Research on Torque Ripple Control of Switched Reluctance Motor

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Abstract: Switched reluctance motor (SRM) has many excellent characteristics, but it has torque ripple. Mathematical model and self-design of SRM based on the theory of disturbance rejection control, an active disturbance rejection control system of SRM is designed, and the system is simulated by using MATLAB. The results show that the ADRC scheme can effectively suppress the torque ripple of SRM.

1. Introduction

Switched reluctance motor (SRM) is of many advantages, such as simple structure, low manufacturing cost and reliable operation. However, due to the special doubly salient structure of SRM and the high saturation characteristics of magnetic circuit in operation, the torque pulsation during operation is large and there is a certain amount of noise, which limits some applications in the field of transmission with higher performance requirements. Therefore, restraining SRM torque ripple has always been an important issue at home and abroad. Fuzzy control, neural network control and other control schemes can be used to a certain extent.Torque ripple is suppressed, but these control strategies are complex.

In this paper, torque ripple technology is applied to SRM control scheme. It is found that active disturbance rejection control system can effectively suppress torque ripple.

2. Control System

2.1 Auto Disturbance Rejection Control Theory

Active Disturbance Rejection Control (ADRC) is a control that estimates compensating uncertainties. Technology, which does not depend on the precise mathematical model of the controlled object, can be realized. The disturbance of the system can be estimated and compensated in time [1].

ADRC consists of four parts: tracking differentiator (TD), extended state observer (ESO), nonlinear states error feedback (NLSEF) and disturbance compensation, the first order ADRC system is shown in Fig 1. For fhan function in disturbance rejection control theory is proposed in reference [2].The theory of ADRC is improved. Using fsun function can make the state variables of the second order discrete system reach the steady state without overshoot [3].The number of steps is less than that of fhan function [4]. This reduces the size of the system.The energy loss also improves the control performance of the system [5]. The expression of functions fsun (x_1, x_2, r, h) is

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$$\begin{cases} y = x_1 + hx_2 \\ k' = \frac{1}{2}(\sqrt{1+\frac{8|y|}{h^2 r}}+1) \\ k = \mathrm{sgn}(k' - \mathrm{fix}(k')) + \mathrm{fix}(k') \\ \mathrm{fsun}(x_1, \ x_2, r, \ h) = \begin{cases} -r\mathrm{sat}((1-\frac{1}{2}))\mathrm{sgn}(y) - \frac{x_1 + khx_2}{(k-1)h^2 r}, |y| > h^2 r \\ -r\mathrm{sat}(x_2 + \frac{y}{h}, hr), |y| \le h^2 r \end{cases} \end{cases} \tag{1}$$

Where r determines the tracking speed. h is the sampling time, x_1, x_2 is the state variable, sgn(•) is the symbol function, fix(•) represents the take integral function , sat(•) represents the saturation function.

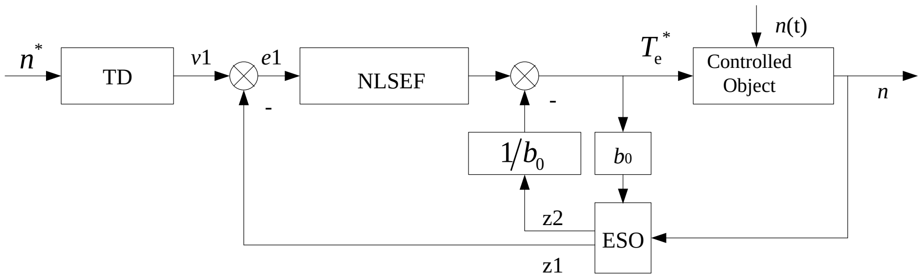


Figure. 1 The block diagram of speed controller adopted ADRC

2.2 Controller Design Adopted ADRC

The motion equation of switched reluctance motor is

$$\frac{\mathrm{d}\omega}{\mathrm{d}t} = \frac{T_e}{J} - \frac{T_L}{J} - \frac{B\omega}{J} \tag{2}$$

Where, ω is the angular speed of the rotor, J is the moment of inertia, Te is the electromagnetic torque.TL is load torque; B is damping coefficient. It can be seen that the changes of J, TL and B all affect the control accuracy. We can think of this effect as disturbance and the change of J as a system. The internal disturbance regards the change of TL and B as the external disturbance of the system. The sum of internal and external disturbances of the system is recorded as $n(t)$, so formula (2) can be expressed as

$$\frac{\mathrm{d}\omega}{\mathrm{d}t} = \frac{T_e}{J} + n(t) \tag{3}$$

For the total disturbance n(t) , according to the ESO,we can estimate the change of disturbance with time and compensate it to the control quantity.The velocity given value ω*is used as the input signal of the tracking differentiator.

The first-order tracking differentiator is designed by using fsun function. Its mathematical model is as follows

$$\dot{v}_1 = \mathrm{fsun}(v_1 - \omega^*, \ r, \ h) \tag{4}$$

TD will determine transition reasonably according to the endurance of the controlled object.The system can output the tracking value v1 of the given speed ω*.The contradiction between overshoot and rapidity is solved.

Taking the actual speed ω as the input signal, the second-order expansion is adopted.After the state observer is processed, the observed value z_1 of the actual speed ω is obtained, and the estimated value of total perturbation z_2, ESO equation is

$$\begin{cases} e = z_1 - \omega \\ \dot{z}_1 = z_2 - \beta_1 \mathrm{fal}(e, 0.5, \delta) + b_0 u \\ \dot{z}_2 = -\beta_2 \mathrm{fal}(e, 0.25, \delta) \end{cases} \tag{5}$$

Where, β_1 and β_2 is the feedback gain whose value affects the convergence rate of ESO,β_1 takes the reciprocal of integral step, and β_2 takes a higher value than β_1, b0 is the compensation factor, fal is a non-linear function.The expression is

$$\mathrm{fal}(e, \alpha, \delta) = \begin{cases} |e|^{\alpha} \mathrm{sgn}(e), |e| > \delta \\ \dfrac{e}{\delta^{1-\alpha}}, |e| \le \delta \end{cases} \tag{6}$$

Among them, e is the error signal, α is the filter factor, and δ is the linear interval. The width is generally about 0.01.

The tracking value v_1 of the given speed and the observed value of the actual speed. The state error v_1-z_1 is obtained by z_1. The non-linear form is formed by using fsun function. State error feedback control law

$$u_0 = -\mathrm{fsun}(v_1 - z_1,\ r_1,\ h) \tag{7}$$

Then the disturbance z_2 estimated by ESO in real time is compensated and the final result is obtained. The output control quantity is

$$T_e^* = u_0 - \frac{z_2}{b_0} \tag{8}$$

2.3 Simulation and result analysis

The SRM of ADRC controller based on MATLAB/SIMULINK is adopted in this paper. The speed control system is simulated. Velocity wave under dynamic, sudden load and variation of moment of inertia .Torque waveform under load operation is simulated. The simulation results of PI and speed regulation under the same conditions are compared. The prototype is three phase 6/4 SRM, rated power 55 kW, B=0.03 N.m.s,J=0.0046 kg•m2.

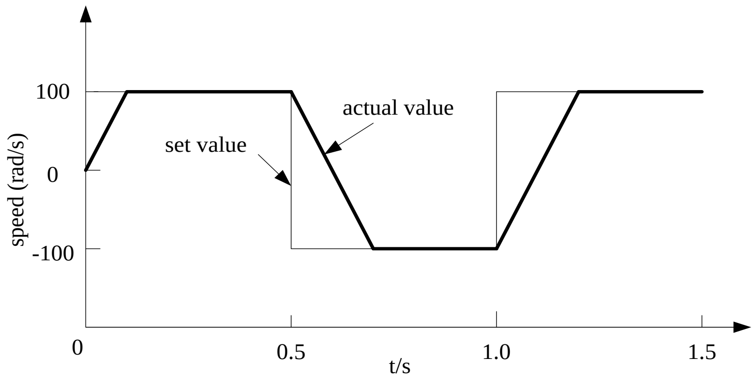


Figure. 2 Speed set value and actual value curves

Figure. 2 shows that under the condition of no-load operation of SRM and given speed of square wave. The speed tracking waveform obtained by ADRC is used.

As can be seen from Figure.2, the actual speed can be well tracked to a given speed value, small overshoot, fast response and good performance in the whole speed regulation process satisfactory dynamic performance.

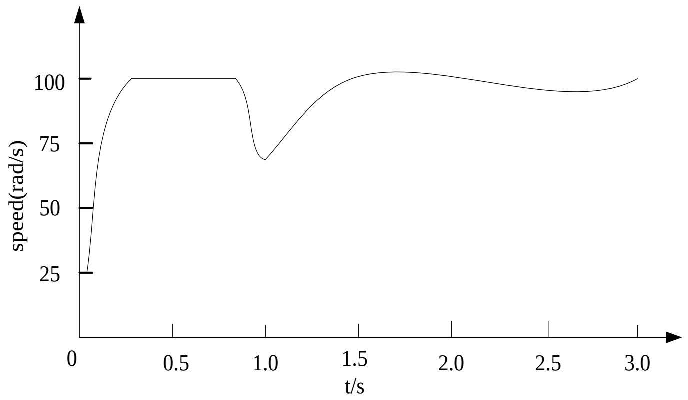


Figure. 3 The speed curve PI controller adopted

When the speed is 100 rad/s, the load torque changes abruptly from zero to 10Nm, the speed curve based on PI regulator is shown in Figure.3.The speed curve of ADRC regulator is shown in Figure 4.

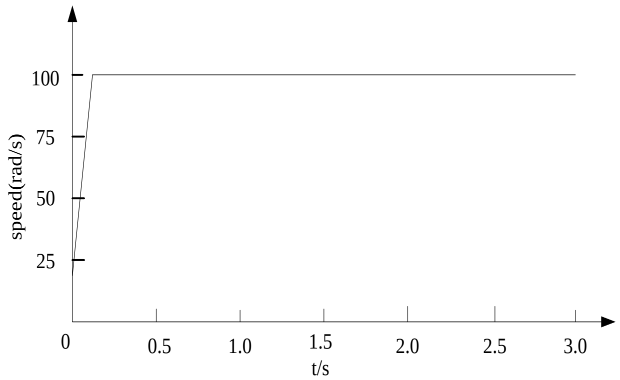
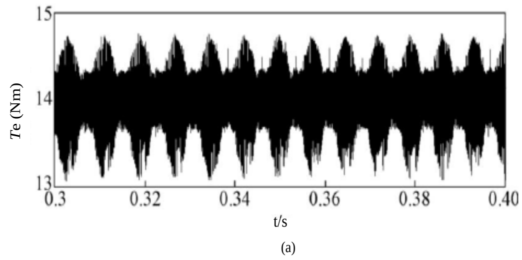


Figure. 4 The speed waveform based on ADRC controller

Figure 5 shows the torque waveforms under different control modes when the load torque is 12N ·m.

From Figure 5(a) and Figure 5(b), it can be seen that the range of torque ripple under PI regulator is 13.2-14.5 N.m, and that under ADRC regulator is 13-14 N.m. Given a load torque of 12 N.m, the range of torque ripple can be maintained within S 0.5 N.m. It can be seen that the ADRC is better than the traditional PI regulator in suppressing the torque ripple.



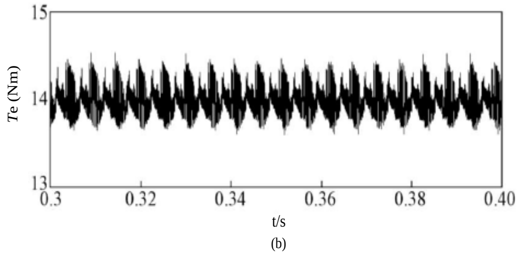


Figure. 5 The torque waueform for different control methods at load torque of 12Nm

3. Conclusion

In this study, the ADRC technology is applied to the speed regulation system of SRM, and the ADRC speed regulator is designed. The effectiveness of the design is verified by simulation analysis. The simulation results show that compared with the traditional PI control method, ADRC enhances the robustness of the system to various disturbances, effectively suppresses the torque ripple, and greatly improves the speed control performance of the system.

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