Abstract. This paper presents a position estimate model of switched reluctance motor based on the single threshold angle. In view of the relationship of between the inductance and rotor position, the position is estimated by comparing the real-time dynamic flux linkage with the threshold angle position flux linkage (7.5° threshold angle, 12/8SRM). The sensorless model is built by Matlab/Simulink, the simulation are implemented under the steady state and transient state different condition, and verified its validity and feasibility of the method.

1. Introduction
The switched reluctance motor (SRM) is a robust, low-cost, fault-tolerant machine suitable for several niche applications, salient pole structure, the magnetic of the motor is relatively saturated, the motor is nonlinear characteristics, so the flux linkage characteristic is detected difficulty. But flux linkage characteristic is important to optimize motor design, and improve motor performance, and sensorless control, so the detection of the magnetic flux linkage characteristics has attracted extensive attention of many scholars.

The position estimated is proposed based on the flux linkage character in [1-2], in view of the relationship of between the inductance and rotor position, the position is obtained by look-up table, the advantage of the method is that the principle is simple, the disadvantage need to establish a three-dimensional flux linkage data table. The model is improved in [3-4], a simplified flux linkage sensorless model is presented, which position is estimated by comparing the flux linkage of maximum inductance position and the dynamic flux, the advantage is that it only needs two-dimensional flux linkage data table, small memory required, but is not suitable for APC control, and reduced motor torque efficiency. The sensorless model is studied in [5] based on the simplified flux position estimation under the variable angle and energy optimization control, optimize turn-on angle and turn-off angle; improve the efficiency of the system. On the basis of literature [5], an improved simplified flux method is proposed, in which turn-on angle can be set optionally and separate from turn-off angle in [6], the method only needs the fixed turn-off angle and current chopping control. In [7-8], the method is studied research sequentially, it is applied to control system of the SRG and the double switched reluctance motor.

In the paper, a new position estimate model is proposed based on the single threshold angle for switched reluctance motor. In view of the relationship of between the inductance and rotor position
for a three-phase 12/8 SRM, the 7.5° threshold angle is defined. The position is estimated by comparing the real-time dynamic flux linkage with the threshold angle position flux linkage.

2. Position estimation principle

2.1. Relationship of inductance and position
SRM is a doubly salient structure, the particulars of axial symmetry, so the magnetic flux particulars, rotor position, current, inductance are related to each other.

Fig.1 shows the relationship between the three phase inductance curve (LA, LB, LC) and the rotor position signal (PA, PB, PC) for the 12/8 SRM. The rising edge of phase A is defined as 0 deg, we can clearly figure out that the falling edge of the PA signal is correspond to the 7.5° position of phase B, the rising edge of the PA signal is correspond to the 15° position of phase C. The falling edge of the PB signal is correspond to the 7.5° position of phase C, the rising edge of the PB signal is correspond to the 15° position of phase A. The falling edge of the PC signal is correspond to the 7.5° position of phase A, the rising edge of the PA signal is correspond to the 15° position of phase B. Therefore, it is feasible that the position estimate is studied based on the 7.5° and 15° position for 12/8 SRM.

\[
\begin{align*}
\text{Figure 1. Relationship phase inductance and position signal}
\end{align*}
\]

2.2. Flux linkage model
Neglecting mutual coupling between the phase windings, the phase voltage equation of SRM is given by

\[
u_k = i_k \cdot R_k + \frac{d\psi_k}{dt}
\]  

(1)

Where \( u_k, i_k, R_k \) are the phase voltage, phase current, and winding resistance respectively, \( \psi_k \) is phase flux linkage. The integral form of the phase voltage equation is given by the next equation from (2)

\[
\psi_k = \int_0^t (u_k - i_k \cdot R_k) dt + \psi_k(0)
\]  

(2)

The equation (2) is dispersed and can be expressed as

\[
\psi_k(n) = \left[ \sum_{i=1}^{n} [U_i(n) - R_i n_i(n) I_i(n)] \right] + \psi_k(0)
\]  

\[
\Rightarrow \psi_k(n) = \psi_k(n-1) + [U_k(n) - R_k i_k(n)] I_k
\]  

(3)

2.3. Position estimation based on single threshold angles
According to the analysis of the Fig.1, the 15° and 7.5° position are defined as the two threshold angle, the rotor position is estimated by comparing the threshold angle position flux linkage and the real-time dynamic flux linkage of the motor. The model is improved in the paper, the 7.5° threshold angle position is only detected, the 15° threshold angle position is obtained based on the real-time delay
7.5°, the real-time dynamic flux linkage can be obtained by equation (3) with the real-time phase current and phase voltage, the two-dimensional look-up table with the phase current is established, which stores the functional relationships between the phase C and phase C for 7.5 deg position, which is obtained by look-up table, as shown in Fig.2.

\[ \Delta \theta \approx 360 \times n \times \frac{\Delta t}{60} (\text{deg/s}) \]

The position angle:

\[ \theta(k + 1) = \theta(k) + \alpha \Delta t \]

Where \( \theta(k) \) : Estimated position angle for preceding sampling time;

\( \theta(k + 1) \) : Estimated position angle for present sampling time;

3. Simulation analysis

In order to verify the feasibility of the proposed algorithm, the simulation model of sensorless technology is built based on Matlab/Simulink for 12/8 SRM. Fig.4 shows a block diagram of controller used in the study. The estimated speed \( \omega_{\text{ref}} \), is compared with the speed reference \( \omega_{\text{ref}} \), and the error is sent back to the speed PI controller, the output of the PI controller is the current reference \( I_{\text{ref}} \).
The simulation of sensorless control system is shown in Fig. 5. The motor run in steady state, the simulation conditions: the turn-on angle 0 deg, the turn-off angle 20 deg, the speed 2000 r/min, the chopping current limit 20 A, the maximum position error is not more than 0.8 deg, as shown in Fig. 5(a).

Fig. 5(b) shows the simulation diagram of the dynamic closed-loop control during the motor starting from standstill, no-load, the reference speed \( n_{\text{ref}} \) is 2000 rpm, the estimating error is less than 0.5 deg.

The simulation diagram when the control system is increased the 1.5 N.m load suddenly at the 0.025 s, the dynamic performance of the system is changed, as shown in Fig. 5(c), under the PI controller condition, the phase current is raised, the motor reach to the new steady state, the maximal error is 0.5 deg.

Fig. 5(d) shows the simulation of position estimation under the reference speed sudden change condition, the initial \( n_{\text{ref}} \) is 2000 r/min, the system reach to the steady state at 0.01 s, the reference speed \( n_{\text{ref}} \) is raised to 3500 r/min, the system reach to the new steady state at 0.04 s, the position estimating error is less than 1 deg. Therefore, it can be seen that the position estimation method has high precision, the sensorless simulation results are also presented to verify the feasibility of the method.

![Figure 4. Block diagram of controller system](image-url)
4. Conclusion
In this paper, a new position estimation model of switched reluctance motor is proposed based on the single threshold angle, which compare the real-time dynamic flux linkage with the threshold angle position flux linkage. From sensorless simulation results, the rotor position can be accurately estimated by the proposed method, and verified validity and feasibility of the proposed method.

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