단상 하이브리드 SRM의 센서리스 제어기법

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A Sensorless Control Method of Single-Phase Hybrid SRM

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ABSTRACT

In this paper, a novel method of sensorless control scheme is proposed to apply on a single phase hybrid SRM used in high speed operation. The proposed method utilizes beneficially permanent magnet field whose performance is motor parameter independent to estimate the rotor position. Also, the current slope is adopted to complete the sensorless control when the motor running with heavy torque at high speed condition. Through this approach, the adjustable turn on/off position can be achieved without prior knowledge of inductance profile which is always employed by many sensorless schemes. And this paper may offer an available method to do the sensorless control in hybrid SRM used for high speed running.

1. INTRODUCTION

For various industrial applications [1 2], the multi phase switched reluctance machine(SRM) has dominated the electrical drives for long decades. However, to be applied on high speed operation, the multi phase SRM suffers from high manufacture cost due to the switching power electronics and also the low efficiency caused by high switching loss. So, an effective way is to replace the multi phase SRM drive system with unipolar drives by decreasing the number of switches in converter. Single phase switched reluctance motors suit naturally unipolar excitations and have been involved in many studies as a proper candidate.

In order to assure the motor operated normally, accurate knowledge of rotor position is indispensable. With consideration of size reduction and easy to maintenance, the sensorless control techniques are attractive more than ever. Some sensorless control method has been proposed and applied on single phase hybrid SRM. In [4], the back EMF generated by permanent magnet flux linkage is utilized to achieve the rotor position detection. But this proposed idea has the limited application at high speed with heavy load. Usually, the current needs to be prebuilt to reach the ideal current level before inductance rising region and long freewheeling time should be shorten by advancing the switch off angle under high speed running condition, especially in heavy load situation. However, the turn on angle in scheme proposed in [4] cannot be regulated arbitrarily due to crossing zero detection of back EMF. Also the zero position of back EMF is different under different motor speed ,therefore there should exist some additional compensation lookup table to assist the detection which burden the control scheme. Thus, a novel method can be employed to estimate the rotor position with adjustable switch on/off angle should be come up with.

In this paper, an optimized high speed single phase hybrid SRM is regarded as a target to achieve the sensorless control scheme. So, the working principle of a new single phase hybrid switched reluctance (HSR) motor which uses both the reluctance torque and permanent magnet interaction torque together to increase high torque density is presented first. Then the sensorless scheme is presented in detail and some experiment results can prove the reliability of proposed scheme is shown.

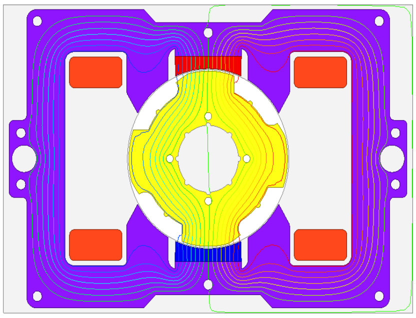
2. THE SENSORLESS CONTROL METHOD OF SINGLE PHASE HYBRID SRM

2.1 The working principle of proposed hybrid SRM

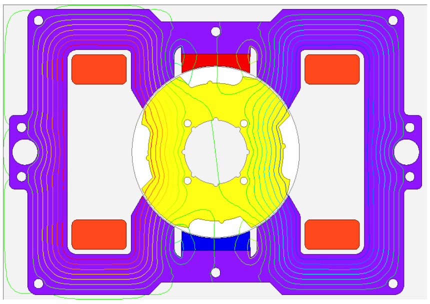
When there is no current flowing in the motor, the rotor will park at the position shown in Fig.1(a) (defined as the zero degree of rotor position), due to the asymmetrical structure of the rotor poles under the effect of two PM embedded in stator.

ingding+PM working period: When voltage is added to winding terminals, the generated current will flow in the coils and produce flux to circulate in the machine, thus, will produce a positive reluctance torque to pull the rotor to rotate forward, until the rotor poles are aligned with the stator reluctance poles shown in Fig.1(b), which is around 45 mechanical degrees.

Only PM working period: After about 45 mechanical degrees later, the current in winding coils should then be reduced to zero for the remaining about fouty five mechanical degrees to allow the rotor align with stator poles again under the function of PM as shown in Fig.1(a).



(a) Sart/unaligned Position(Rotor aligned with PM)



(b) Aligned Position

Fig. 1. Section view of the single phase hybrid SRM

2.2 Sensorless control method

The freewheeling period is a very valuable region that can be utilized to do sensorless control. During this period, only the permanent magnets act on rotor, and the phase current has to be maintained zero for roughly half of an electrical period due to the single phase nature of this machine. The back EMF generated by PM flux linkage is rotor position dependent and this value can be captured at the terminal of the winding. The previous sensorless control research on hybrid SRM is shown in Fig.2.By detecting the crossing zero position of back EMF at terminal, the 0 degree,90 degrees,180 degrees, and 270 degrees (in mechanical) can be got to do the prediction of rotor speed which completes the sensorless control at the same time. However, generally, the current needs to be prebuilt to reach the ideal current level before inductance rising region and long freewheeling time should be shorten by advancing the switch off angle under high speed running condition, especially in heavy load situation, but the turn on angle in [4] must be later than 0 degree (in electrical), which means it cannot be regulated arbitrarily due to crossing zero detection of back EMF. Also, the zero position of back EMF is different under different motor speeds, therefore an additional compensation lookup table is essential to assist the detection which burden the control scheme.

To reach the goal of adjustable turn on angle, the differential value of back EMF is used instead of the back EMF value and this allows a simple estimation of the rotor position without involving any motor parameters. Fig.3 shows the proposed position estimation scheme diagram. It can be concluded that if the zero crossing point of the slope of back EMF is got, the 67.5degrees or 157.5 degrees or 245.5 degrees or 337.5 degrees (in mechanical) is arriving at that time. Thus, the rotor position estimation can be obtained by the following two equations.

The zero rotor position in figure below refers to the positon which rotor is aligned with PM, same as the experiment situation. Since the HSRM has four rotor poles, the estimation of the speed is updated four times per revolution, synchronized to the rotor position.

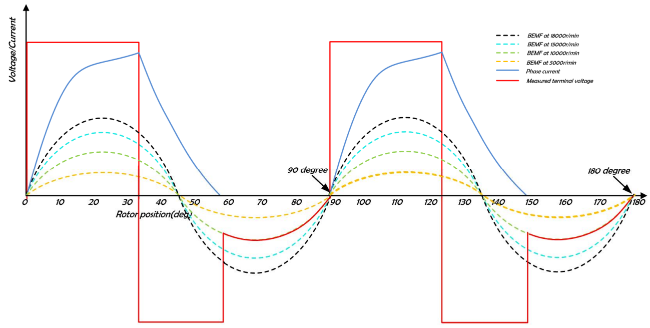


Fig.2 Previous research sensorless sheme[4]

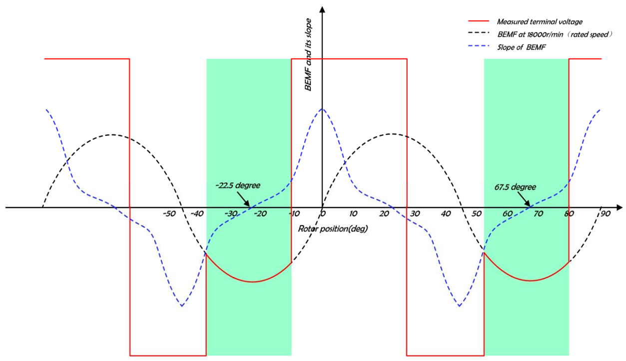


Fig.3 Proposed rotor position detection method

To run the motor to rated speed, both the PWM voltage control and speed feedback control are needed to control the voltage and speed simultaneously. Because the specific position obtained by this detection has lead a long distance from the switch on point region, this proposed method can realize the advance opening of converter, which in most high speed system is very essential to sustain a perfect efficiency.

$$\theta_{(k+1)} = \theta_k + \omega \Delta t \qquad (1\ 1)$$

$$\omega = \frac{\Delta\theta}{\Delta t} \qquad (1\ 2)$$

Suppose the motor is running with light load ,there is enough time for crossing zero detection of the differential of back EMF since the light load operation only needs a relative small current which corresponding to a short tailing time. So it leaves sufficient span to capture the value of back EMF differentiation, which is same with no load condition. However, when rotating with heavy load, the big phase current causes long tailing time and back EMF at 67.5 degrees(in mechanical) is almost covered by negative terminal voltage generated by freewheeling period, so another method should be adopted together.

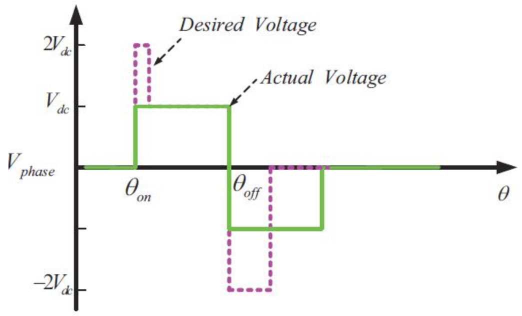


Fig.4 Voltage and current of desired converter

Fig 5 is the proposed boost converter structure in[5], based on the operation modes, the proposed active boost converter has three excitation modes and high voltage demagnetization mode. In the excitation modes of SRM operation, dc link voltage and double dc link voltage can be freely selected by the state of power switch. In the demagnetization mode, the double dc link voltage is applied to phase winding to cut down tail current and negative torque. So the detected position of back EMF at 67.5 degrees (in mechanical) will not covered by negative terminal voltage under heavy load condition(see Fig.4). The fast demagnetization mode is shown in Fig. 6. In this mode, the power switches QAH and QAL turn off, the recovery energy want to feed back to the capacitor side. Because the direction of diodes D1 and D3 are opposite, two capacitors series connected by the diode D2. The demagnetization current through DAL, DAH and D2 to charge the boost capacitor C1 and the dc link capacitor C2.

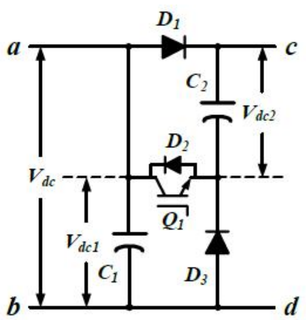


Fig 5 Boost capacitor structure

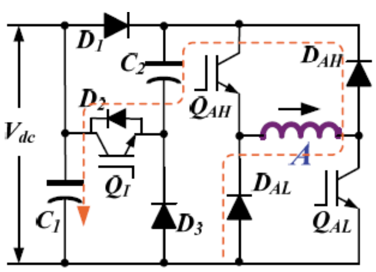


Fig.6 Fast demagnetization

2.3 Simulation of proposed idea

Fig.6 shows open loop simulation block of proposed method, and Fig.7 shows the open loop simulation results in which the position estimation method are used.

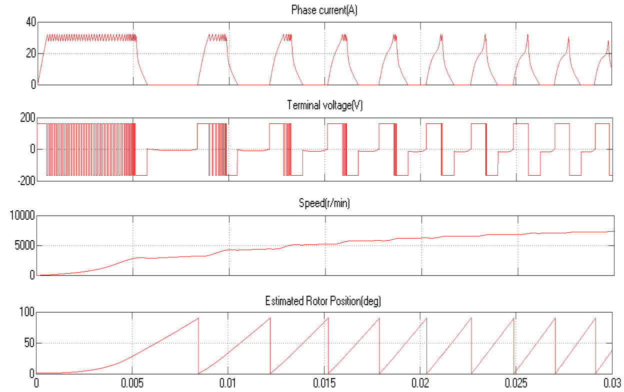


Fig.7 Simulation result of sensorless control scheme

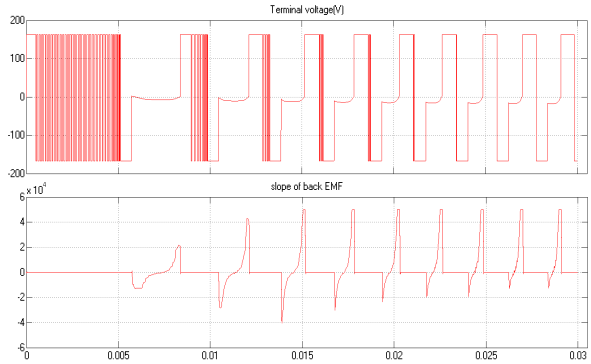


Fig.8 Terminal voltage and the slope of BEMF

3. CONCLUSION

In this paper, a sensorless controlled HSRM drive scheme is presented. The introduction of sensorless control to this drive is essential to maintain its small volume. By using the unique feature of this new HSRM, the sensorless control can be implemented simply and reliably. Such a drive system may offer a competitive solution to existing high speed hybrid SRM which uses permanent magnet to realize self start capability. And the performance of this scheme need to verified in further study.

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