역기전력을 이용한 단상 하이브리드 SRM의 위치 추정 방법

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Sensorless driving strategy of Single-Phase Hybrid SRM basing on Back-EMF detection

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ABSTRACT

This paper presents a novel scheme to estimate the rotor position of a single-phase hybrid switched reluctance motor (HSRM). The proposed method uses the differential of back-EMF within a position region to estimate rotor position. By detecting the crossing-zero signal of back-EMF differential value, the minimum position of back-EMF corresponding to an absolute rotor position can be captured and used for position estimation four times in every mechanical rotation. In this way, a sensorless operation with adjustable turn on/off angle can be achieved without substantial computation. For the starting, two current comparators are adopted. The experimental verification using a prototype drive system is provided to demonstrate the viability of the proposed sensorless scheme.

1. Introduction

In existing sensorless control methods, the main approaches can be classified as current waveform based methods, high frequency pulse injection methods, flux linkage based methods, state observer based methods, and intelligent algorithm based methods. In [1], the current rising time during current chopping control(CCC) is regarded as a medium to reflect the variation of inductance. And the comparison of rising time is used for the judgement of the inductance slope of the motor. But in order to determine the current rising and falling time, a fast MCU is needed and the noise caused by switching is very difficult to reject. In [2], the rotor position of the SRM of a PWM-voltage controlled system is estimated by the change of the phase current gradient when a rotor pole and stator pole start to overlap. Another kind of approach is to inject the impressed voltage pulse into phase winding of SRM, and set appropriate thresholds to determine the exciting timing of the next phase. However, this method will cause additional torque ripple, large switching loss and complication in both hardware and software.

Although there are a lot of pervious researches proposed to estimate the rotor position based on the inductance or flux linkage, the sensorless scheme of HSRM is not much researched. Differing from the conventional SRM, the single-phase HSRM has inherent torque ripple due to the restriction of the torque controllable region. So a simple sensorless approach is better than the complex estimation.

2. Single-phase HSRM

Fig.1 shows the basic structure of the single-phase HSRM. At standstill without excitation, the rotor poles are aligned to the permanent magnets. Yet, there exists a little bias from the precise directly aligned position due to the asymmetrical rotor pole design. Once the DC-link voltage is impressed into phase winding, the rotor pole will rotate to align with the reluctance pole immediately under the function of flux linkage produced by phase current and PM collectively. Almost half an electrical cycle later, the phase current should turn to be zero for avoiding the negative torque production. Meanwhile, the rotor will be rotated to the location aligned with PM poles again by PM flux linkage individually.

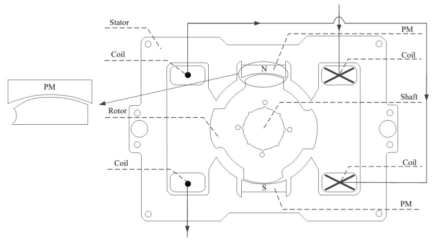

Fig. 1 Structure of single-phase HSRM

3. Proposed position estimation scheme

(1) is the voltage equation of the single-phase HSRM. During the time span that the rotor is rotated only by PM, the phase wingding current value is zero and the voltage that can be measured at winding terminal is the back-EMF generated by PM flux linkage which can be expressed as (2).

$$V_{ph} = i_{ph}R + \frac{d}{dt}(\psi_{PM} + \psi_{winding}) \quad (1)$$

$$V_{ph} = \frac{d\psi_{PM}}{dt} = \frac{d\psi_{PM}}{d\theta}\omega = V_{back-EMF} \quad (2)$$

Although the magnitude of back-EMF generated by PM is dependent on the speed, the minimum back-EMF position is fixed by the inherent PM flux property. This fixed position could be a valuable timestamp for rotor position estimation. Mathematically, the differential curve describes both the direction and the steepness of the line and here, the crossing zero points of differential curve of back-EMF reflects the emerging of the minimum position of back-EMF.

Fig.2 explains the proposed sensorless scheme in general area.

Firstly, the differential value ($\dot{e}$) of back-EMF(e) is calculated, then compared with zero to capture the crossing zero point of it, which means the arrival of the minimum position(θ_{280°) of back-EMF. The estimated rotor position and angular velocity can be got from the following equation:

$$\theta_{est} = \theta_{280^\circ} + \hat{\omega}t \qquad (3)$$

$\hat{\omega}$ can be figured out from the time duration of two minimum back-EMF points owned by two neighboring electrical cycles.

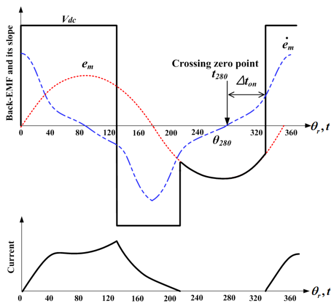

Fig. 2 Proposed scheme in general area

Since the proposed scheme is to detect the minimum back-EMF position, the method in determination of turn off point in starting area also necessary for normal starting of the motor. In the proposed drive system, hardware current limitation is adopted for overcurrent protection(Fig.3) The realtime current (I_{act}) is compared with $I_{\max}$ which is the maximum current that can be accepted by this system. Once I_{act} exceeds $I_{\max}$, the current limiter should be low electrical level, and this signal will do the and logic with the current controller output(C_p). Notice should be paid that without the permission of current limiter, even is high electrical level, the final gate drive signal (PWM_3) will still be the low. Every time I_{act} is bigger than $I_{\max}$, the current should be switched off to guarantee that I_{act} will never be over than $I_{\max}$. However, due to the device delay, the current doesn't be switch off in time until later.

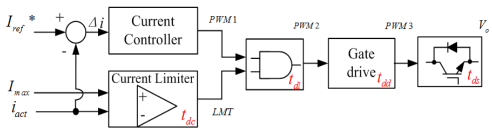

Fig.3 Block diagram of hardware current limitation

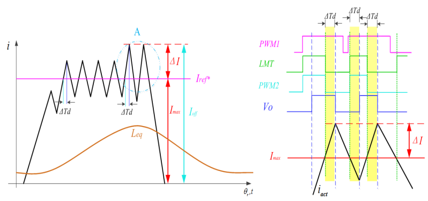

Fig.4 Proposed starting algorithm

The voltage equation(1) of the HSRM can be rewritten as:

$$V_{ph} = Ri_{ph} + L_{eq}(\theta)\frac{di_{ph}}{dt} + i_{ph}\frac{dL_{eq}(\theta)}{d\theta}\omega \qquad (4)$$

In the inductance saturation region, the inductance slope is zero, so the motional electromotive force is almost zero and if the resistance voltage drop is neglected, the increment current at inductance saturation region during $\triangle T_d$ can be calculated as :

$$\triangle I = \frac{V_{ph}}{L_{eq}(\theta_{sat})}\triangle T_d \qquad (5)$$

The $\triangle T_d$, L_{eq} can be obtained from hardware component, thus the increment current can be calculated and used as a threshold to switch off the winding in the first electrical cycle.

4. Experimental result

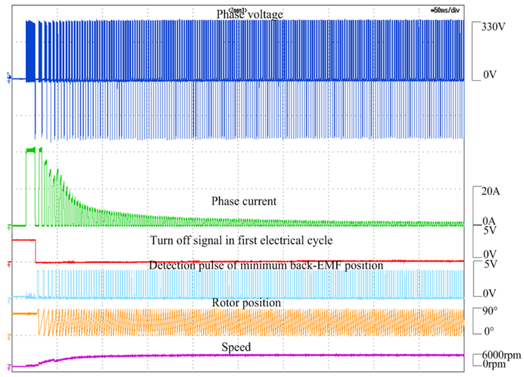

Fig.4 Sensorless operation at 6000rpm

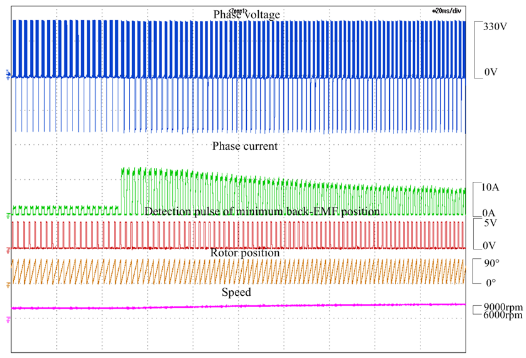

Fig.5 Sensorless operation with speed changing from 6000 to 9000rpm

4. Conclusions

This paper presented a new method for the sensorless control of hybrid switched reluctance motor. The proposed scheme can be implemented successfully according the simulation and experiment results and this allows a simple estimation of the rotor position without involving any motor design parameter. Measurements show the feasibility and accuracy of the proposed scheme.

감사의 글

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Refernece

[1] J. Kim, H. Y. Yang, and R. Krishnan, “Parameter insensitive sensorless control of single-controllable-switch-based switched reluctance motor drive,” IEEE International Conference on Power Electronics and ECCE Asia, Seoul, Korea, May 2011, pp. 132-139.

[2] G. Gallegos-Lopez, P. C. Kjaer, and T. J. E. Miller, “A new sensorless method for switched reluctance motor drives,” IEEE Trans. Ind. Appl., vol. 34, no. 4, pp. 832-840, Jul./Aug. 1998.