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Servo Motor Decoupling Control Based on PI Fuzzy Adaptive Method

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ABSTRACT

This paper introduced the permanent magnet synchronous motor mathematical model, using the vector control principle combined with decoupling control to effectively cancel out the rotating electromotive force in the motor model. Aiming at the traditional PI controller of varying parameters and nonlinear problems, proposed a fuzzy adaptive PI controller and then applied to speed cycle, PI controller parameters on-line self-regulation is achieved. The consequences of simulation indicated that the method modified the dynamic performance and obtained high robustness servo system simulation.

Keywords: *fuzzy adaptive, PI method, servo motor, decoupling control, simulation*

1. Introduction

The differences between AC permanent magnet synchronous motor (PMSM) with a traditional electrical excitation motor is using permanent magnet replaces the field winding on the rotor to eliminate the need for excitation coil, slip ring and brush, which has many advantages such as simple and compact structure, small size, light weight, high power, easy to heat and easy maintenance. The Vector control of PMSM realized the high-precision, high dynamic performance, a wide range of speed needs, positioning controls, and has become the mainstream of modern AC servo control systems [1].

The conventional PID control is widely used in practical applications because it's simple, good stability, ease of application, but the conventional PID control method could not solve the nonlinear problems of strongly nonlinear system. Fuzzy control method has a strong adaptive ability for complex nonlinear systems and can be effectively controlled. By combining these two control strategies together the controller is able to achieve precise control and obtain strong self-adaptability.

This article combined fuzzy adaptive control methods with PI control methods then applied to PMSM servo system speed circle to build adaptive fuzzy PI controller, using MATLAB to establish the entire simulation system. Theoretical analysis and simulation results showed the fuzzy adaptive PI control method has good robustness and satisfactory control effects.

2. PMSM Vector Control Principle

In 1971, Blaschke of Siemens proposed the AC motor vector control theory which solved the speed control problem of AC motor and made AC motor speed control as easy as DC motor control [2]. For AC motor, the magnetic flux direction of the current magnitude and direction are changed every time, to be able to use a similar control method of the DC motor, assuming the AC motor can capture every moment of the magnetic field direction and establish the coordinate system by variation of magnetic fields. At this coordinate system, the AC torque is very similar to the DC motor. This is the original intention of AC motor vector control.

The basic idea of AC motor vector control is to try to simulate the three-phase DC motor torque control principle on AC motor [3]. In the magnetic field orientation coordinates, the current vector is decomposed into magnetizing current component and torque current component which are perpendicular to each other, mutual decoupling, and then be separately adjusted. Figure 1 is the block diagram of PMSM vector control system.

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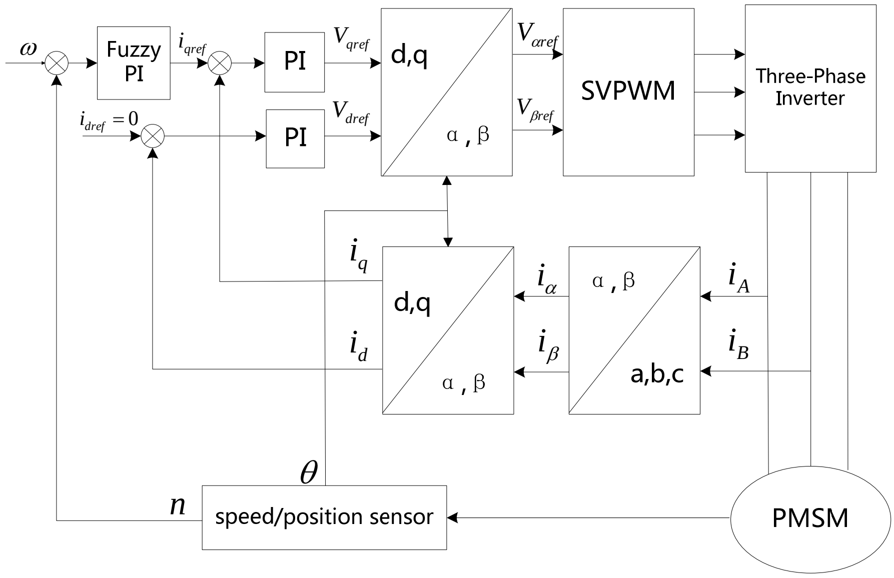

Figure 1. PMSM Vector control system

The vector control method for PMSM including: i_d=0 control method, Maximum torque / current control, Weakening control and the maximum output power control. This article uses i_d=0 control method, when i_d=0, the torque T and i_q has a linear relationship, so by control i_q will be able to achieve the purpose of torque control.

3. The Decoupling Control of PMSM

The task of the motion control system is to control the motor speed and torque angle, for linear motor is to control the velocity and displacement.

$$J\frac{d\omega}{dt}=T_e - T_L - D\omega - K\theta \quad (1)$$

$$\frac{d\theta}{dt}=\omega \quad (2)$$

J is mechanical rotational inertia ω is mechanical angular velocity of the rotor; θ is mechanical angle of the rotor, T_e is electromagnetic torque T_L is load torque; D is Torque damping coefficient; K is torsion elastic torque coefficient.

From the formula (1), (2), to control the speed and angle, the only way is to control electromagnetic torque of the motor, so torque control is the fundamental problem of motion control [4].

In PMSM the control of the torque is actually the control of d , q axis current and it is using d , q axis voltage to realize the control of i_d, i_q .There is a mutual interference rotation electromotive force between the two d , q axis and cannot directly control i_d, i_q without eliminating it. Even though we could not directly measure $\omega L_a i_q, \omega\left(\psi_f + L_a i_d\right)$, but we can measure ω, i_d, i_q and also L_a, ψ_f are constant, so to calculate the rotating electromotive force then to cancel out the coupling terms in the PMSM motor model. Figure 2 is the PI controller with the feed forward decoupling method [5] [6].

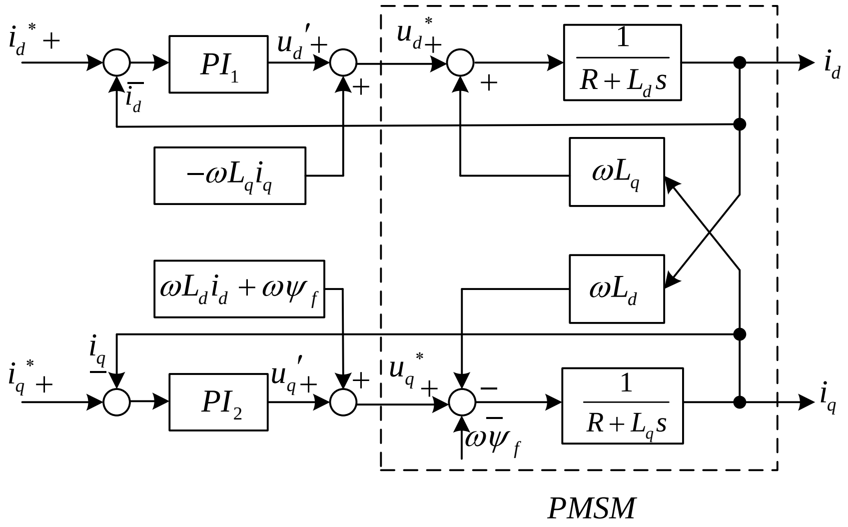

Figure 2. PI controller with the feed forward decoupling method.

$$
\begin{cases} u_d = u_d' - \omega L_a i_q \\ u_q = u_q' + \omega(\psi_f + L_a i_d) \end{cases} \tag{3}
$$

The formula is i_d=0 control method. u_d', u_q' is the impedance voltage. Figure 3 is the block diagram of PMSM decoupling control. As can be seen, the decoupling control enables the control system to be quite accurate.

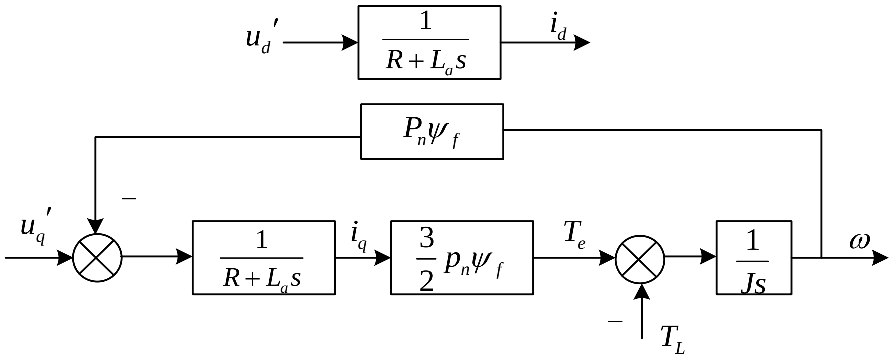

Figure 3. Decoupling control of PMSM

4. Fuzzy Adaptive PI Controller

Using the deviation of control amount e and deviation rate ec as the input variables of two dimensional fuzzy controllers, by means of fuzzy adaptive rules to modify the PI parameters, the controlled object has good dynamic and static performance [7]. Figure 4 is the block diagram of fuzzy adaptive PI controller.

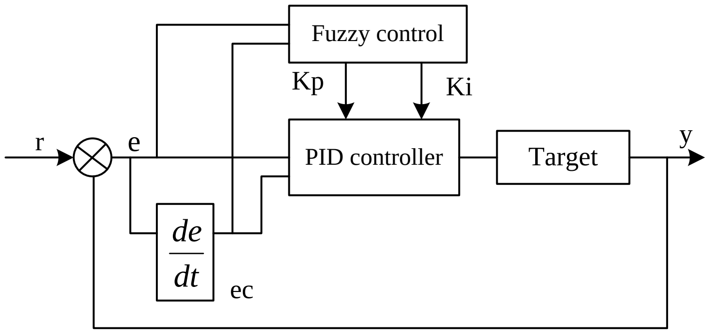

Figure 4. PI controller based on fuzzy adaptive method

The function of proportionality factor k_p is to accelerate the response speed and regulation accuracy of the system, but if it is too large would cause the system to overshoot, or even make system unstable, and if it is too small would reduce the regulation accuracy of the system. Integral coefficient k_i is used to eliminate the steady-state error of the system, but if it is too large can produce the windup phenomenon, thus resulting in a larger overshoot, and if it is too small would cause the phenomenon that is difficult to eliminate static errors [8] [9].

Using the deviation of control amount e and deviation rate ec as the theory field of Fuzzy set, and then define its fuzzy set e , ec={NB, NM, NS, Z, PS, PM, PB}, the elements in the subset in turn represent negative large, negative medium, negative small, zero, positive small, positive medium, positive large. The membership functions of e , ec and k_p, k_i can be triangular or normal distribution curve, and then calculate the value of the membership of each fuzzy subset, according to the membership assignment form and the variation of various parameters, using fuzzy synthesis inference the fuzzy rules of PI parameters, identified amendment values into the following formula [10]:

$$k_p = k_p' + \Delta k_p$$
$$k_i = k_i' + \Delta k_i \qquad (4)$$

Table 1.The Adaptive fuzzy table of ΔK_p , ΔK_i

ec \ e	NB	NM	NS	Z	PS	PM	PB
				ΔK_p			
NB	PB	PB	PM	PM	PS	Z	Z
NM	PB	PM	PM	PS	PS	Z	NS
NS	PM	PM	PM	PS	Z	NS	NS
Z	PM	PM	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NB
PB	Z	Z	NM	NM	NM	NB	NB

ec \ e	NB	NM	NS	Z	PS	PM	PB
				ΔK_i			
NB	NB	NB	NM	NM	NS	Z	Z
NM	NB	NB	NM	NS	NS	Z	Z
NS	NB	NM	NS	NS	Z	PS	PS
Z	NM	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	Z	Z	PS	PM	PM	PB	PB
PB	Z	Z	PM	PM	PB	PB	PB

5. The Simulation Model and Results of PMSM System

In this paper, based on the vector PI control of PMSM speed control system, establish a PMSM adaptive fuzzy PI control system, the system uses the speed loop and current loop to realize the double closed-loop control. The current loop uses a PI controller, while the speed loop uses an adaptive fuzzy PI controller. Control system has the advantages of both fuzzy control [11] and PI control. Based on fuzzy control rules to automatically adjust the PI parameters which realize the fuzzy control has no integral control effect and the PI control has no differential control effect. For verify this method, using module library Sim Power System Toolbox, adaptive fuzzy PI speed control system under MatlabR2008a Simulink environment [12]. Simulation model is shown in Figure 5.

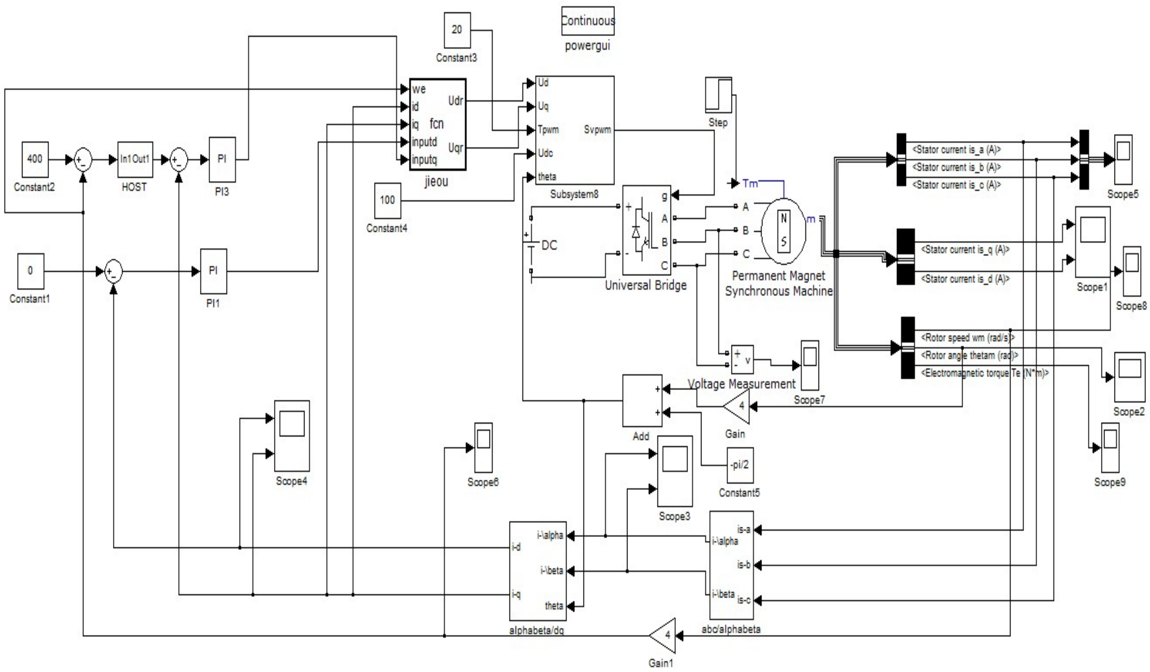

Figure 5. The simulation model of PI speed system based on fuzzy adaptive method

The system parameters: the rated voltage is 310V, stator phase winding resistance is 2.875Ω, quadrature axis and direct axis inductance is 0.0085H, main pole flux is 0.175 Wb, the moment of inertia is 0.0008 Kg • m, friction factor is 0.001N • m • s, the pole pairs number of PMSM model is 4. The simulation results are as follows.

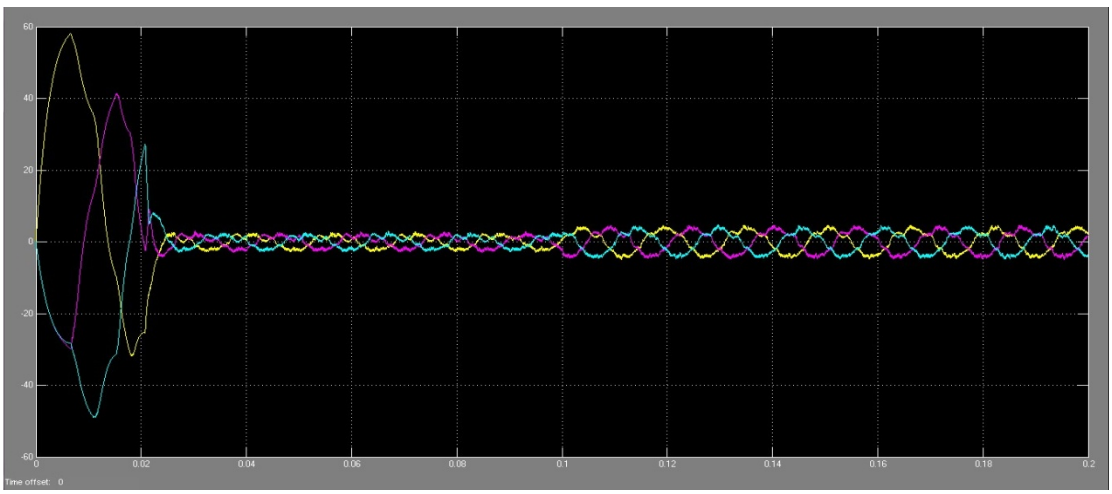

Figure 6. Three stator current curve of PI fuzzy adaptive control method

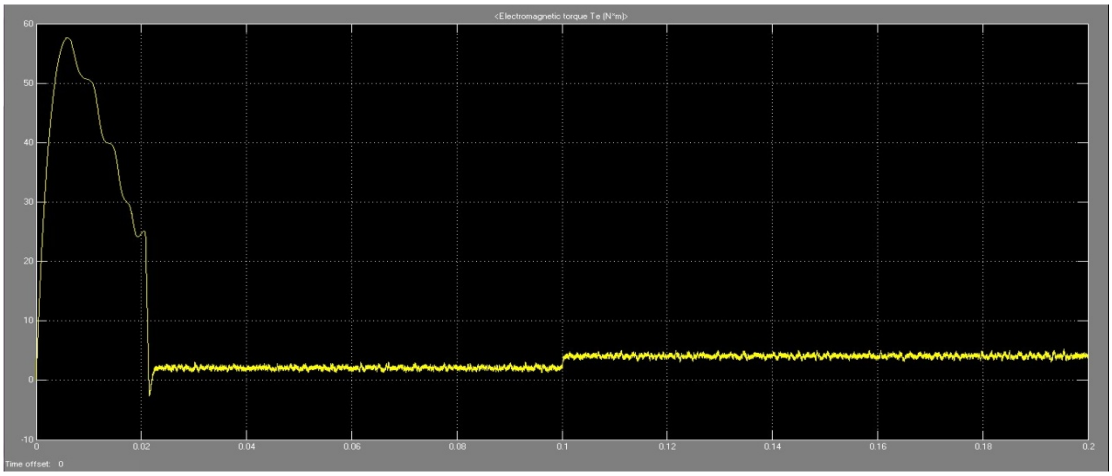

Figure 7. Torque curve of PI fuzzy adaptive control method

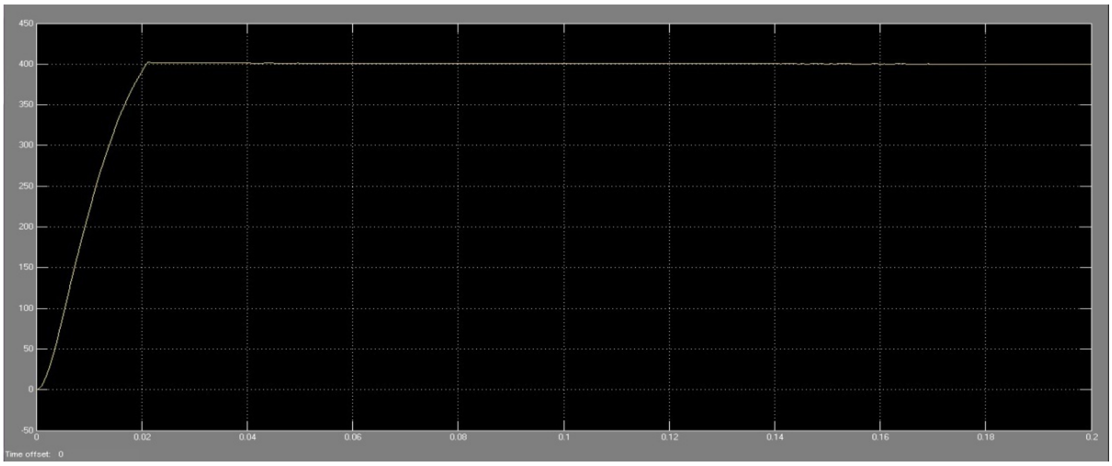

Figure 8. Speed curve of PI fuzzy adaptive control method

The systems simulation time is 0.2s (system time), at 0.1s the torque load added from 2N to 4N. As can be seen from the Figure the fuzzy adaptive PI control system speed curve has no concussion and the overshoot is very small. When the torque of the motor suddenly changes motor speed smoothly without overshoot, this is because, when the load changes, fuzzy controller real-time detected the error and its error change rate between the speed and the given value of motor. And through fuzzy control rules correspondingly inference PI controller parameters which realize the varying parameters of the PI control. So that the motor speed control system has a short rise time, small overshoot and robustness dynamic performance.

6. Conclusion

In this paper, based on the mathematical model of PMSM then combined the vector control, decoupling control with fuzzy adaptive PI algorithm. The entire system simulation is established in MATLAB / SIMULINK environment, simulation results showed the system has good dynamic performance and robustness which indicated by the adaptive fuzzy PI controller has high practical value.

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