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Research on Advanced Control Strategies of Induction Motor System

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Abstract

The induction motor (IM) is a nonlinear, uncertain, and complex controlled object that is difficult to drive and control. When the system parameters change or has external disturbance signal, the system cannot return to the original state of equilibrium, to which active disturbance rejection control (ADRC) has been shown to be an effective solution. ADRC regards the external disturbance and strong coupling structure of induction motor (IM) as the total disturbance, which is observed and compensated by extended state observer, and does not depend accurate system mathematical model, and has strong anti-interference and robustness. In this paper, a new control strategy----Tornambe control is used in the speed regulator of IM system instead of ADRC. It has the similar control thought to the ADRC, and has the simple structure, less setting parameters, and is convenient to study and use. In this paper, the direct torque control strategy is adopted to drive the IM. The active disturbance rejection control and Tornambe control are used instead of traditional speed regulator, the system performance of the two control strategy are compared. The results show that the system performance of TC strategy is better than that of ADRC.

Keywords: *direct torque control, active disturbance rejection control, speed control, Tornambe control*

1. Introduction

The induction motor (IM) is a nonlinear, uncertain, strong coupling, multivariable, and high-order system [1]. The two main drive strategies are vector control (VC) and direct-torque control (DTC).VC and DTC belong to the high-performance IM control strategies. VC lays the theoretical foundations for high performance AC speed regulation control, realizes the decoupling control of flux and torque, but VC requires an accurate IM model, and has complex coordinate transformations and large system calculations [2]. However DTC does not require complex coordinate transformations and large system calculations, has improved IM control system performance, but has a large torque ripple at low speed [3]. In order to solve this problem, many advanced control strategies were put forward. A type constraint error with DTC was put forward in [4].Using each difference of 180 degree triangle wave to modulate the torque error controlled by PI controller, the duty time of vectors change depends on torque error, thus reducing torque ripple [5]. D.Cassadei etc. implemented the IM torque ripple using the discrete space vector technology [6-8].

In traditional DTC system, speed regulator uses PI regulator. When speed, condition and system parameters change, PI regulator can not make the system return to the equilibrium rapidly, the system response slower, system accuracy decreasing, system robustness worse [6]. In order to solve this problem, ADRC is used in the DTC system. ADRC was put forward by Han Jingqing. ADRC was applied in PMSM control system [8].ADRC was used in the RBF neural networks [9].ADRC was applied in the CFBB

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main steam pressure control system.[7].ADRC technology is derived from the PID control theory. ADRC has higher stability and strong robustness than the PID controller and has been used to address the inherent defects of classical PID [6]. But for the complex systems, setting parameters of ADRC is more, it is not easy to study and apply. In this paper, a new control strategy-Tornambe control (TC) is applied in the DTC system. TC was put forward by Antonio Tornambe, its control thought is similar to ADRC, and it has many advantages: It does not depend on exact model of controlled object; it has a strong anti-interference ability; it has a strong coupling characteristics; it is easy to study and apply because of simple structure, few setting parameters. TC has been applied to many fields: robot system, power unit, aircraft design, tank gun control system, missile guidance system. TC has strong robustness and adaptability, effectively improves the performance of controlled system.

2. Direct Torque Control of Induction Motor

Figure 1 shows the DTC system structure of IM [10]. The structure includes the current acquisition, speed detection, speed control, torque and flux control, SVPWM modules, inverters, IM. Combing SVPWM and DTC, the desired voltage vector in the next sampling period is determined by flux and torque error in the previous sampling period. The voltage vector can be made up of two non-zero voltage vectors and a zero voltage vector. Three switch voltage vectors are get after the voltage vector modulated by SVPWM. Because the flux hysteresis regulator and torque hysteresis regulator were removed. The system influence because of hysteresis regulator has been overcome. The torque ripple is largely reduced.

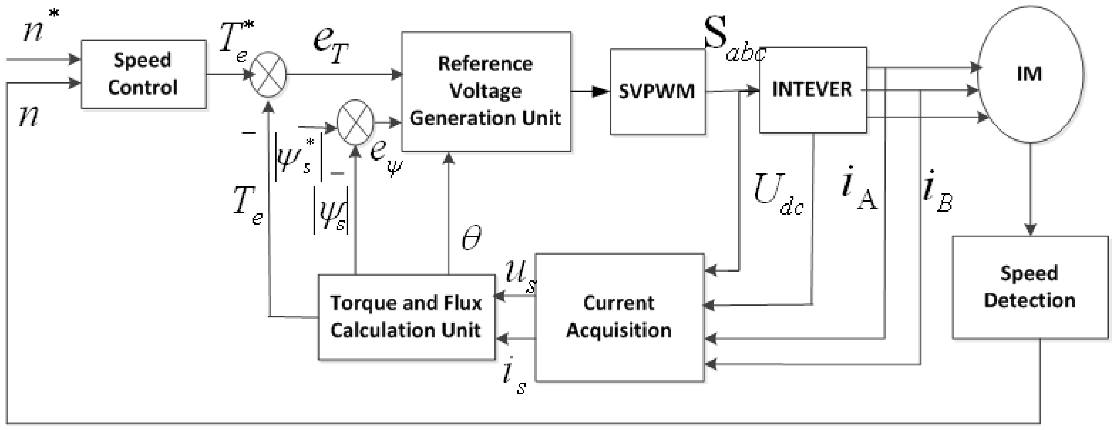


Figure 1. DTC System Structure of IM

But in this system, speed regulator uses PI regulator, when the system has unknown load disturbance and the system parameters changes, PI regulator can not adjust system quickly. In this paper, ADRC is substituted for PI regulator.

3. Application of ADRC in IM Speed Control

The ADRC technology is derived from the PID control theory, but is different to the PID control. The ADRC has higher stability and robustness and adaptively than the PID controller and has thus been used to address the inherent defects of classical PID.

3.1 ADRC

The ADRC consists of three parts. The first part is the tracking differentiator (TD), which is used to arrange the transient process, give the reasonable control signal, solve the contradiction between the response speed and overshoot. The second part is the extended state observer (SEO), which is used to solve the influence of unknown part model and unknown external disturbances on the control object. The third part is nonlinear state error feedback (NLSEF), which gives the control strategy of the controlled object [8].

3.2 ADRC Design

ADRC equations of induction motor are described as follows:

Differentiation-tracker

$$\varepsilon_0 = z_{11} - v$$
$$\dot{z}_{11} = -rf_{al}(\varepsilon_0, \alpha_0, \delta_0) \quad (1)$$

Extended state observer

$$\begin{aligned} \varepsilon &= z_{21} - y \\ \dot{z}_{21} &= z_{22} - \beta_{01} f_{al}(\varepsilon, \alpha, \delta) + bu(t) \\ \dot{z}_{22} &= -\beta_{02} f_{al}(\varepsilon, \alpha . \delta) \end{aligned} \quad (2)$$

Nonlinear state error feedback

$$\begin{aligned} \varepsilon_1 &= z_{11} - z_{21} \\ u_0 &= \beta_1 f_{al}(\varepsilon_1, \alpha_1, \delta_1) \\ u(t) &= u_0(t) - \frac{z_{22}}{b} \end{aligned} \quad (3)$$

The expression of optimal control function f_{al} is

$$f_{al}(\varepsilon, \alpha, \delta) = \begin{cases} |\varepsilon|^{\alpha} \operatorname{sgn}(\varepsilon) & |\varepsilon| > \delta \\ \dfrac{\varepsilon}{\delta^{1-\alpha}} & |\varepsilon| \le \delta \end{cases} \quad (4)$$

The structure of ADRC controller is shown in Figure 2:

Where v is a given signal for ADRC; z11 is tracking signal to v; r is tracking speed factor; y is system output; z21 is tracking signal to y; z22 is tracking signal to disturbance signal ω(t); ε is error signal; α is nonlinear factor; δ is ESO filter factor; β01、β02 are correction gain for output error; β is gain error.

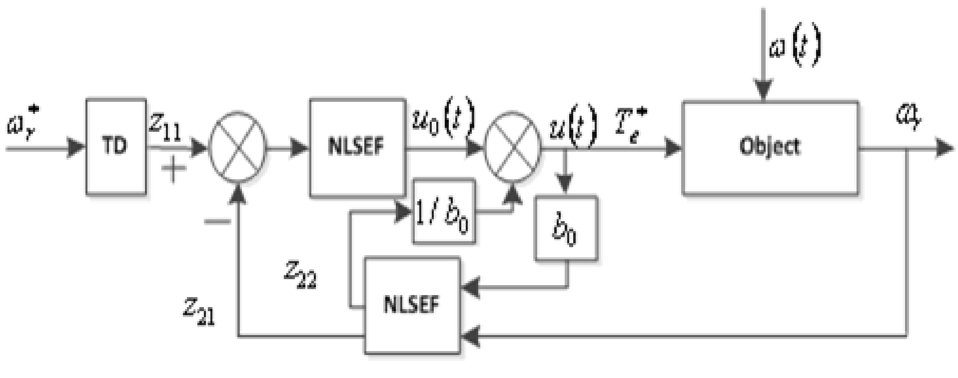


Figure 2. Structure of ADRC Controllers

In Figure 2, ω_r^* and T_e^* are given speed and given torque; ω_r is system speed feedback signal; z_{11} is tracking signal to ω_r^*; z_{21} is tracking signal to ω_r; TD arranges transition process for ω_r^* ,obtaining smoothing input signal, causing system quick response without overshoot. ESO link estimates all state variables in real time, and observes internal and external disturbances and uncertain model accurately, feedback linearization of dynamic system can be come true to compensate uncertainty of controlled object in the feedback so that we can achieve the goal of refactorying object; NLSEF can realize integrated disturbance compensation and nonlinear control of “small error and great gain” in order to improve system steady-state accuracy.

4. Application of TC in IM Speed Control

In view of the advantages and disadvantages of PI controller, ADRC has a corresponding solution. But adjustment parameter is more complicated. In this paper, TC is proposed instead of ADRC.TC has the same control thought to ADRC, does not rely on accurate mathematical model of system, has strong anti-disturbance ability, has perfect decoupling,. And furthermore TC has simple structure, has fewer adjustment parameters and facilitates research and utilization [11].

In the DTC system of IM, a second-order TC controller is designed. Speed n is considered as controlled variable, a second-order TC as follows:

$$\begin{cases} u = -h_0 n - h_1 \dot{n} - \hat{d} \\ \hat{d} = \xi + k_0 n + k_1 \dot{n} \\ \dot{\xi} = -k_1 \xi - k_1 (k_0 n + k_1 \dot{n}) - k_0 \dot{n} - k_1 f \end{cases} \quad (5)$$

The DTC system structure of IM based on the TC is shown in Figure 3.

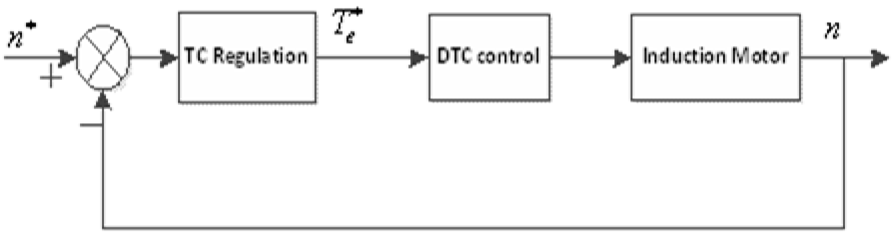
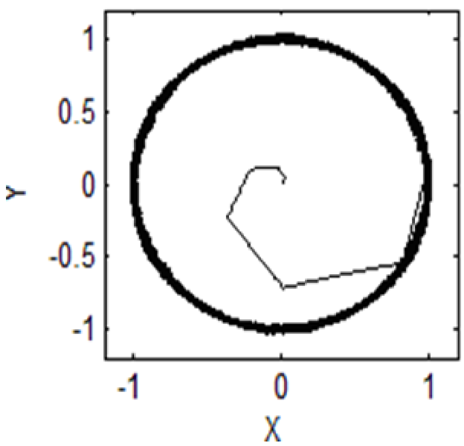


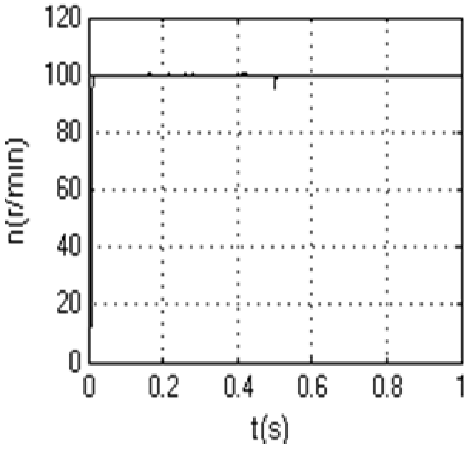
Figure 3. DTC System based on TC Regulation

The MATLAB/SIMULINK is used to build a simulation model. The specific parameters are as follows:

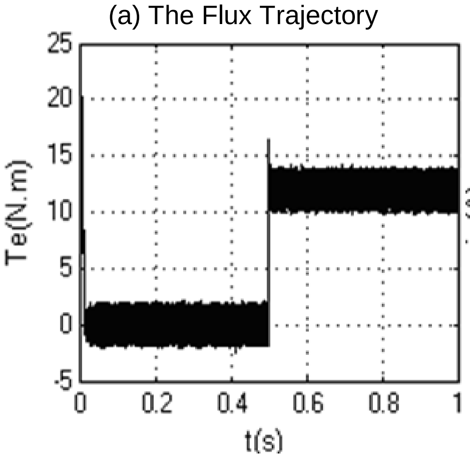
The nominal voltage is U=380V, the stator resistance is Rs=2.7Ω, the rotor resistance Rr=2.23Ω, the stator inductance Ls=0.3548H, the rotor inductance Lr=0.3548H, mutual inductance Lm=0.3432H, rotational inertia J=0.00825Kg·m2 , pole pairs np= 2.

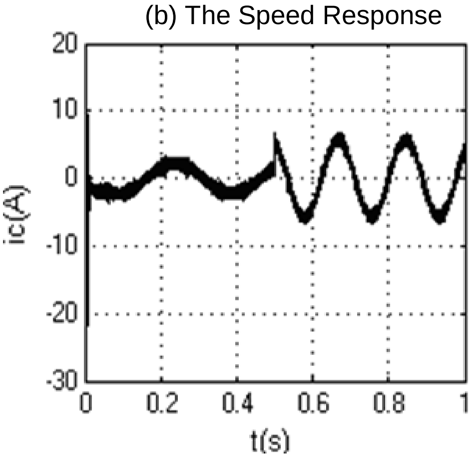
TC performance will be researched from two aspects: the motor speed is constant, the load torque has a sudden change; the load torque is a constant, the given speed has a sudden change. The IM speed is set to 100r/min, the load torque input stars to stabilize at 0 N•m, increases to 12 N•m at 0.5 second. Figure 4 shows the stator flux linkage and system waveform. Figure 4 shows that the IM system has good performance at low speeds: The trajectory of the stator flux is circular; the actual IM speed can return to its original speed quickly after the load torque changes, the response curve of the stator current is stable.





(a) The Flux Trajectory (b) The Speed Response

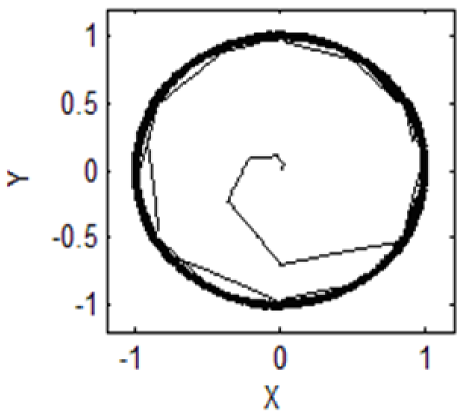


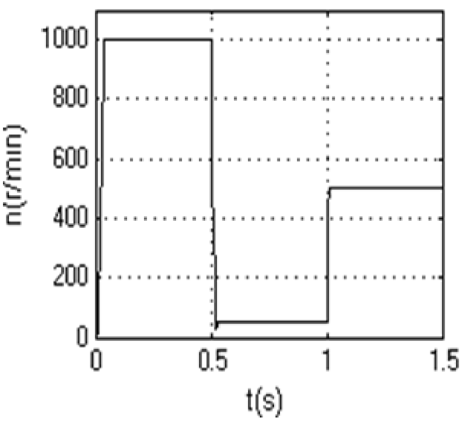


(c) The Torque Curve (d) The Stator Current Curve

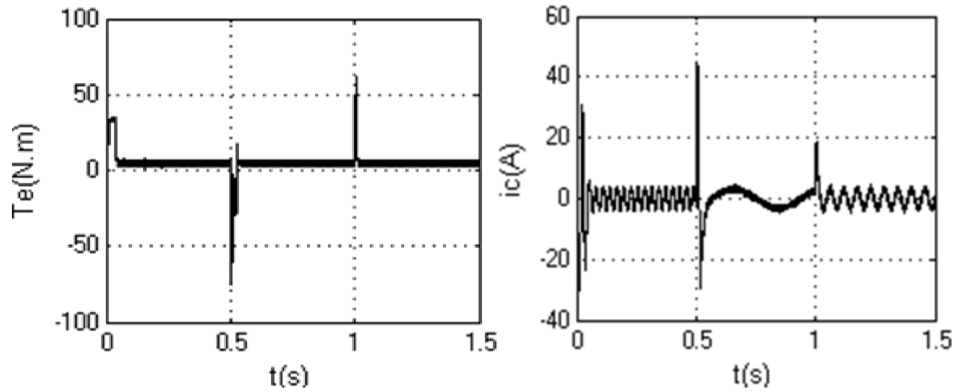
Figure 4 Simulation Results of ADRC Strategy

The load torque is 5 N•m, the IM speed starts to stabilizes at 1000r/min, drops to 50r/min at 0.5 second, and then drops to 500r/min at 1 second. Figure 5 shows the system response waveform in this case. In the case of given torque, although the IM speed changes, the trajectory of the stator flux is still round, the actual speed can track the given speed quickly, the stator current curve is stable sine curve, system can keep stable and has good robustness.





(a) The Flux Trajectory (b) The Speed Response



(c) The Torque Curve (d) The Stator Current Curve

Figure 5. Simulation Results of ADRC Strategy

5. Simulation Comparison between ADRC and TC Controller

The current loop adopts the PID control method, whereas the speed loop uses the PID control, ADRC strategy and TC strategy. This paper compares the overshooting, response time, and other capabilities of the PID, ADRC and TC methods of IM in a DTC system according to the requirements of the IM speed control. In order to test control effect of controller in different-speeds, TC, ADRC and PID fixed the parameters which have respectively simulating to high-speed(1300r/min), medium-speed(600r/min),low-speed(50r/min). Figure 6, Figure 7 and Figure 8 are the results of PID control, ADRC control and TC control at the different speeds.

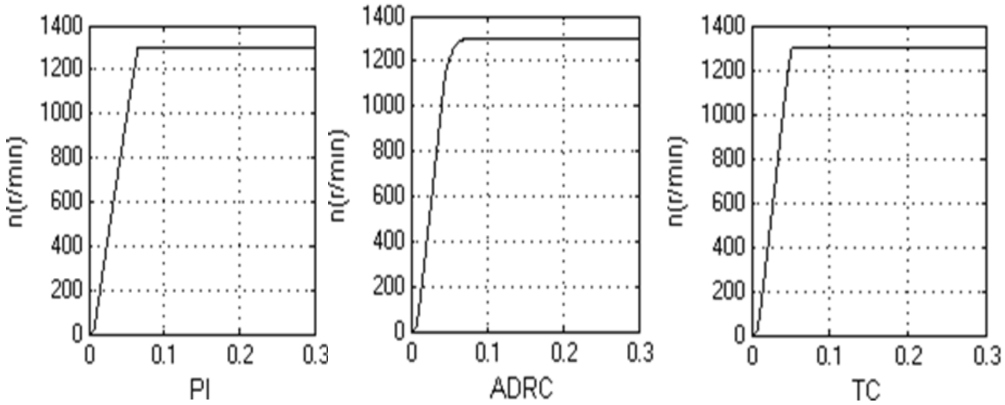


Figure 6.The Comparison of PI, ADRC and TC at 1300r/min

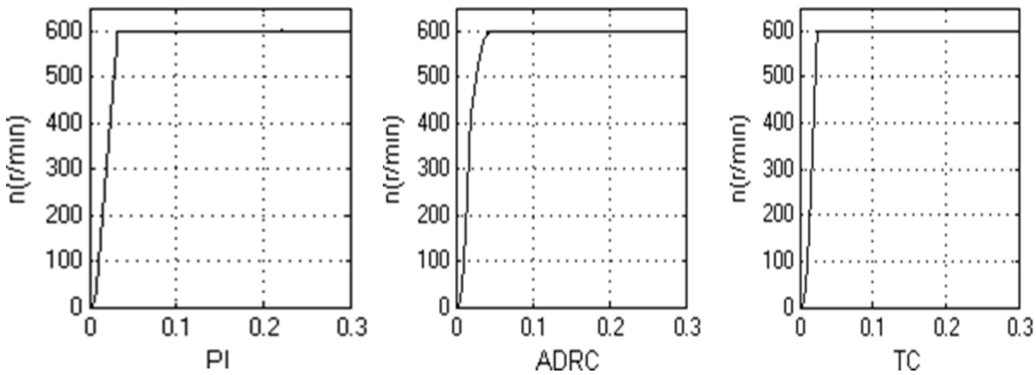


Figure 7.The Comparison of PI, ADRC and TC at 600r/min

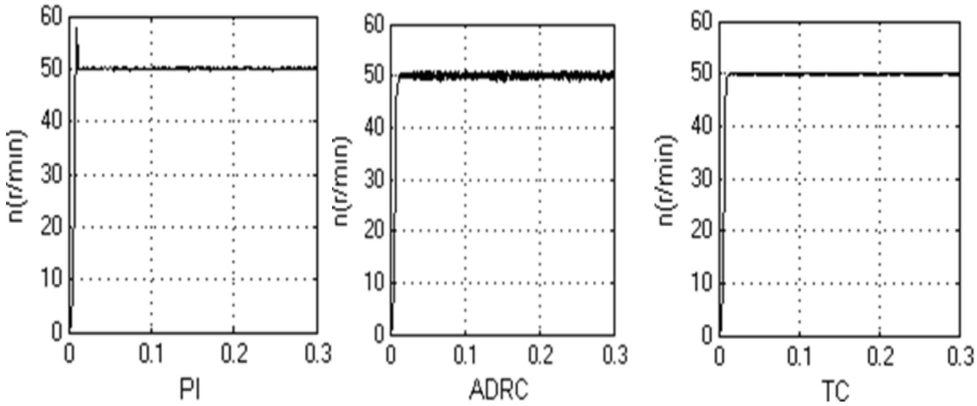
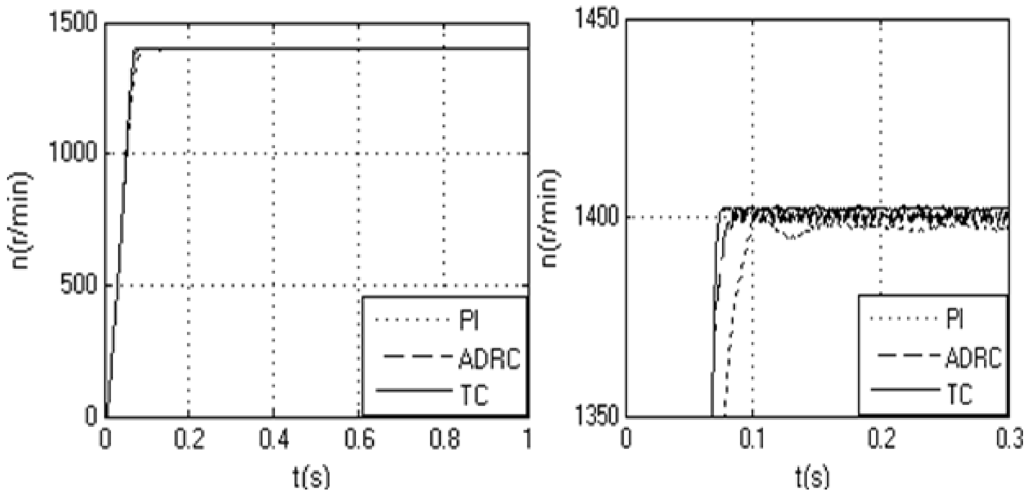


Figure 8.The Comparison of PI, ADRC and TC at 50r/min

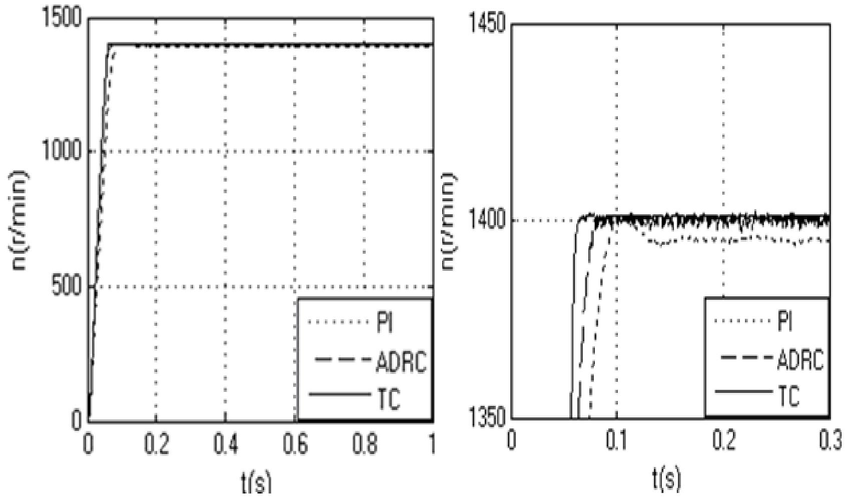
Figure 6,Figure 7 and Figure 8 show that the system response time of PID control is longest ,respectively is 0.066 second,0.033 second,0.0125 second; the system response time of TC strategy is shortest, respectively is 0.052 second, 0.024 second, 0.01 second. The system of three strategies has no overshoot at high-speed and intermediate speed. The system of PID control has overshoot and the system has no overshoot of ADRC strategy and TC strategy. Both from the dynamic performance and the steady-state performance, TC is superior to other two kinds of control strategies.

In actual operation, the induction motor working for long time can cause resistance increasing. It is significant to study the effect of resistance changes on system performance. Figure 9 and Figure 10 show the system speed response curve when the stator resistance and rotor resistance increased 10 times.



(a) The Actual Curves (b) The Partial Enlargement Curves

Figure 9 The System Response Curve on Stator Resistance Increasing



(a) The Actual Curves (b) The Partial Enlargement Curves

Figure 10 The System Response Curve on Rotor Resistance Increasing

From Figure 9 and Figure 10, when the stator resistance and rotor resistance is increasing, the induction motor system of PI control has a smaller oscillation amplitude, The system performance of ADRC and TC is similar, the response curves are rising smoothing and the system has no overshoot. But the system response time of TC control is shortest. The system of TC can observe and compensate disturbance caused by IM parameters change. The system has strong anti-disturbance and robustness.

6. Conclusions

IM is difficult to drive because that it is a nonlinear, complex, high-order, uncertain control object. ADRC is an excellent controller in industrial control. But the setting parameters of ADRC control system are more and complex. In this study, we use TC to achieve a closed-loop control of IM. A linearization method is also adopted to simplify the computational complexity. The simulation results show that the traditional PI control only adapts to the specific control mode. When control mode changes, PI control does not observe and compensate the system parameters change and the system stability and control accuracy become worse. The system performance of ADRC strategy is good, rising smoothing, small overshoot. The system can observe and compensate disturbance when the system has outside interference and parameters change, and has strong robustness. But the control step is complicated and the system has many parameters to be adjusted. The system of ADRC is helpless for a large complex system. However, TC strategy can obtain similar control effect to ADRC strategy, has a higher accuracy than ADRC strategy. The setting parameters of TC strategy are few and system structure is simple. TC strategy got the favor of more and more scholars and is facilitate to study the large complex system control.

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