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The Research on Control Method of Variable Speed System of Permanent Magnet Synchronous Motor

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Abstract

In order to solve the problem that the traditional PI controller can not meet the high performance speed control requirement of permanent magnet synchronous motor, the fuzzy control theory is applied to the speed loop of speed control system of permanent magnet synchronous motor, and realized the parameters tuning in real time of PI controller. Finally, by means of the simulation experiment, the solution verified the new fuzzy PI control system has good robustness to the system load and disturbance.

Keywords*: permanent magnet synchronous motor, parameters self regulating, fuzzy PI, robustness*

1. Introduction

Sine-wave permanent magnet synchronous motor (PMSM for short)has many features like high power factor, simple structure, high efficiency, small size, high power density, high torque current, the moment of inertia is low, easy for heat dissipation and planning maintenance. In recent years, with the development of microelectronic technology, power electronics, micro-computer technology, sensor technology, rare earth permanent magnet materials and motor control theory, scholars begun to pay attention to research and application of permanent magnet synchronous motor control system [1-2]. Meanwhile, in the PMSM control system, the conventional PI control can not meet the requirements, and it can not achieve good control effect desired.

According to the fuzzy theory, we use fuzzy PI controller as a speed loop controller in the whole system. And based on the simulation experiments to the system, we verified the effective and feasible of this methoed.

2. Vector Control Theory of Permanent Magnet Synchronous Motor

Essentially, vector control aimed at the motor stator current vector phase and amplitude control. This requires establishment of dq axis mathematical model of permanent magnet synchronous motor [3]:

$$T_{em} = p[\psi_f i_q + (L_d - L_q) i_d i_q]$$

As can be seen from the mathematical model, if the excitation flux of permanent magnet and direct-axis inductance, cross-axis inductance is determined, the motor torque can be determined by space vector of stator current is, and the magnitude and phase of is are determined by id and iq, then it can be said the motor torque can be controlled by controlling id and iq. Any speed and torque corresponds to a set of id* and iq*, by controlling these two currents, the actual value id and iq would tracking the instruction value id* and iq*, in this way, we realized the motor torque and speed control.

In this paper, we use id=0 control strategy. Control system is shown in Figure 1 [4].

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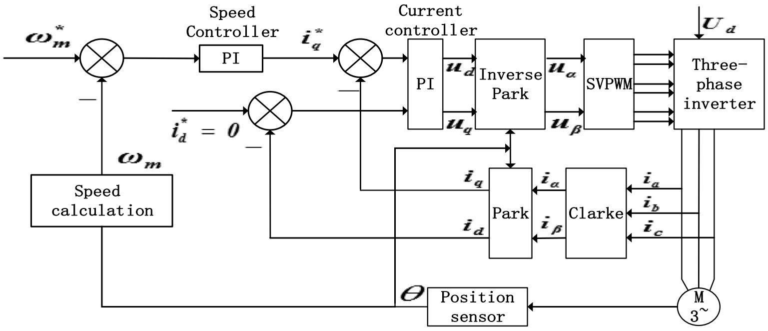

Figure 1. PMSM Vector Control Structure

3. Design of Fuzzy PI Controller

3.1. The Basic Principle of Fuzzy PI Controller

Currently, PI regulator is one of the most widely used controller, if the function of input error is $\mathrm{e}(t)$, output function is $\mathrm{u}(t)$, then the time-domain expression of the relationship between $\mathrm{e}(t)$ and $\mathrm{u}(t)$ can be written as [5]:

$$\mathrm{u}(t) = K_P \mathrm{e}(t) + K_i \int \mathrm{e}(t)dt$$

Where: K_P is proportional coefficient, K_i is integral coefficient, $K_i = 1/\tau$, τ is integration time constant.

However, there are something wrong with the control quality of PI control, in a condition, the PI parameters may be optimal, but it may not be good in another condition. So the traditional PI controller is not able to meet the dynamic requirements of effective control.

Fuzzy PI controller is a combination of conventional PI controller and fuzzy control theory. In this paper, we designed a '2-input(input error is e and error rate is e_c), 2-output(ΔK_P and ΔK_i)' fuzzy PI controller as a speed regulator, the principle is shown in Figure 2 [6-7].

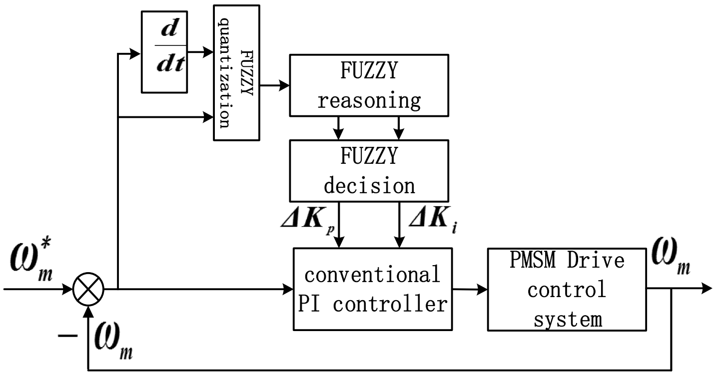

Figure 2. Schematics of Fuzzy PI Controller

Through the real-time detection and calculation of speed of output data, we can obtain the speed error e and change rate of speed error e_c. We fuzzy up e and e_c, and then inputting them into fuzzy controller, by fuzzy inference and defuzzification we can get incremental of PI controller ΔK_P,ΔK_i. Self-tuning controller parameters in real time can be realized through formula (1).

$$\begin{cases} K_p = K_{p0} + \Delta \mathrm{K}_P \\ K_i = K_{i0} + \Delta \mathrm{K}_i \end{cases} \tag{1}$$

Where: K_{p0} and K_{i0} are original set parameters of PI controller, which$K_{p0} = 11.7,\ K_{i0} = 140$.

3.2. The Choice of Universe, Scaling Factor and Quantization Factor

The actual range of inputs (error, error change rate) and outputs (control variable) of fuzzy controller is called basic universe of variable.

We suppose the basic universe of error is $[-x_e \ \ x_e]$, the basic universe of change rate of error is $[-x_{ec} \ \ x_{ec}]$, the basic universe of control volume ΔK_PandΔK_i are $[-y_{up} \ \ y_{up}]$ and $[-y_{ui} \ \ y_{ui}]$ separately. Let the basic universe of fuzzy subset that error take is $[-n,\ n]$, the basic universe of fuzzy subset that change rate of error take is $[-m,\ m]$, the basic universe of fuzzy subset that control volume ΔK_P and ΔK_i take are $[-l_p \ \ l_p]$ and $[-l_i \ \ l_i]$ separately.

For fuzzy processing, input variables need to be multiplied by the corresponding quantization factor, so the input variables from the basic universe are converted to the corresponding fuzzy universe. K represents quantization factor generally, quantization factor of error is K_e, the quantization factor of error change rate is K_{ec}, the calculation formula is shown as (2):

$$\begin{cases} K_e = n/x_e \\ K_{ec} = m/x_{ec} \end{cases} \tag{2}$$

Similarly, control variable derived by fuzzy control algorithm should operate with scale factor, and then, they can be converted to a basic universe that a control object can accept. The scale factor of output control variable ($\Delta K_P$and ΔK_i) are K_{up} and K_{ui}. the calculation formula is shown as (3):

$$\begin{cases} K_{up} = y_{up}/l_p \\ K_{ui} = y_{ui}/l_i \end{cases} \tag{3}$$

Design of fuzzy controller, not only need to have a good fuzzy control rule, but a reasonable choice of quantization factor of fuzzy controller input variable and scale factor of output control quantization is also very important. There are experiment conclusions shows that the control effect of fuzzy controller is influenced greatly by the size of scale factor and quantization factor, and relative relationships of size between different quantization factors.

3.3, Design of Fuzzy Control Rules

Fuzzy control rules are based on long-standing experience and professional knowledge of operator, it is a language representation which reasoning in accordance with people's perception. Fuzzy rules are usually connected by a series of relative words.

The article chooses seven conventional words to describe input and out put variables, namely {positive big, positive median, positive small, zero, negative small, negative median, negative big}, abbreviated as {PB, PM, PS, ZO, NS , NM, NB}. If the vocabulary is too small, it will make the variable description becomes rough, which led to poor performance of the controller. But too much vocabulary will make control rules become so complex that brings rule explosion problem [10].

In the choice of membership functions, in order to simplify the calculation, the article uses triangle as membership functions of input and output variables. Control rules are shown in Table 1, and Table 2.

Table 1. Fuzzy Control Rules of ΔK_P

e				ec			
	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2. Fuzzy Control Rules of ΔK_i

e	ec						
	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NB	NB	NB
NM	NB	NB	NB	NB	NB	NB	NB
NS	NB	NB	NB	NB	NB	NM	NM
ZO	NB	NB	NB	NB	NM	NS	NS
PS	NB	NB	NB	NM	NM	NS	ZO
PM	NB	NB	NM	NM	NS	ZO	ZO
PB	NB	NB	NM	NS	NS	ZO	ZO

4. Simulation Research

In the environment of Matlab / Simulink, the simulation model of permanent magnet synchronous motor vector system is established, shown in Figure 3.

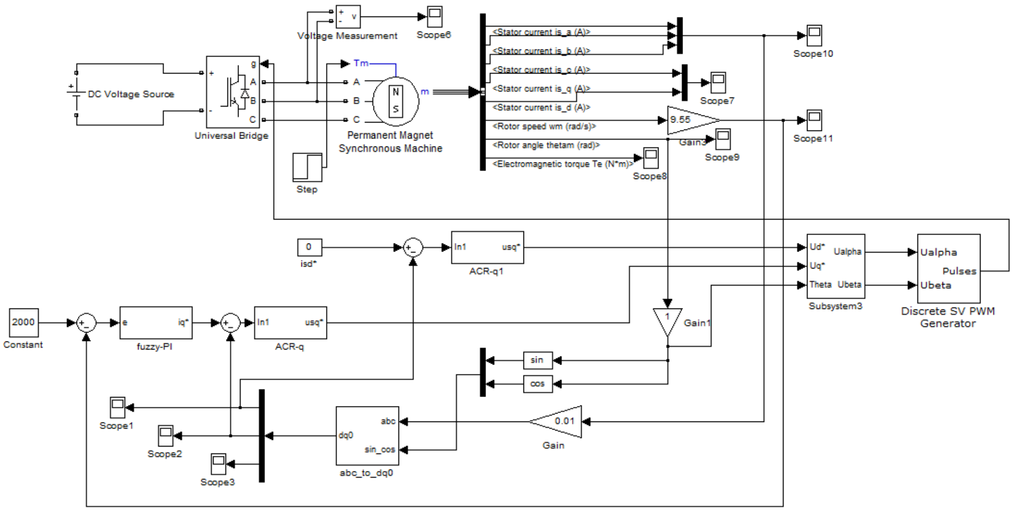

Figure 3. Vector Control Simulation Model of PMSM Based on Fuzzy PI

Motor model parameters shown in Table 3：

Table 3. Parameters of PMSM

Motor parameters	
stator resistance Rs	2.875Ω
stator d-axis inductance Ld	0.0085H
moment of inertia J	0.008Kg·m^2
Excitation flux	0.175Wb
stator q-axis inductance Lq	0.0085H
number of pole pairs p	1

In order to verify the performance of the designed system, the article compared the fuzzy PI control with conventional PI control. Simulation time is set to be 0.2s, the motor no-load startup, the given speed is 2000r/min, when time comes to 0.1s loaded 4 N • m. Simulation waveforms shown in Figure 4-9.

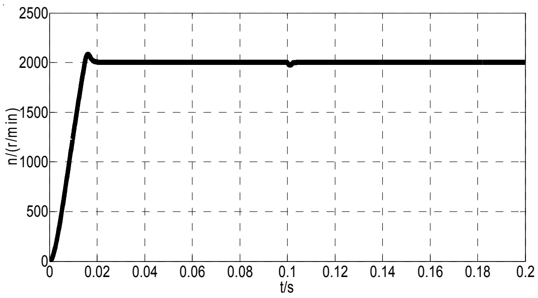

Figure 4. Speed Curve under the Fuzzy PI Control

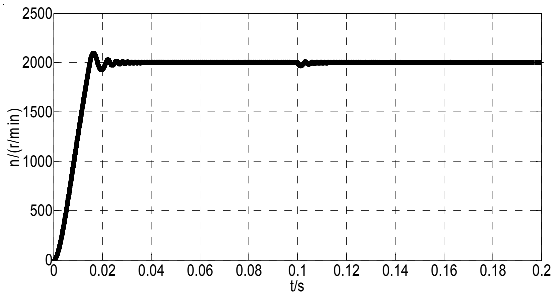

Figure 5. Speed Curve under Conventional PI Control

From the speed test results shown in Figure 4 and Figure 5, we can see that the regulating time of Fuzzy PI controller system is shorter than the traditional PI control system obviously, and in the case of sudden load when the time is 0.02s, the speed of fuzzy PI system almost have no disturbance and can quickly return to equilibrium. It follows that, the fuzzy PI controller that we design is much better than the conventional PI controller in response speed and capacity of disturbance rejection.

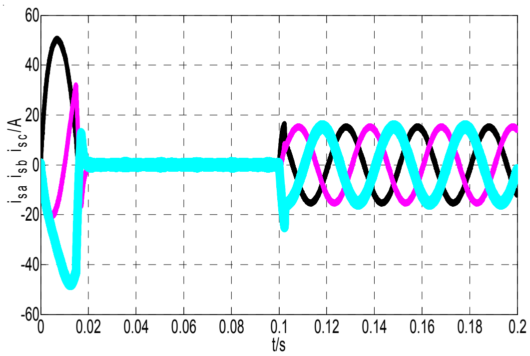

Figure 6. stator 3-phase Current Waveforms under the control of fuzzy PI controller

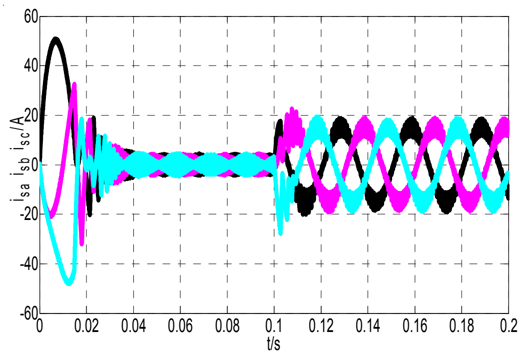

Figure 7. stator 3-phase Current Waveform under the control of conventional PI controller

From the simulation results of three-phase stator current waveform that Figure 6 and Figure 7 shows we can see that under the control of the fuzzy PI controller, the three-phase stator currents is large after starting the motor and sudden loading, but soon achieving stability, and stability effect is better than the traditional PI control system.

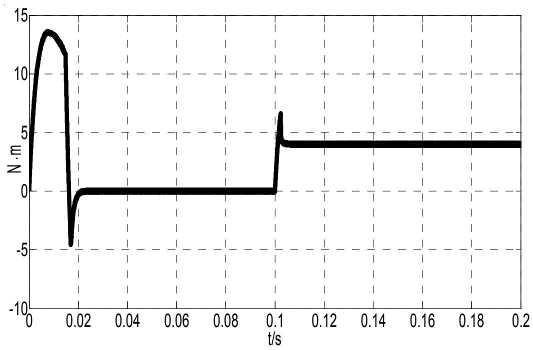

Figure 8. Torque Waveform under the control of fuzzy Pi controller

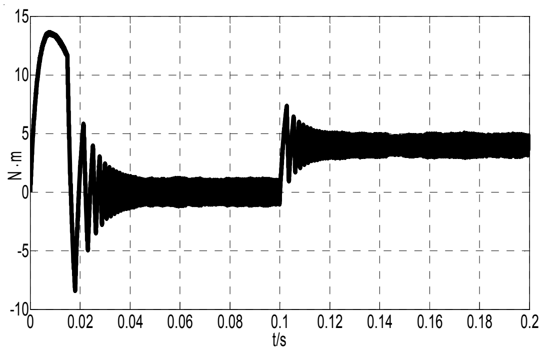

Figure 9. Torque Waveform under the Control of Conventional PI Controller

From the load torque waveform that Figure 8 and Figure 9 shows we can see that both the two systems have fluctuations when starting, but load torque of fuzzy PI control system back to 0 N • m quickly, while the load torque of conventional PI control system fluctuates near 0 N • m, and the pulse amplitude is greater; when 0.1s loaded 4 N • m, the load torque of fuzzy PI control system restored to 4 N • m quickly, the traditional PI control system fluctuates near 4 N • m, and the pulse amplitude is greater.

5. Conclusion

Replace speed loop PI controller in the permanent magnet synchronous motor vector control system with fuzzy PI controller, there are outstanding advantages in making full use of fuzzy control in dealing with imprecise and complex systems with uncertain control objects. In improving the speed control performance of permanent magnet synchronous motor, the fuzzy PI control shows stronger advantages than PI control. Finally, simulation results show that, the control system combined with fuzzy control theory is better than conventional PI control in response speed, anti-interference ability and other static and dynamic performance.

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