeted torque.

## References


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