Modeling and simulation of three-phase 6/4 switched reluctance motor speed control system

Huihui Bian*, Hua Chen, Ronghua Wang
Shandong Labor Vocational and Technical College, Jinan 250022, China
*leitengfei2017@qlit.edu.cn
bianhui1985@126.com

Abstract. To improve the response ability of the motor and reduce the torque ripple, we take the three-phase 6/4 SRM as the research object, according to the structure and characteristics of the SRM speed control system, the SRM speed and current double closed-loop control system are established and the current chopping control mode is adopted to change the motor speed. According to the mathematical model of SRM, then the model of each module of the speed control system is established by Matlab/Simulink. The simulation and performance analysis are carried out. The results show that the simulation model double closed loop control method can improve the system response ability, improve the stability of the motor and reduce the torque ripple.

1. Introduction
Switched reluctance motor (SRM) has many advantages, such as low price, firm and simple structure, good speed regulation, good start performance and high running efficiency[1]. References [2] the whole driving system of three-phase 12/8 SRM is modeled and simulated with the Matlab/Simulink, however the whole model of the system is not given. In [3], 12/8 SRM is modeled and simulated by double closed-loop control, the advantages and disadvantages of each control method are analyzed by changing the variables in the system. References [4] uses the control method which combines the mold and PI with the variable angle control, and establishes the simulation model. References [5] design of the mold and the controller by the rate of rotational speed deviation, and compare the simulation results.

In this paper, the SRM, its rated speed is 1500 rpm, and is chosen to establish a double closed-loop control system for the speed and current of SRM. The CCC method is used to change the speed of SRM to avoid excessive current and flux peak, making the torque smooth, and based on Matlab/Simulink set up speed control system model, the simulation and performance analysis are carried out in the speed control model.

2. Structure of Switched Reluctance Motor Speed Control System
The switched reluctance motor speed control system consists of five main parts, namely SRM, power converter, controller, position detection and current detection[6]-[7]. Its system structure is shown in Fig. 1. Position detection module is used to detect the motor rotor position signal and current detection module is mainly used to collect stator winding phase current. The switching device which is on the power converter module controls the input signal.
3. Mathematical model of SRM

The working principle and structure of SRM are very simple, and the mathematical model can be set up according to the electromagnetic induction law, conservation of energy and so on.

Voltage equation for the $k$ phase of SRM [8]:

$$u_k = R_k i_k + \frac{d\psi_k}{dt}$$ (1)

Where, $u_k$ represents the $k$ phase voltage; $i_k$ represents phase current; $R_k$ represents the phase winding resistance; $\psi_k$ represents the phase winding flux linkage [8].

The flux linkage equations of the $k$ phases are obtained by neglecting the mutual inductance of each phase of SRM:

$$\psi_k = L_k (\theta_k, i_k)$$ (2)

Where $\psi_k$ is the $k$ phase winding flux linkage; $\theta$ is the motor rotor position angle.

According to the principle of mechanics, the mechanical equation of the rotor is obtained:

$$T_e = J \frac{d^2 \theta}{dt^2} + K_\omega \frac{d \theta}{dt} + T_L$$ (3)

Among them, $T_e$ represents the electromagnetic torque of the motor; $J$ represents the moment of inertia of the motor system; $K_\omega$ represents the friction coefficient of the motor; $T_L$ represents the load torque of the motor.

4. Simulation model of switched reluctance motor speed control system

The simulation model of switched reluctance motor speed control system is established by using Matlab/Simulink, which consists of five modules: SRM motor module, hysteresis current controller module, PI controller module, position detector module and Power converter module [9].

4.1. Position detection module

Position detection module is mainly used to detect the relative position of the stator and rotor, to determine whether a phase winding is energized, so as to complete the speed control. The simulation model is shown in Fig. 2.

The changing period of the inductance of each phase winding is 90 degrees. The mod function is used to calculate the displacement angle and 90-odd angle, and the initial state of the backward integrator is used to set the parameters, compare the angle with the closing angle (Port 3) and the opening angle (Port 2). When the opening angle is less than the closing angle, the corresponding opening and closing signals will be output.
4.2. **Current chopper controller module**

The hysteresis comparator is designed in the current chopper controller. The open angle and the turn-off angle are kept constant, the chopper frequency is changed, the up and down value of current chopper is set, the current in the motor winding is changed, and the speed of motor is regulated. The simulation model is shown in Fig. 3.

4.3. **Power converter module**

Power converter which is the interface between the power supply and the motor, can play the role of switch. The simulation model is shown in Fig. 4. The IGBT and reverse flyback diode are used as the main switch device, at the same time the switch device is controlled to turn on and off by the gate control signal. C1, C2 respectively connected to the two ends of the motor winding, can output three-phase voltage.

4.4. **PI controller module**

In the speed loop, PI controller is mainly composed of three parts: comparison module, integral module and limiting module. The simulation model is shown in Fig. 5.

4.5. **Model of speed governing system**

SRM is controlled using the classic double closed-loop control, and the motor model calls the switched reluctance motor model in the Matlab/Simulink library. The simulation model is shown in Fig. 6.
5. Result analysis
In the simulation model, the initial speed is 1500r/min, the upper and lower limit of the hysteresis controller is (10,-10), set $K_p = 3, K_i = 0.5$ in the PI controller, the turn-off angle of the position detector is 40, the turn-on angle is 75. The simulation time is 0.2s, no-load start, load torque of 30N.m after 0.1s run. The simulation curve is shown in the following figure.

As can be seen from the Fig. 7, the torque is relatively large when the motor is just starting, and the torque ripple decreases with the normal operation of the motor when the motor is running steadily, and is stable in a certain range.

As can be seen from the Fig.8, when the motor is started, the speed is not overshoot. After running for 0.08s, the speed reaches the rated speed of 1500r/min, and the speed drops slightly when the load is added, which accords with the actual situation.

6. Conclusion
This paper proposes establishing the mathematical model of SRM, based on the structure and characteristics of switched reluctance motor, the mathematical model of SRM is established firstly, then the model of each module of SRM is established by using Matlab/Simulink, and finally the model of switched reluctance motor is established. According to the simulation results, we conclude that the simulation model has the advantages of stability, short response time and accurate speed regulation.

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