Model Construction and Simulation of Switched Reluctance Motor Based on MATLAB/S Function

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Abstract. According to the mathematical model and direct torque control method of switched reluctance motor, the principle of direct torque control is introduced, and the overall simulation model is built under the matlab/Simulink environment. The complete program code is compiled by using M file, and then debugged and run. The results show that the control method and S function are reasonable and effective, and the torque ripple is small, so it can provide reference for the control of solid switched reluctance motor.

Keywords: Switched reluctance motor; s function; Direct torque control; MATLAB.

1. Introduction

Switched reluctance motor (SRM), as a traction device and an energy conversion device, SRM has many advantages, such as simple structure, high reliability, flexible system control, high operation efficiency and simpler structure than squirrel cage induction motor, it has been rapidly applied in various fields. However, with the development of science and technology, the torque ripple index is more and more strict in many applications. Because of its double salient pole structure and high saturation of magnetic circuit during operation, the nonlinear function of rotor position angle and stator phase current in electromagnetic torque causes the occurrence of torque ripple, which is the main reason for its rapid development. At present, to solve this problem, we mainly start with the structure of the motor body and the optimization control method.

The control effect of traditional control method is not good, and it is not suitable for the present high-precision occasions. At present, the direct torque control applied to AC motor at home and abroad can avoid the complex mathematical model and control the torque directly, which can effectively reduce the torque ripple and do not need to change the motor structure, so it has a wide application prospect. Therefore, this paper adopts direct torque control strategy. However, the simulation of switched reluctance motor is based on the existing package module of Simulink, the connection is complex, and it is inconvenient to modify the parameters. After reading a lot of literature, the simulation research on switched reluctance motor with s function is basically not found. Therefore, this paper proposes to write s function to build SRM simulation control calculation module, and further research on simulation control.

2. Mathematical Model of Switched Reluctance Motor

Basic equation of SRM.

The k-phase voltage balance equation of the motor is

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

(1)
In which the flux linkage equation

\[ \psi_k = L_k(i_k, \theta) \cdot i_k \] (2)

Where: \( U_K \) - phase K winding voltage, \( R_k \) - resistance of phase K winding, \( I_k \) - phase K winding current, \( L_k \) - inductance of phase K winding.

Mechanical motion equation of SRM rotor

\[ \int \frac{d\omega}{dt} = \sum_{j=1}^{m} T_j - T_L - f \omega \] (3)

Where, \( \omega \) - angular velocity of rotor, \( J \) - moment of inertia, \( T_j \) - phase J electromagnetic torque, \( T_L \) - load torque, \( f \) - damping coefficient, \( m \) - number of motor phases.

Electromechanical equations, among them, \( W_e \) is the electrical energy input from the motor winding

\[ dW_e = dW_f + dW_c \] (4)

\( W_f \) is the magnetic energy storage stored in the inductor,

\[ W_f = \int_{\psi_0}^{\psi} i(\psi, \theta_0) d\psi \] (5)

\( W_c \) is the magnetic function transferred to the load,

\[ W_c = \int_{i_0}^{i} i(i, \theta_0) di \] (6)

Where

\[ T_e = \frac{aw_e}{d\theta} |_{i=const} \] (7)

3. Control Method of Switched Reluctance Motor

Direct torque control (DTC) method is used in this simulation, the DTC method was used in AC induction motor before, and it is widely used in high-precision occasions due to its high response speed and high speed regulation accuracy. After transformation, it is applied to switched reluctance motor. In the basic method of DTC, the instantaneous flux linkage and the torque of the switched reluctance motor are measured and compared with the given electromagnetic torque, and then the differential value is obtained, so as to determine the adjustment direction of the torque, control the size of the flux linkage and the switching angle, and select the appropriate value to control the power converter, so that the instantaneous torque of the SRM can quickly keep up with the given electromagnetic torque, and achieved direct control of SRM torque, form double closed-loop control, which can also reduce torque ripple. The control principle is shown in Fig 1.

![Figure 1. Schematic diagram of direct torque control.](image1)

![Figure 2. Motor body model.](image2)

4. Overall System Modeling

4.1. Establishment of SRM Ontology Model

Matlab / Simulink has three models of switched reluctance motor, which are 6 / 4 pole, 8 / 6 pole and
In this paper, the self-contained 6 / 4-pole switched reluctance motor is adopted. The model is shown in Fig. 2.

### 4.2. Power Converter Module

The power converter adopts asymmetric half bridge circuit which is widely used. The biggest advantage of this circuit is that it is convenient to carry out single control. When the SRM motor is in single or two working states, the voltage of the conduction winding carries the power supply voltage, and each phase is independent. When each winding is in freewheeling state, each winding has its own freewheeling circuit, so it can be connected to multi-phase switched reluctance motor. The circuit is shown in Figure 3.

### 4.3. Voltage Vector Switch Selection Module

The voltage vector is converted into the switching control signals of each phase of the power converter. The module stores the switching signals of six sectors in the lookup table by looking up the table. The on-off of each sector is selected by the input signals of S and section to control the power converter, and then the operation of switched reluctance motor is controlled to obtain stable output torque. The establishment of the model is shown in Figure 4.

![Figure 3. Power converter circuit diagram.](image1)

![Figure 4. Vector selection switch module.](image2)

### 4.4. Programming of S-function Module for Switched Reluctance Motor

Matlab software has powerful functions, and its language programming module can be written according to the established mathematical model. If the direct torque control model of switched reluctance motor is built by Matlab / Simulink, it is very complex. However, using s function to write each module can not only realize the accurate description of complex system, but also reduce the complexity of multi module connection, which has great flexibility and convenience, and can accurately simulate the model and get accurate results.

Input variables :fa,fb,fc,Te,n
Output variable: Fa,Fb,s,section
state variable: det_Speed,sum_det,

The main function is as follows

```matlab
function [sys,x0,str,ts] = d_sfunc_dtc(t,x,u,F,
st,Speed,Kp,Ki,Temax)
  switch flag,
    case 0,
      [sys,x0,str,ts] = mdlInitializeSizes;
    case 2,
      sys=mdlUpdate(t,x,u,Fset,Speed,Kp,Ki,Tema x);
    case 3,
      sys = mdlOutputs(t,x,u);
    case {1,4,9 }
      sys =[];
    otherwise
      error(['unhandled flag = ',num2str(flag)]);
  end
end
```

where ,Take 0 for flag, call initialization sub function, mdlinitializeizes;
Take 3 for flag and call the output sub function MDL outputs;
The flag of each module is taken as 0, and the initialization sub function, mdlinitializeizes,

Discrete state update subroutine (coordinate transformation and sector judgment)

```matlab
function sys=
mdlUpdate(t,x,u,Fset,Speed,Kp,Ki,Temax)
  Fb=0.86605*(u(2)-u(3));
  Fs=sqrt(Fa*Fa+Fb*Fb);
  if (abs(Fa)<1e-5)
    Fa=u(1)-0.5*u(2)-0.5*u(3);
  case 2,
    sys=mdlUpdate(t,x,u,Fset,Speed,Kp,Ki,Tema x);
  case 3,
    sys = mdlOutputs(t,x,u);
  case {1,4,9 }
    sys =[];
    otherwise
      error(['unhandled flag = ',num2str(flag)]);
end
```

The establishment of the model is shown in Figure 4.
\begin{verbatim}
Fa=1e-5;
end
Fba=Fb/Fa;
delta=atan(Fba);
if (Fa<0)
delta=delta+pi;
end
det_speed=Speed-u(5);
sum_det=x(7)+det_speed;
x(8)=det_speed*Kp+sum_det*Ki;
if x(8)>Temax
x(8)=Temax;
end
if x(8)<-Temax
x(8)=-Temax;
end
if (Fset-Fs)/Fset>0.005
x(1)=1;
end
if (Fset-Fs)/Fset<-0.005
x(1)=0;
end
if (x(8)-u(4))/x(8)>0.005
x(2)=1;
end
end
if (x(8)-u(4))/x(8)<-0.005
x(2)=0;
end
x(3)=x(2)*2+x(1)+1;
end
(2) Output state subroutine
function sys = mdlOutputs(t,x,u)
sys(1)=x(3);
sys(2)=x(4);
sys(3)=x(5);
sys(4)=x(6);
end
Initialization state subroutine
function [sys,x0,str,ts] = mdlInitializeSizes()
sizes = simsizes;
sizes.NumContStates = 0;
sizes.NumDiscStates = 8;
sizes.NumOutputs = 4;
sizes.NumInputs = 5;
sizes.DirFeedthrough = 0;
sizes.NumSampleTimes = 1;
sys = simsizes(sizes);
x0 =[1 1 1 1 0.001 0.001 0 0];
str = [];
ts = [-1 0];
end
\end{verbatim}

According to the above modules, the overall simulation model is built. Among them, PID controller, coordinate conversion and commutation interval module, flux calculation, flux PI regulation module and flux hysteresis module are all written by s function. The overall simulation model is shown in Fig. 5.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{Overall simulation model of DTC control.}
\end{figure}

5. Simulation Results and Analysis

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure6.png}
\caption{Simulation waveform of each parameter(Flux, current, torque, speed, voltage).}
\end{figure}
SRM body motor is a motor model with MATLAB. Its parameters are: stator resistance 0.05 Ω, inertia torque 0.02 N.m, speed 4500 r/min, power supply voltage 300 V, simulation time 5 s. Fig. 6 to Fig. 11 are the parameter waveforms at no-load speed, among which figures 7 to 11 are amplification waveforms of parameters, and figure 12 are simulation amplification waveforms after load stabilization. It can be seen from the figure that the speed can reach the rated speed, the torque is stable, the commutation is stable, the current and flux linkage can output stable waveforms within reasonable results, so the load simulation system is stable, it is consistent with the theoretical analysis.
6. Conclusion
According to the direct torque control method of switched reluctance motor, the overall simulation model is built in MATLAB software, and the s function is compiled. The model of motor body model is built with MATLAB, which has high accuracy. Through the analysis of the simulation results, the system can run smoothly, get the ideal simulation waveform, and further optimize the s function code to get more rational results. At the same time, the simulation waveforms of the control system under various conditions show that the switched reluctance motor can effectively limit the flux linkage amplitude and electromagnetic torque of the switched reluctance motor within the respective hysteresis width, ensure the system response speed, load carrying capacity and speed regulation ability, and can better suppress the torque ripple of the switched reluctance motor, which verifies the established model. The model and simulation results provide a basis for further research and optimization of SRM speed control system. In the following research, fuzzy control or intelligent control strategy is added to further optimize the S-function code to reduce the torque ripple amplitude to a smaller value, so that the switched reluctance motor can be applied to more platforms.

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