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스위치드 릴럭턴스 전동기의 위치 센서리스 제어시 위치오차에 의해 발생하는 토크리플 해석과 그 보상 방법

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Analysis and a Compensation Method for Torque Ripple caused by Position Error in Switched Reluctance Motor Position Sensorless Control

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Abstract - This paper presents a new sensorless controller used with both the classical sliding mode observer(SMO) and the rate of current change in order to a reduced torque ripple for switched reluctance motor (SRM) sensorless drives. The new sensorless scheme consists of a sliding mode observer (SMO)-based position sensorless approach for high speeds along with a low-resolution discrete the rate of current change for low speeds and standstill. The new position estimation resets between the SMO and the low-resolution of current change according to the speed sign and the position error difference between the SMO and the low-resolution rate of current change. The simulation results show the robustness of this new high performance sensorless control approach with the hybrid sensorless control topology.

1. INTRODUCTION

The sensorless methods of position estimation can be classified into state observer-based and inductance-based estimation schemes[1]-[6]. The inductance-based estimation methods utilises the three dimensional relationship between the flux linkages, current and rotor position.

The inductance-based position estimation can be derived by a family of flux linkages and current curves at various rotor positions. The estimation method needs the parameter with the applied voltage and current of the conducting phase without extra circuits. The flux linkages are computed from the applied voltage and current, not extracted by measurement. However, This method requires additional circuitry to be implemented, adds an additional cost, and is sensitive to mutual inductance effects. This method is only suitable for low-speed operation. Also, because the accurate inductance calculation by a phase current, it should repeat the experiment and the accurate inductance calculation is difficult because of the current noise.

On the other hand, state observer can reduce the above disadvantages. However, the accuracy of estimated rotor position by observer is dependent on mathematical model of SRM and electrical parameters. the estimation error is large in the low speed range. And it is very difficult to get the rotor position in standstill. Although the flux detecting method can easily estimate the rotor position without any complex mathematical model of SRM, the look-up table of flux and rotor position is required. And the relationship of flux and rotor position has non-linear characteristic due to the saturation effect. Also, the observer control gain according to electrical parameters of SRM should be changed in real time.

However, the gain compensation of observer according to a variety of driving environments of SRM is limited. So, if the estimated angle is inaccurate, it may raise current ripples and torque ripples, leading to increased copper losses. In addition, torque ripples resulting from the deterioration of the current causes speed ripples and amplifies audible noise, which is one of the major complaints in industrial appliance products. In these respects, it is necessary to find a decent solution for the satisfactory operation of motors with a gain and estimation position of inaccurate.

There have been many studies on the driving methods of SRM with the hybrid sensorless position control method[1]-[3]. In [1], it was proposed that the sliding observer with low resolution discrete hall sensor would enhance the accuracy of the rotor angle estimation. However, the method still had some difficulties in estimating the angle at low speed and cause several disadvantages from the standpoint of cost, encumbrance. In [2], it was used a hybrid observer sensorless control strategy. However, this method is dependent on the electrical model of SRMs in which the electrical parameters are sensitive to temperature and operating conditions. In [3], it was used the pulse injection method for low speed and an observer for high speed operations. However, the pulse injection method is susceptible to electrical noise, and the look up table of flux and rotor position is required.

In this paper, we presents a new sensorless controller in order to the torque ripple caused by SRM sensorless driver. The rotor position is estimated by the sliding mode observer and a rotor position error caused in a sensorless control process is compensated by the rate of current change without a complex phase inductance calculation and the experimental data(lookup table).

2. SLIDING MODE OBSERVER BASED SENSORLESS

2.1 Switched Reluctance Motor

The switched reluctance motor drives are accomplished by switching the phase current on and off synchronously with the rotor position. The voltage equations of the SRM can be described as followings.

$$v_n = R_n i_n + L_n \frac{di_n}{dt} + \frac{dL_n}{d\theta_r}\omega_r i_n \tag{1}$$

$$\frac{di_n}{dt} = \frac{v_n}{L_n} - \frac{R_n}{L_n} i_n - \frac{1}{L_n}\frac{dL_n}{d\theta_r}\omega_r i_n \tag{2}$$

where, $n = a,b,c...s$ stator phase, R_n is the resistance of stator phase winding, L_n is the inductance of stator phase winding, i_n is the stator phase winding of current, θ_r is the rotor position, ω_r is the rotor angular speed.

2.2 Position Estimation using Sliding Mode Observer[3]

The use of observer-based state estimation has been investigated for indirect position sensing in SRM drives[3][5]. In the case of SRM, terminal measurements of phase currents and voltage are sufficient to develop the observer. An error correction term is computed based on the difference of the motor flux computed from the mathematical model and that derived from motor measurements.

From (2), the sliding observer is made as the following structure

$$\frac{d\hat{i}_n}{dt} = \frac{v_n}{L_n} - \frac{R_n \hat{i}_n}{L_n} - \frac{dL_n}{L_n d\hat{\theta}_r}\hat{\omega}_r \hat{i}_n + K_s\left(i_n - \hat{i}_n\right) \tag{3}$$

where, $\hat{}$ is estimated values.

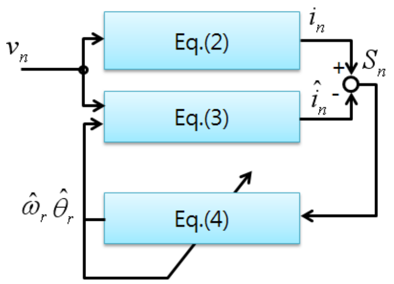
$$K_s = K_{s1} + K_{s2}sgn\left(\hat{i}_n\right)$$

$$\hat{\omega}_r = K_p\left(i_n - \hat{i}_n\right)sgn\left(\hat{i}_n\right) + K_i \int \left(i_n - \hat{i}_n\right)sgn\left(\hat{i}_n\right) \tag{4}$$

$$\hat{\theta}_r = \int \hat{\omega}_r dt$$

The observer system is driven by the difference between the flux model output and the flux estimator output. This provides a continuous position and speed information based on the two measurable quantities, voltage and phase current.

Fig. 1 shows the block diagram of the SMO-based model. In Eq.(3), because the rotor position estimates by the current error, the position estimation gain K_s should be compensated. In case of the sensorless control, if it is not consider the gain control, SRM sensorless drive is causes a significant torque ripple. Also, However, since generally the parameter of the dynamic equation such as stator winding resistance or machine inertia are not well known and these values are easily changed during normal operation, there are many restrictions in the actual implementation.



<Fig. 1> Block Diagram of Sliding Mode Observer

3. Torque Ripple and Compensation

3.1 Torque Ripple Analysis

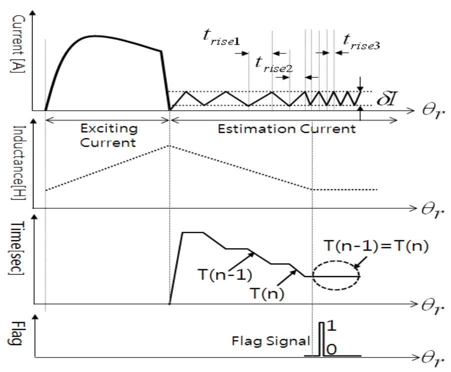
If a normal current and rotor position angle is correct, a torque equation of general SRM is written as the inductance slope and winding current. However, in case of the rotor position error $\Delta\theta_r$, the output torque is included torque ripple as in the following.

$$T_{en} = \frac{1}{2} i_n^2 \frac{dL(\theta_r, i_n)}{d\theta_r} + \frac{1}{2} i_n^2 \frac{dL(\Delta\theta_r, i_n)}{d\Delta\theta_r} \quad (9)$$

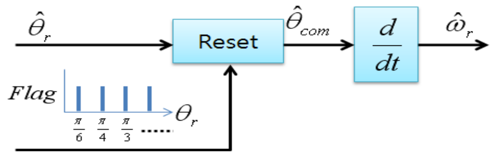
3.2 Compensation using The rate of Current Change

Modeling by a parameter estimation and exact state equation of SRM through change in a load and speed is very important in the sensorless control performance. However, from the differential and integral functions used in order to design the state equation of SRM, the estimated speed and rotor position are inaccurate. And the exact parameter estimation of SRM during operation is a some difficulty.

In order to the position and speed compensation, this paper is not need the complex inductance calculation and experimental data(lookup table), It is proposes a method to compensate by the rate of current change. The rate of current change is compared a switching on-time using a hysteresis current control method, it can be measured the actual rotor position. The measure method of the rate of current change, shown in Fig. 2, uses the measured maximum phase currents to estimate the on-time produced by the injected phase current. the sensorless block diagram is designed as shown in Fig.3.



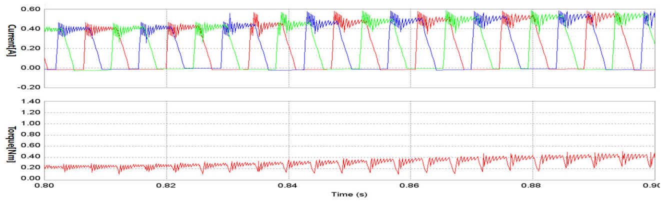
<Fig. 2> Measure Method the Rate of Current Change



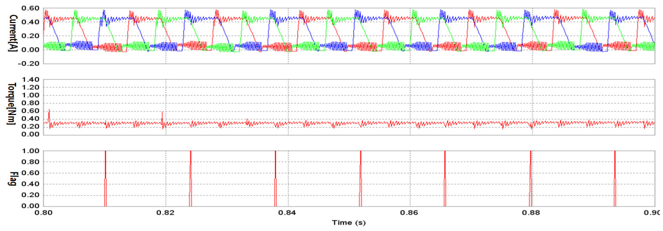
<Fig. 3> Block Diagram of Rotor Position Error Compensation

3.3 Simulation Result

In Fig. 4, the sensorless method using the proposed error compensator is reduced torque ripple than a normal SMO. And, a current maximum change slope and a inductance slope of SRM was affordable according to rotor position.



(a) without rotor position error compensation



(b) with rotor position error compensation

<Fig. 4> Simulation Result

4. CONCLUSION

New SRM sensorless drive using the rate of current change have to compensate the position error caused from the normal sensorless control using the state observer, which the torque ripple caused due to the rotor position error can be minimized. The proposed sensorless control can be applied all on the observer based sensorless as well as the sliding mode observer.

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