Modeling and Dynamic Simulation of the Switched Reluctance Motor

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Keywords: Switched reluctance motor, Nonlinear model, Simulation.

Abstract. According to the description of the basic principles of the SRM, the current chopping control is selected and the speed loop current chopping control strategy is used as the control strategy. The PID control strategy is made based on the speed and current loops. Then the speed-loop simulation experiments are carried out and the best turn-on and turn-off angles are selected according to the simulation data at the given speed conditions, so that the torque ripple of the motor is minimal. At last, the electric vehicle can use the motor model and the simulation results is analyzed and compared.

Introduction

The switched reluctance motor is beginning to emerge as an attractive selection for the electric vehicle because of some advantages, such as flexible control, simple structure and low cost, etc. when compared to other motors [1-3]. But the switched reluctance motor is suffering from its torque ripple which is bad for the switched reluctance motor and the electric vehicle [4]. And the driving range of the electric vehicle is directly determined by the motor efficiency. So in the electric vehicle driving system, it is very significant to design a high torque controller in order to reducing the torque ripple and increasing the average torque. Based on it, good traction performance of the electric vehicle can be obtained.

Switched Reluctance Motor Basic Equations

According to the basic law of circuit, each phase of the switched reluctance motor flux linkage can be calculated according to the phase voltage and winding voltage difference of the integral:

\[
\psi_k(i, \theta) = \int (u_k - R_k i_k) \, dt
\]  

(1)

Where \( \psi_k \) is the K phase flux, \( u_k \) is the k phase winding voltage at both ends, \( R_k \) is the phase winding resistance, \( i_k \) is the current, \( \theta \) is the rotor angle.

Switched reluctance motor electromagnetic torque can be calculated by magnetic chain characteristics according to the measured current and rotor position:

\[
T_e(i, \theta) = \frac{\partial}{\partial \theta} W'(i, \theta) = \frac{\partial}{\partial \theta} \int \psi(i, \theta) \, di
\]

(2)

Where \( T_e \) is the electromagnetic torque, \( W'(i, \theta) \) is the magnetic co-energy.

According to the principle of mechanics, the switched reluctance motor under the action of electromagnetic torque and load torque, the equation of motion of the mechanical rotor:

\[
T_e(i, \theta) = J \frac{d\omega}{dt} + B \omega + T_L
\]

(3)
Where $J$ is the moment of inertia of system, $B$ is the coefficient of friction, $\omega$ is the rotor angular velocity, $T_L$ is the load torque.

**Switched Reluctance Motor Nonlinear Model**

In this paper, the proposed research switched reluctance motor in different position angles and the current situation of flux values can be obtained by finite element analysis method. According to the switched reluctance motor mathematical model, in the MATLAB/Simulink environment, motor modules, angle of the power converter module, collection module, current control module and switch control module are established. Switched reluctance motor drive system dynamic model is set up as shown in figure 1.

![Simulation model diagram of switched reluctance motor system.](image)

### The Selection of Optimum Switch Angle Simulation

The torque ripple is the minimum when the switch angle is the optimum value and the switched reluctance motor is in stable operation. And the minimum torque ripple is selected as the objective function:

$$f = \min(T_{\text{max}} - T_{\text{min}})$$

Where $T_{\text{max}}$ is the maximum torque of motor in the stable operation, $T_{\text{min}}$ is the minimum torque of motor in the stable operation.

Firstly, the rotate speed or turn-off angle is set as a fixed value. A group of torque ripple values changing with turn-on angles in the stable operation can be obtained by giving some special values to the turn-on angle. And another group of torque ripple values in the stable operation can be obtained by changing the value of rotate speed. Turn-on and turn-off angles in each set of data when the torque ripple value are the minimum can be selected, the turn-on angle and rotate speed diagram with the minimum torque ripple of motor in the stable operation can be obtained under a given turn-off angle.
Similarly, the turn-off angle and rotate speed diagram with the minimum torque ripple of motor in the stable operation can be obtained under a given turn-on angle. Finally, the diagram obtained can be utilized into the simulation diagram, and simulation analysis can be done. Based on the simulation experiment started by the PID speed closed-loop, according to the simulation data, under the condition of giving a special turn off angle, the relationship between the turn-on angle and the rotate speed with the minimum torque ripple of motor in the stable operation can be obtained, the simulation results before and after improvement can be analyzed and contrasted. Figure 2 is the improved simulation principle block diagram.

Figure 3 and figure 4, respectively, are the simulation results at the condition of the improved turn-on angle and not improved turn-on angle. After the improvement, the torque ripple is the optimum in stable operation, which can be found by contrasting figure 3 and figure 4.

Similarly, the turn-off angle which makes the minimum torque ripple at a given turn-on angle can be obtained. According to the situation above, the speed can be set with the change over the time. Figure 5 and Figure 6 are the rotate speed and torque results figures in the selection of turn-on angle when the torque ripple is the minimum in the stable operation.

Figure 2. Simulation diagram of turn-on angle selection with minimum torque ripple.

The Selection about Parameters of Electric Vehicle

Based on an electric parameter configuration, the model of switched reluctance motor established above can be applied in the electric vehicle.

Vehicle Load Simulation

Motor model is applied to the electric vehicle is to build the relationship between torque required for electric vehicle and motor load torque. The principle which is similar to the formula 5 can be used.

\[
\frac{T \cdot i \cdot i_r \cdot \eta_T}{r} = Gf + Gi + \frac{C_D A}{21.15} u_a^2 + \delta m \frac{du}{dt}
\]  

(5)
Where $T_{eq}$ is the engine torque, $G$ is the total weight of the car, $f$ is the coefficient of rolling resistance, $i$ is the climbing gradient, $A$ is the windward area, $C_D$ is the coefficient of air drag coefficient, $u_a$ is the speed of the vehicle, $r$ is tire radius, $\delta$ the transmission system overall efficiency, $\eta_T$ is the transmission system overall efficiency, $i_g$ is the transmission ratio.
Figure 5. The simulation results of speed.

Figure 6. Torque simulation results.

Figure 7. Phase current simulation results.
Conclusions

In this paper, a kind of strategy of speed loop current chopping control is proposed. The speed of the switched reluctance motor can be controlled by the speed loop. And the current of the switched reluctance motor can be controlled by the current chopping loop. Based on the simulation results, on the condition of giving a special speed, turn-on angle and turn-off angle with the minimum torque of motor can be obtained. When the switched reluctance motor is in the stable operation, the minimum torque ripple can be obtained on the condition of giving the optimal angle above. Finally, the model of switched reluctance motor established above can be applied in the electric vehicle. The method in this paper is verified by the simulation results.

![Torque simulation results.](image)

![Speed simulation results.](image)
Acknowledgements

This research was financially supported by the National Natural Science Foundation of China (51505332), Tianjin Research Program of Application Foundation and Advanced Technology (15JCQNJC06900) and The Youth Innovation Fund of Tianjin University of Science and Technology (2014CXLG19).

References


