TELKOMNIKA, Vol. 11, No. 6, June 2013, pp. 3433 ~ 3438
e-ISSN: 2087-278X

Permanent Magnetic Synchronous Motor Control System based on ADRC

Song Wang
School of Mechanical, Electrical & Information Engineering, Shandong University, Weihai, Shandong, China, 86-0631-5688338
e-mail: wszbs3@sdu.edu.cn

Abstract

Permanent magnetic synchronous motor (PMSM) is a strong coupling and non-linear system. In the PMSM speed-regulation system, PID controller is the conventional one, it is difficult to decide the parameters of PID. Moreover, the performance of PID controller is not very well in large disturbance. In the paper, the Active Disturbance Rejection Controller (ADRC) is applied to the PMSM speed-regulation system. The result of simulations and experiments show that this algorithm has better anti-load-disturbance performance than PID controller.

Keywords*: PMSM, ADRC, PID*

1. Introduction

The high-field-strength neodymium–iron–boron (NdFeB) magnets have become commercially available with affordable prices, so the permanent magnet synchronous motors (PMSM) is receiving increasing attention due to its high speed, high power density, and high efficiency. It is very suitable for some high-performance requirement applications, e.g. robotics, aerospace, electric ship propulsion systems, wind power generation systems [1-3]. It has been shown that PMSM can provide significant performance improvement in many variable speed applications [4]. Currently, most of the current-speed closed-loop control in PMSM servo system adopt PID controller [5, 6]. PMSM is a complex plant to control, due to its high nonlinearity and strong coupling. When modeling, we supposed that there is no iron saturation, rotor damping winding, eddy current and hysteresis loss. Under these conditions, the mathematic model can't reflect the real running situation of motor. Therefore, the PID controller has poor control effect for the systems.

ADRC [7] is a new nonlinear method applied in the control of PMSM. ADRC can estimate and compensate the internal and external disturbance of system real-time and can reach good control quality combined with nonlinear control strategy. Compared with PID controller, Active Disturbance Rejection Control technology has the following improvement [8]: It arranges appropriate transition process to overcome the contradiction between rapidity and overshoot of PID controller; It rationally extracts differential signals, which is realized approximately by difference, to overcome the defects of differential signal distortion; It changes the linear combination forms of proportion, integration and differentiation to the nonlinear combination; It discusses estimate method of the internal and external disturbance to estimate the internal and external disturbances and produces a compensation for internal and external disturbance on system performance.

In order to improve the dynamic performance and anti-load-disturbance performance of PMSM, we use the ADRC controller instead of classic PID controller. The experiments indicate the algorithm have wide range of speed regulation and strong robustness than the PID controller.

2. The PMSM Control System Model

Supposed that, there is no iron saturation, no rotor damping winding, no eddy current and no hysteresis loss. We use the d-q rotating coordinate, which fixed on rotor axis to analyze

Received January 22, 2013; Revised April 21, 2013; Accepted April 29, 2013

PMSM's steady and dynamic performance, it is more convenient than other coordinates. The mathematic model of PMSM on d-q coordinate system is as follows [9].

$$\frac{d}{dt}\begin{cases} i_d = \frac{1}{L_d}\left(u_d - R_S i_d + \omega_e L_q i_q\right) \\ i_q = \frac{1}{L_q}\left(u_q - R_S i_q - \omega_e L_d i_d - \omega_e \varphi_f\right) \\ \omega = \frac{1.5 n_p{}^2\left(\varphi_f i_q + \left(L_d - L_q\right) i_d i_q\right) - n_p T_L - B\omega_e}{J} \end{cases} \tag{1}$$

From Equation (1), we can know the controlled object is a first order system and meet the following state space Equation (2).

$$X = -AX + BU + W \tag{2}$$

From ADRC, we can know the coupling of d-q coordinate current and speed and other perturbations can be taken as the internal perturbations of the system. We can compensate it by observer, and realize decoupling of the current and speed.

Supposing $\frac{L_q}{L_d} i_q \omega_e = w_1(t)$

$$-\frac{L_d}{L_q} i_d \omega_e - \frac{\varphi_f}{L_q}\omega_e = w_2(t)$$

$$\frac{1.5 n_p{}^2\left(L_d - L_q\right) i_d i_q - n_p T_L - B\omega_e}{J} = w_3(t)$$

Therefore, the Equation (4-18) can describe as:

$$\begin{bmatrix} \dot{i}_d \\ \dot{i}_q \\ \dot{\omega}_e \end{bmatrix} = -\begin{bmatrix} \frac{R_s}{L_d} \\ \frac{R_s}{L_q} \\ 0 \end{bmatrix}\begin{bmatrix} i_d \\ i_q \\ \omega_e \end{bmatrix} + \begin{bmatrix} \frac{1}{L_d} \\ \frac{1}{L_q} \\ \frac{p_n^2 \varphi_f}{J} \end{bmatrix}\begin{bmatrix} u_d \\ u_q \\ i_q \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix} \tag{3}$$

Active disturbance rejection controller consists of three parts: Tracking Differentiator (TD), Extended State Observer (ESO) and Nonlinear State Error Feedback (NLSEF), which are shown in Figure 1. First, TD is used to track the system input quickly and without overshoot and to produce good differential signal. Second, ADRC sees the uncertainties of ADRC model as internal disturbances. ESO does not differentiate internal and external disturbances and considers them as a whole disturbance which is observed by ESO. Third, NLSEF is used to obtain the compensation of disturbances. ADRC technology essentially has stronger robustness, which also compensates the disturbances of internal system parameters and restrains the external disturbances.

ADRC uses TD and ESO to process outputs and reference inputs of the system, and select proper nonlinear combination of errors to get the law of nonlinear state feedback control [10]. The graph below shows the structure of ADRC. N order TD has no overshoot transition process, and gives differential signal of reference inputs z_{11} order ESO estimates of state variable z_{21} and total disturbance z_{22}. According to the outputs of TD and ESO, NLSEF calculates errors of outputs and produces the control signal *u*.

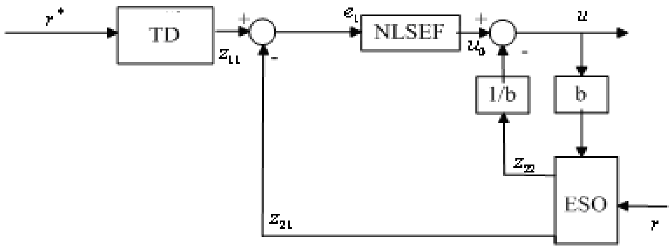

Figure 1. Active Disturbance Rejection Controller

From figure 1, we can know the description of first order TD is:

$$\begin{cases} e_0 = z_{11} - r^* \\ z_{11} = -a\text{fal}(e_0, a_0, \delta_0) \end{cases} \quad (4)$$

The second order ESO is described as:

$$\begin{cases} e_1 = z_{21} - r \\ z_{21} = z_{22} - \beta_1 \text{fal}(e_1, a_1, \delta_1) + bu(t) \\ z_{22} = -\beta_2 \text{fal}(e_1, a_1, \delta_1) \end{cases} \quad (5)$$

The NLSEF is described as:

$$\begin{cases} e_2 = z_{11} - z_{21} \\ u_0 = \beta_3 \text{fal}(e_2, a_2, \delta_2) \\ u = u_0 - \dfrac{z_{22}}{b} \end{cases} \quad (6)$$

Wherein:

$$fal(x, a, \delta) = \begin{cases} x / \delta^{1-a}, |x| \le \delta \\ sign(x)|x|^a, |x| > \delta \end{cases} \quad (7)$$

In the equation, r is the system setting value, z_{11} is the tracking signal of setting value, z_{21} is observed value of controlled system, z_{22} is the perturbation of controlled system, and b is the gain of control input.

For current loop of d coordination: b_1=1/L_d=985.22
For current loop of q coordination: b_2=1/L_q=985.22
For speed loop: $b_3 = (1/J)1.5 n_p^2 \varphi_f = 3391.95$

3. Experiments
3.1. Simulation

The PID regulation system is shown in Figure 2, and the ADRC regulation system is shown in Figure 3. In the simulation system, the setting value is 500r/min. The PMSM has a no-load startup and a nominal load was added at 0.5s. The parameters of PID controller are kp=0.5 and ki=55 in current loop, kp=0.5 and ki=50 in speed loop. The ADRC parameters are selected according part 2. The dynamic performance of PID regulation and ADRC regulation are shown in Figure 4. From the Figure 4, we can know the PID controller has an overshoot of 7r/min and the ADRC has no overshoot, and when the load of 7 N.m was added suddenly, the speed of PMSM decreased 33r/min in the PID regulation system, however the speed decreased 8r/min in the ADRC regulation system. The ADRC controller has a strong capacity of against load disturbance.

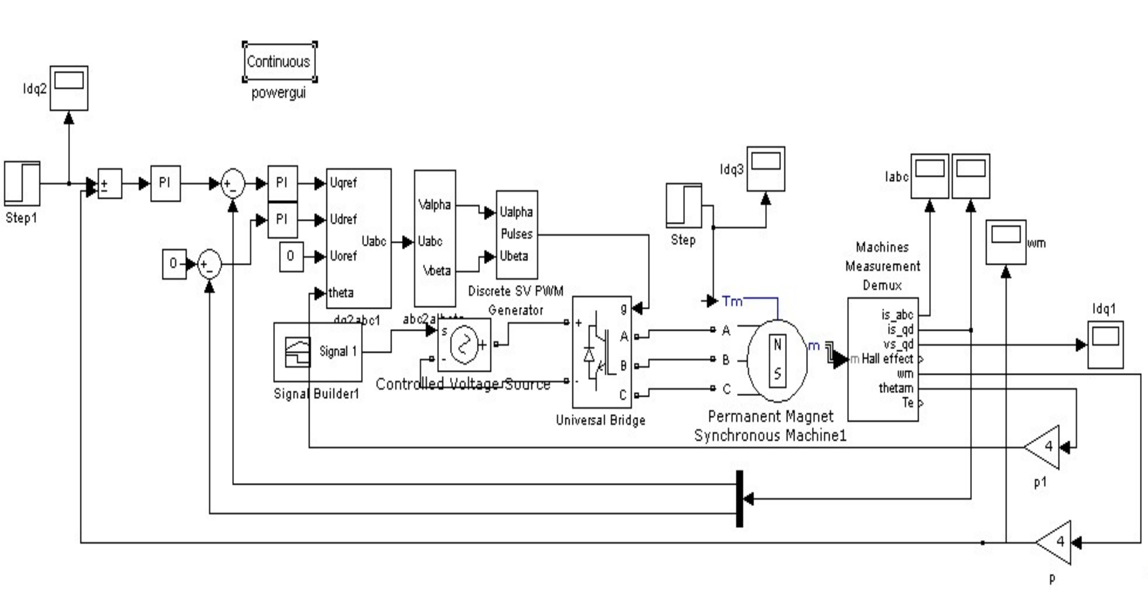

Figure 2. Simulation Diagram of System by PID Controller

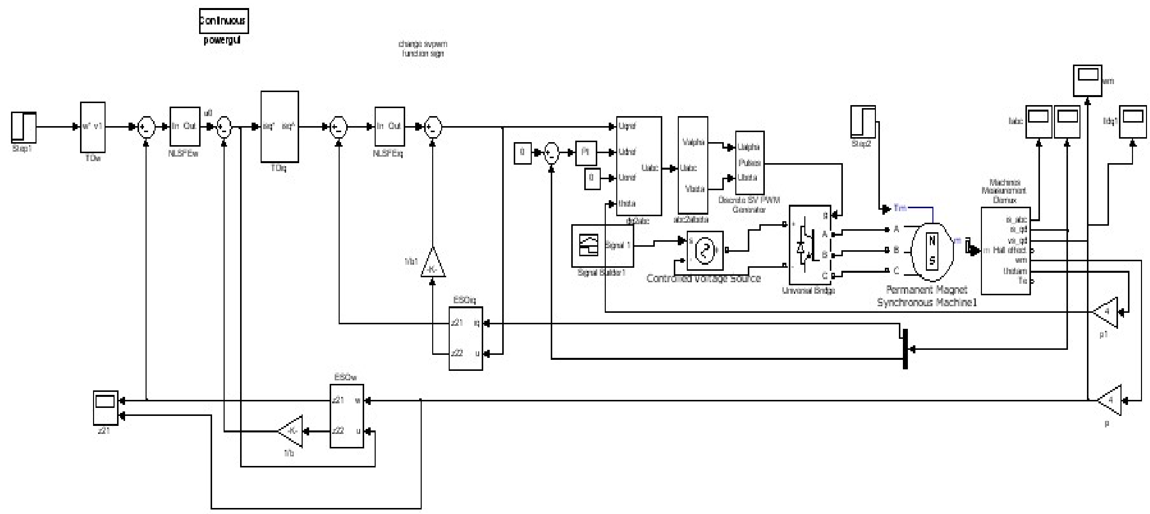

Figure 3. Simulation Diagram of System by ADRC

In the condition of 0r/min and no load, when a load was added at t=0.5s. The performance comparison of PID and ADRC is shown in Figure 5. From the figure, we can know, the ADRC controller has a strong capacity of against load disturbance.

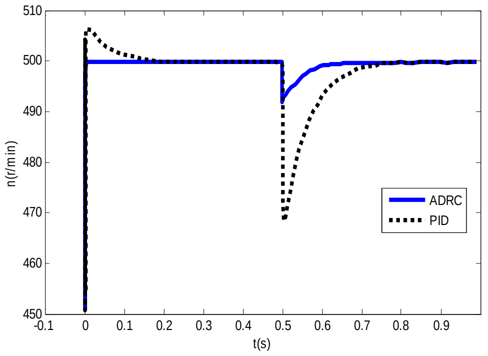

Figure 4. Response Curve of Rotor Speed

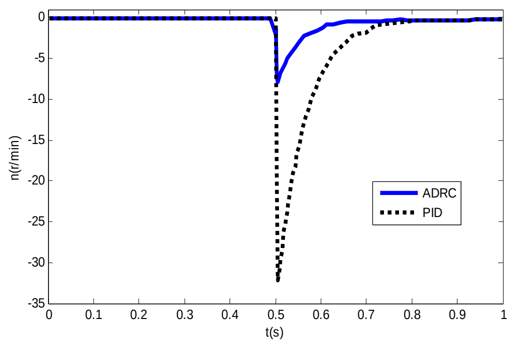

Figure 5. The Response Curve of Rotor Speed (n=0)

3.2. PMSM Experiment

In the experiment, we use ST110-series motor to test the system in our lab. The test platform includes a motor platform, a rectifier device supplying the DC power, an IPM board providing an interface of CPU board and three phases AC power source. Figure 6 is the experiment component, and Figure 7 is the CPU board.

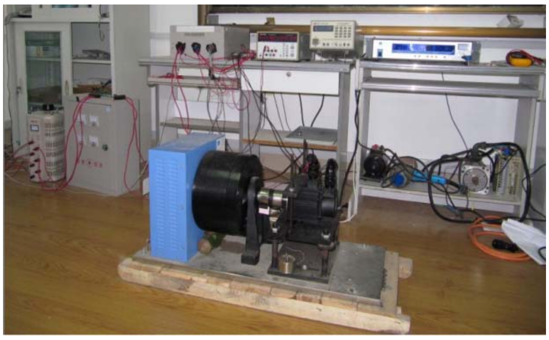

Figure 6. The Experiment System

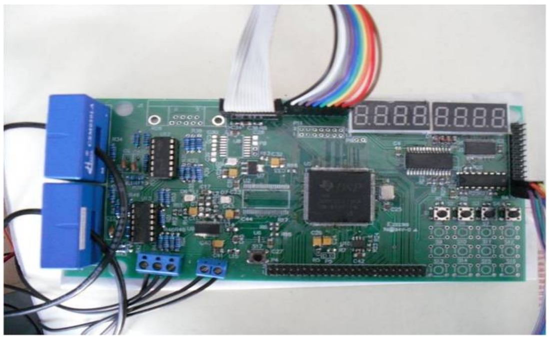

Figure 7. DSP and Current Detection Board

We use the dynamometer to test the control system. The speed set point is 500r/min. A kind of load 0.5N.m was added to the motor when motor is stable. Figure 8 and Figure 9 are the motor test reports. From Figure 8 and Figure 9, we can see the ADRC is valid and the capacity of resisting disturbance of the system is strong.

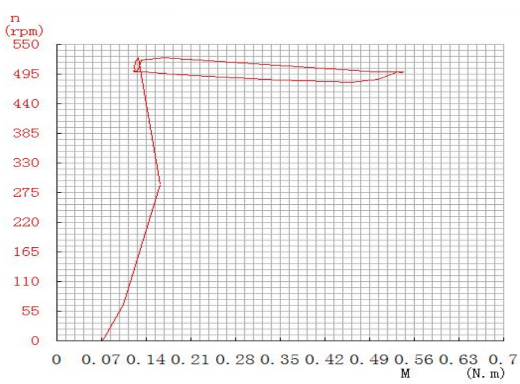

Figure 8. Load Test based on PID

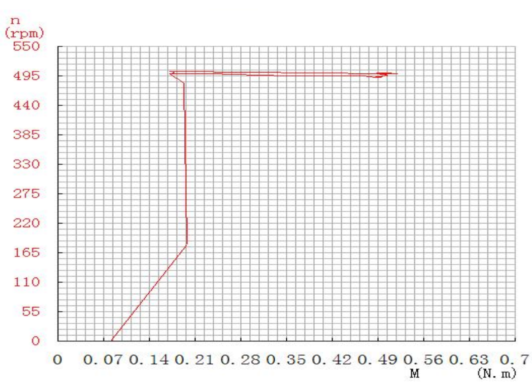

Figure 9. Load Test based on ADRC

4. Conclusion

The ADRC controller is applied to the PMSM speed-regulation system in the paper. The simulation results show that ADRC can improve the performance of the controller, especially the control quality of transition process. In the meantime, anti-load-disturbance ability is enhanced. The ADRC has good application prospects and it can be applied in many control fields.

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