Sensorless Control of Switched Reluctance Motor Based on Matlab/Simulink Simulation

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Abstract. This article mainly introduces the acquisition of the position information of the switched reluctance motor through the inductance, which can make the switched reluctance motor(SRM) correct commutation. The main method is to apply high-frequency and low-duty pulse voltages to the two non-conducting phases of the switched reluctance motor when the motor is in low-speed operation, so that the non-conducting phase generates a response current through the rising slope of the response current. The current change rate is obtained by the difference with the falling slope, and then the current change rate is converted into inductance through a formula, and whether the inductance reaches the inductance threshold is judged whether it reaches the commutation position, and the motor is subjected to timely and accurate commutation processing. This method is realized by matlab/simulink simulation, and combined with the high-speed inductance method obtained by the flux ratio current, to realize the position sensorless technology combined with the inductance method in the full speed cycle, and the simulation verifies that the low-speed and high-speed algorithms can be smooth Switch, and can realize its commutation control function, and It provides simulation support for applications such as lawn mower.

Keywords: Switched reluctance motor, Inductance, Pulse injection, No position sensor.

1. Introduction
In order to ensure stable operation of a switched reluctance motor, it needs to obtain accurate commutation signals, which requires a position sensor to obtain the position of the rotor. Common position sensors include Hall sensors and encoder sensors. They all convert the real-time position signal of the motor into electrical signals and provide them to the control chip for commutation control. The position sensor ensures the smooth operation of the motor and provides a speed basis for the motor speed control system. But the position sensor still has many shortcomings. First of all, although the switched reluctance motor can operate normally in harsh environments (high temperature, dust), the position sensor is more affected by the harsh environment and its accuracy is reduced, which limits the application of the switched reluctance motor in harsh environments. Nowadays, the main application areas of switched reluctance motors are still in the harsh environments with high dust and high temperature such as coal mines and aerospace [1]-[6]. Secondly, the position sensor increases the cost and volume of the entire control system, which forms a huge obstacle to the promotion and application of the switched reluctance motor, so the research on the position sensorless technology becomes particularly important. At present, many scholars have...
conducted research on the sensorless technology of switched reluctance motors, and have also proposed many feasible methods, which are gradually moving towards practicality. Literature [7] proposed a position sensorless algorithm based on neuro-fuzzy inference system (ANFIS). Literature [8] proposed a method of motor static starting phase estimation, injecting short-term pulses into each phase, and judging the motor position according to the magnitude of the response current peak. Reference [9] points out that the fluctuation of power supply voltage, different turn-on angle and the peak value of current of conduction phase under load will change. In reference [10], the position is determined by detecting the peak value of the conduction phase current when the stator and rotor are overlapped. This method is still affected by the load and saturation inductance. In this paper, the non conduction phase injection is used, the current will not reach the saturation current range, and it has great stability.

2. The Theoretical Basis of SRM

2.1. Basic Structure of Switched Reluctance Motor
The stator and the casing are connected to facilitate heat dissipation. The rotor has no complicated structure. The entire motor body is parallel. Without permanent magnets, SRM has the advantages of low cost, simple structure and long life compared with permanent magnet synchronous motors. The stator and rotor structures of common SRM motors include two-phase 4/2 poles, three-phase 6/4 poles.

2.2. Operating Principle of SRM
The SRM generates a certain current by turning on each phase in turn. It follows the principle of reluctance. Under the action of magnetic force, the motor rotates mechanically. When the rotor and stator are aligned, the stator and rotor When the next phase is in an unaligned position, when the next phase is turned on, the motor will continue to rotate. By constantly switching the conduction phase, the motor will continue to rotate, and its direction of rotation has nothing to do with the direction of current flow. It is related to the conduction sequence of each phase.

2.3. Mathematical Model of SRM
Due to its unique double salient pole structure, the switched reluctance motor is often in a state of alternating saturation and non-saturation when the motor is running, and is affected by the eddy current effect. It has obvious nonlinear electromagnetic characteristics. This requires us to establish a precise mathematical model to have a clearer understanding of it.

2.3.1. According to the voltage balance relationship, the voltage equation of the k phase is:

\[ U_k = R_k I_k + \frac{d\psi_k}{dt} \]  

(1)

\[ U_k \] is the terminal voltage of the k phase winding, \( R_k \) is the resistance of the k phase winding, \( I_k \) is the current of the k phase winding, and \( \psi_k \) is the flux linkage of the k phase winding.

The flux linkage is also a function of current and angle:

\[ \psi_k(\theta, I_k) = L_k(\theta, I_k)I_k \]  

(2)

\( L_k(\theta, I_k) \) is the inductance of the k phase of the motor.

Formula 1 and Formula 2 can derive the formulas of voltage, current and inductance:

\[ U_k = R_k I_k + L_k \frac{dI_k}{dt} + I_k \frac{\partial L_k}{\partial \theta} \omega \]  

(3)
2.3.2. Mechanical motion equation. The magnitude of electromagnetic torque is related to current, inductance and position:

\[ T_e = \frac{1}{2} I^2 \frac{dL}{d\theta} \]  

(4)

3. Principle of no Position Sensor in Full Speed Range

3.1. Principle of Inductance Acquisition by Non-conducting Phase Pulse Injection

Formula 5 is the relational expression of the bus voltage, inductance, and current change rate under the low-speed state, ignoring the electromotive force, the current does not reach the saturation value.

According to Formula 3, the slope of voltage, inductance and rising current is shown in Formula 6. The slope of voltage, inductance and drop current is shown in Formula 7:

\[ U_{dc} = L_k \frac{I_{ph}}{\Delta t} + R_k \frac{\partial L_k}{\partial \theta} \omega \]  

(6)

\[ -U_{dc} = R_k I_k + L_k \frac{\partial L_k}{\partial \theta} \omega \]  

(7)

It can be obtained by combining formula 6 and formula 7:

\[ 2U_{dc} = L_k \frac{I_{ph}}{\Delta t} - L_k \frac{I_{ph}}{\Delta t} \]  

(8)

We can derive the inductance value from formula 8 and compare the real-time inductance value with the inductance threshold value of commutation to perform commutation control. This method does not have complicated table data, and will not be affected by saturation current or incremental inductance. When the bus voltage is stable, the current slope is only related to the inductance, and the inductance is related to the position, so as to obtain the rotor position of the motor to achieve efficient and stable commutation control, and this method subtracts the influence of the moving electromotive force by making a difference. The accuracy of the model is less affected by speed.

3.2. Method for Obtaining Flux Linkage and then Inductance by High-speed Voltage Integration

As the rotation speed increases, although the accuracy of the method of injecting pulses into the non-conducting phase can be guaranteed at low speeds, at high speeds, the number of injected pulses decreases as the duration of the non-conducting phase decreases. The acquisition accuracy decreases, which requires a high-speed inductance method. In this method, formula 1 shows that the size of the flux linkage can be converted into the difference between the bus voltage and the resistance voltage drop and then integrated. Once the inductance value is obtained, the current value can be obtained through the current sensor, and then the real-time inductance of the motor can be obtained by formula 2. The expression for obtaining the inductance can be expressed by formula 9:

\[ L_k = \frac{\int U_{dc} - R_k I_k \, dt}{I_k} \]  

(9)

3.3. Inductance Method Commutation Control Method

After obtaining the real-time inductance, compare it with the inductance threshold to determine whether it has reached the commutation position, and perform commutation processing on the motor.
In the end, both methods use the inductance value as a reference to perform commutation processing on the motor, so the low-speed algorithm is switched to. The high-speed algorithm has no obvious speed fluctuations, and can smoothly transition from low speed to high speed, and realizes the position sensorless control of the motor's full speed range.

4. Simulink Simulation Model Building and Result Waveform
The basic model of the motor used in the simulink system, the motor parameters are 240V DC voltage power supply, 6/4 type motor, stator resistance 0.05 ohm, 48KW power, on-current set to 200A fluctuates 10A up and down. PID double closed loop current speed control, build low-speed algorithm to obtain inductance module, high-speed algorithm to obtain inductance module, commutation control module, etc. The simulation system of SRM without position sensor is shown in the figure below.

![Figure 1. General block diagram of simulink sensorless system.](image)

The low-speed algorithm module is

![Figure 2. Low-speed algorithm module.](image)

The commutation control module is
5. **Result Analysis**

When the commutation control module is set at 1200r/min, the motor switches from low-speed algorithm to high-speed algorithm, that is, the inductance is provided by the high-speed module, the commutation logic is programmed by S-function, and the commutation control signal is output to determine the three-phase motor's each phase is on and off.

Under no-load conditions, it can be seen that the motor speed rises from 0r/min to 1200r/min and then smoothly accelerates to the closed-loop reference speed of 3000r/min, realizing the static, low-speed, and high-speed full-speed operation of the SRM. And the speed remains stable after reaching the reference speed, the flux linkage and current signals are symmetrical.

6. **Conclusion**

In this paper, the inductor is obtained by injecting current into the idle phase and integrating the voltage of the conducting phase in the low-speed range. The work and simulation verification proves the feasibility of position sensorless control of SRM based on the inductance method, and provides theoretical and simulation support for the materialization and productization of position sensors, but the simulation is only in ideal conditions. When running under the environment, physical research needs to consider signal interference, sampling accuracy, high-frequency noise and other factors that may affect the results. Productization still requires your continuous efforts.
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