Fixed Turned Off Angle Rotor Position Estimation of SRM

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Abstract - Many precise and high resolution sensorless rotor position estimation techniques have been published in the past literature for switched reluctance motor (SRM) drive. This paper presents simplified coarse rotor position estimation method suitable for low cost SRM drive such as water pump, washing machines and electric vehicles. Proposed method is applicable where speed control is achieved by PWM or hysteresis current controller. This method utilizes flux-linkage characteristics of the motor to estimate rotor position. It requires information about magnetic curve only at one rotor position instead of entire magnetic characteristics of the motor. Simulation results for sensorless SRM drive validate feasibility of proposed method.

Key Words: sensorless, switched reluctance motor, srm, rotor position estimation

1. INTRODUCTION

The high performance motor drive and motion control applications demands ripple free torque, precise speed control and optimized efficiency. It makes necessary to incorporate an optimized angle control scheme or one of the torque control algorithms like TDF (Torque Distribution Function) [1], TSF (Torque Sharing Function) [2] or look-up table based current profiling [3]. All these methods require an accurate rotor position feedback system such as absolute encoder and resolver. However, there has been enormous attention in eliminating the mechanical position sensor for reducing the cost, overall physical dimension and weight which also increases the reliability of operation in all environmental condition. Numbers of sensorless rotor position estimation techniques have been proposed by the researchers over the last two decade [4-16] that include state observer [3, 8, 14], active probing [4, 9, 11], modulates signal injection [6,7], fluxlinkage based method [15] and current waveform monitoring technique [9, 17].

In the state observer method the model of the complete system is simulated simultaneously with the real system. The model generates a current for the applied voltage, which is compared with the actual system current. The current error adjust the gain for the three state variables; flux, speed and position. Literature shows that the linear model of the observer has been used for the simulation [14] for simplicity, while nonlinear model of the observer has also been presented [8] along with the experimental results. The observer based method offers high resolution position estimation but its practical implementation is quite complex. The sliding mode based observer has been appeared in literature [12] which reduces the complexity of the model. Past investigation of the state observer based sensorless method [9] shows that the accuracy of this method depends upon the mathematical model and computational power of the hardware. This method uses mathematical model of complete system including mechanical load, thus application of the designed observer model is fixed for the particular system. The real-time implementation requires complex algorithm, extra circuitry and significant amount of stored data. It greatly increases the implementation cost and speed limitation is imposed by hardware due to computation burden.

In the active probing method, the high frequency probing pulses are injected into the non-conducting phase. The magnitude of the injected current pulses is kept low to reduce the negative torque production as compared to the active torque of the motor. The phase inductance is estimated from the peak value of the probing current which is inversely proportional to the inductance. The rotor angle for the estimated phase inductance is found from the relation of rotor position versus phase inductance stored as look-up table. The main advantage of this method is that it is applicable at standstill. However, it is difficult to implement the method for a high speed operation because there is a little time for probing the pulse. Another problem that arises in the implementation is that it is very sensitive to the mutual inductance, as the current of the active phase induces voltage in unenergized phases, which distorts the probing pulse. It is also required to have prior information about phase inductance as a function of rotor position. The variation in the phase inductance is flat near to the unaligned position, thus it is difficult to estimate the rotor position in this region. The major drawback of the method is that it deteriorates the efficiency of the drive because of negative torque production by the probing pulses.

The modulated signals, used in communication systems employing techniques like frequency modulation, amplitude modulation and phase modulation; are used to estimate the phase inductance of unenergized phase [6, 7]. In [6], an unenergized phase is connected to the oscillator which is designed such that the frequency is inversely proportional to the phase inductance, and by measuring frequency, inductance is estimated. Also, the sinusoidal voltage with the fixed frequency and amplitude is applied to an unenergized phase via resistor [7]. The inductance is measured by detecting change in phase displacement between voltage and current. The method is applicable at standstill and offers reasonably good accuracy. This method suffers due to mutual effect of energized phase, speed limit and requires knowledge about the specific inductance of the phase. The method requires a multiplexer to connect and disconnect the modulator from the power circuit. The external modulator and isolation circuit increases the cost and component required compared to previous method. Use of artificial neural network to estimate the rotor position becomes popular as it offers good accuracy [19]. However, it is computational intensive as well requires detail information about motor magnetic characteristics. Accuracy of this method depends up on numbers of data available of magnetic characteristics, which means more experimental readings required to achieve higher efficiency. Efforts have been made in [20] to reduce mathematical complexity for mapping magnetic non-linearity of the motor. This method reduces computation burden as well requires prior information about only few magnetic curves unlike ANN based method. However this method suffers from lower accuracy particular at higher speed.

2. FLUX-LINKAGE BASED SENSORLESS METHOD

Irjet Template Flux-linkage based method offers higher accuracy as it uses an actual motor magnetic characteristic to estimate a rotor position. Lyons made use of magnetic characteristics of the SRM first time in 1991 to estimate the rotor position [15]. The method use a set of magnetization curves stored in a multidimensional table. The basic theory of the flux-linkage based sensorless method is based on the fact that, the magnetic characteristics is a three dimensional non-linear relation amongst current, flux-linkage and rotor angle, thus if any of the two variables are known then the third can be found from the stored magnetic characteristics. A typical magnetic characteristic is shown in Figure 1 where only few magnetic curves for different rotor position are shown for the simplicity.

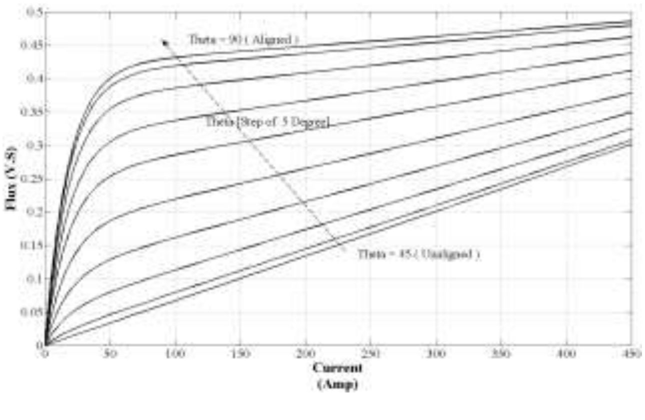
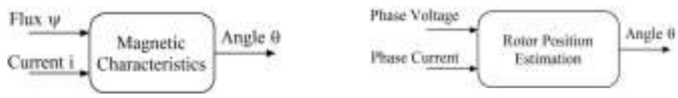


Fig-1: Magnetic Characteristics of 60KW 3-phase 6/4 pole SRM

High resolution rotor position estimation requires large number of magnetic curves to store. It is to be noted that half an electrical cycle is enough to represent the complete magnetic characteristics of the motor from the unaligned to aligned position because unaligned position is a case which occur at the middle of the electrical cycle for the regular motor. The magnetization curve at unaligned position is the straight line while at aligned position it shows two deflections, one at current of 40 amperes and other one at 250 amperes. First deflection is mainly due to magnetic saturation of the stator and rotor pole corners and second deflection is due to magnetic saturation of the stator and rotor core (yoke). The large numbers of magnetic characteristics are stored as 3- dimensional look-up table where phase current and flux-linkage are used as indices to find the respective values of the rotor position. The flux is calculated using equation (1). The block diagram of the sensorless method is shown in Figure 2. The rotor position can be derived from the instantaneous values of phase voltage and phase current as the flux-linkage can be derived from the phase voltage and phase current.

$$\psi(t) = \int (V_{ph} - i_{ph} R_s) dt \qquad (1)$$



(a) (b)

Fig-2: Basic block diagram of the flux-linkage based sensorless method

This method requires experimental setup and takes time to measure the magnetic characteristic of the motor for the range of position [18]. The accuracy of the position estimation depends up on the stored data that means more data is required for higher resolution. The rotor position can be estimated from the active phase only which might be used to commutate the same conducting phase or to energize the succeeding phase. The fixed turn-off angle method of rotor position estimation is proposed which store only one magnetic curve instead of all rotor position. The method gives the coarse rotor position, which decides the turn-OFF instant of the conducting phase.

3. FIXED TURN-OFF ANGLE METHOD

The block diagram of the fixed-turn-off angle sensorless method is shown in Figure 3. The magnetic curve at the reference rotor angle 85° is stored as a look-up table. The reference rotor angle is selected to provide advance phase commutation. The phase voltage and phase current are measured continuously, from which an instantaneous flux for each phase is calculated in real-time using equation (1). The phase current is used as an index to generate the reference flux Ψ_{ref} from the look up table. The calculated flux Ψ_{cal} is compared with the reference flux Ψ_{ref}, which generates a flux difference Ψ_{diff}. The commutation logic block generates an individual phase commutation pulse from the flux difference.

It is assumed that the initial rotor angle is 45° (unaligned position). If the phase-1 is excited at an unaligned rotor position then the difference between Ψ_{cal} and Ψ_{ref} becomes maximum, which reduces as rotor moves toward aligned position. The Ψ_{diff} becomes zero at a reference rotor angle that is 85°. The flux difference increases again with further increase in rotor angle that is from 85° to 90°. However, the conducting phase is commutated when Ψ_{diff} becomes zero and subsequent phase is turned ON at the same time. Thus the phase conduction is advanced by the same degree as the commutation advance. The flux difference of the commutated phase is zero as Ψ_{cal} and Ψ_{ref} both are zero. If the conduction sequence is assumed to phase1-phase2-phase3, and flux differences for the each respective phases are Ψ_{diff1}, Ψ_{diff2} and Ψ_{diff3}, then the phase-1 is commutated and phase-2 is excited at a condition $\Psi_{diff1}=0$.

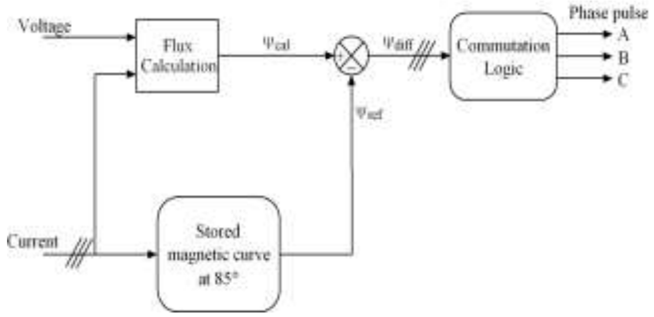


Fig-3: Block diagram of fixed turn-off angle method

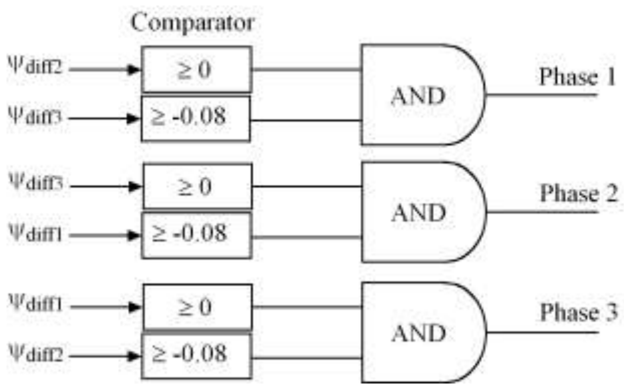
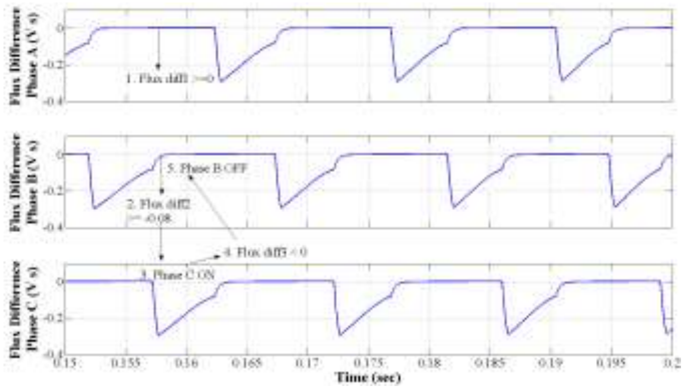


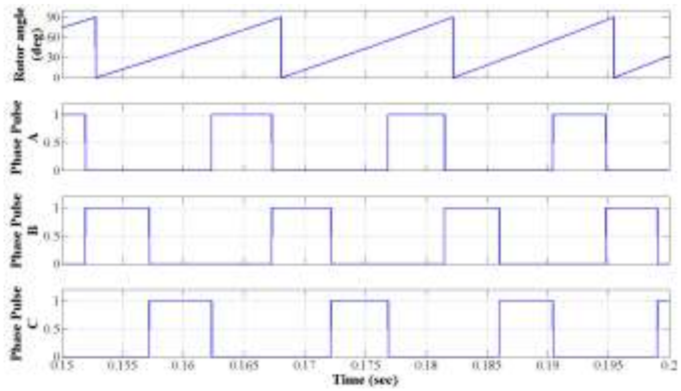
Fig-4: Commutation logic of the fixed turn-off angle method

The logic of commutation is implemented as shown in Figure 4. The comparator output is logic '1' if the specified condition is true else '0'. The waveforms of flux difference and phase commutation pulses are shown in Figure 5. At the instant when only phase-2 is ON, the Ψ_{diff2} is negative which approaches to zero as rotor angle increases, while Ψ_{diff1} and Ψ_{diff3} are zero. At an instant, when Ψ_{diff2} is close to zero (>= -0.08), phase-3 will turn ON as both the inputs of the AND gate are at logic '1'. Consequently Ψ_{diff3} becomes negative which dissatisfies the condition for phase-2 to remain ON. Likewise, each respective Ψ_{diff} turns ON the succeeding phase and self commutates as shown in Figure 5.

The waveform of the flux, phase current and torque are shown in Figure 6 for the sensorless operation of the drive. The result shows that the method gives the same performance as provided by the coarse mechanical sensors like Hall Effect and optical interrupter.



(a)



(b)

Fig-5: Waveform of (a) flux difference and (b) commutation pulse of each phase

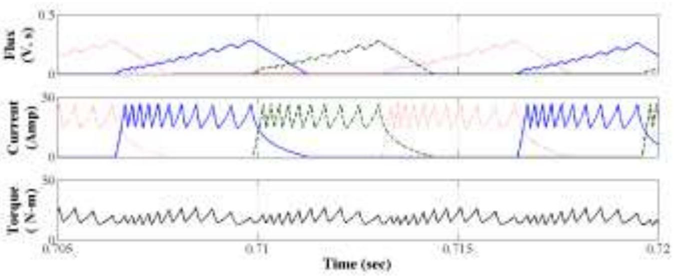


Fig-6: Waveform of the flux, phase current and torque at the speed of 1500 rpm

4. CONCLUSION

This method is simple, cost effective and easy to implement as it does not involve any complex computation and also requires very less amount of data to store. The method also offers high accuracy with the wide speed range operation as flux difference produced does not depends on speed.

However, it is not possible to implement advance angle or dwell angle control techniques as turn ON and turn OFF angles remain constant. But, magnetic curve at any rotor angle can be selected as reference to achieve desire phase advancement. Peak torque capability at high speed operation will deteriorate as dwell angle remains constant. Also multi-phase excitation is not possible as same phase information is use for commutation of self and also to turn ON next subsequent phase. In addition, more than one magnetic curve can be stored to have flexibility in selecting mode of operations like low speed, medium speed or high speed.

This method is suitable for the applications where the use of a mechanical sensor seems to be unreliable due to harsh environmental conditions and comparative cost of drive is a major concern. Proposed method shows potential to replace opto-coupler or hall-effect based course mechanical position sensors effectively with low implementation cost.

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