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Brushless DC Motor Fuzzy PID Control System and Simulation

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Abstract: For digital model of brushless DC motor, simulation models can be built in MATLAB / Simulink. Simulation parameters are selected parameters according to the actual system. The conventional PID control algorithm produce large overshoot and oscillation, we use fuzzy logic PID algorithm to response quickly and back the system overshoot to steady state, the steady state has a higher precision, faster response speed, and bigger anti-jamming capability. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: BLDCM, Fuzzy PID, Speed control.

1. Introduction

Brushless DC motor is nonlinear in the actual work process, the mathematical model of uncertainty and system parameter variability. Traditional PID control has poor adaptability to the work condition, robustness and performance. Intelligent control method is gaining more and more attention. Among them, the fuzzy control is one of the widely used in intelligent control and the most common method. It does not need to establish a mathematical model of the controlled object, has a good ability to adapt to a stronger interference and non-linear characteristic parameters and has more noise or interference suppression. But the performance of the fuzzy control system itself to eliminate the steady state error is relatively poor, it is difficult to achieve high control accuracy. If the fuzzy control combines with traditional PID control and uses fuzzy PID control parameters in real-time tuning. The system will have both the dynamic track quality and steady precision of PID controllers, and exert the advantages of robustness of fuzzy control, to make the brushless DC motor in the process of the practical work in good dynamic response, fast rising time, small overshoot [1].

2. Brushless DC Motor Fuzzy PID Controller Design

2.1. Brushless DC Motor Control System Modeling

BLDCM belongs mechatronic products, its basic structure consists of the motor body, electronically commutated three-phase circuit and position sensors, in which electronic commutation circuit includes a controller, driver circuit and the inverter section [2, 3].

Three-phase winding voltage balance equation:

$$U = Ri + L\frac{di}{dt} + E, \tag{1}$$

Stator windings produce electromagnetic torque equation:

$$T_e = P_n\left(e_a j_a - e_b j_b - e_c j_c\right), \quad (2)$$

Equations of motion:

$$T_e - T_L - B\omega = J\frac{d\omega}{dt}, \quad (3)$$

Modeling and simulation of brushless DC motor system uses double-loop control scheme, as shown in Fig. 1. According to modular modeling idea, the control system is divided into various functional independent modules, including BLCDM ontology module, the current control module, the speed control module, torque calculation module, voltage inverter module. The function module and the S function are formed by the combination of BLCDM simulation system [4-6].

2.1.1. BLDC Motor Ontology Modules

BLDCM ontology is one of the most important modules. Motor ontology is based on voltage equation (1). The input is the output voltage of the three-phase inverter module. The output is three phase current, the piecewise linear method is adopted to calculate the back EMF. Module structure diagram is shown in Fig. 2.

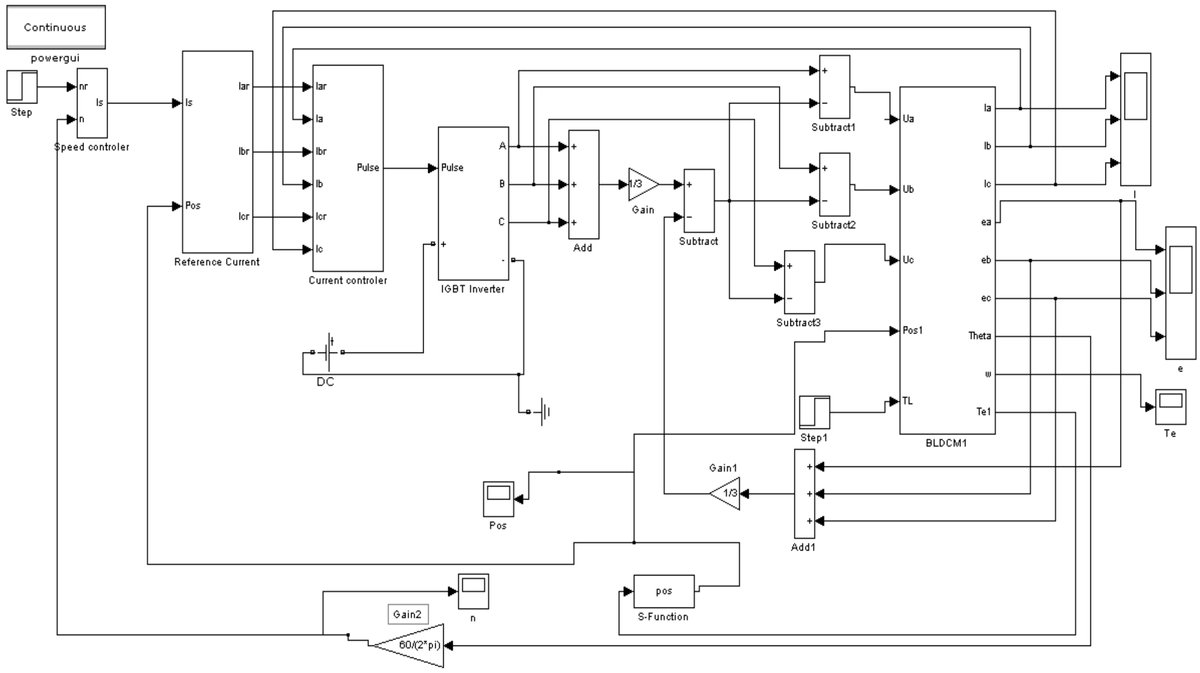

Fig. 1. BLCDM simulation system.

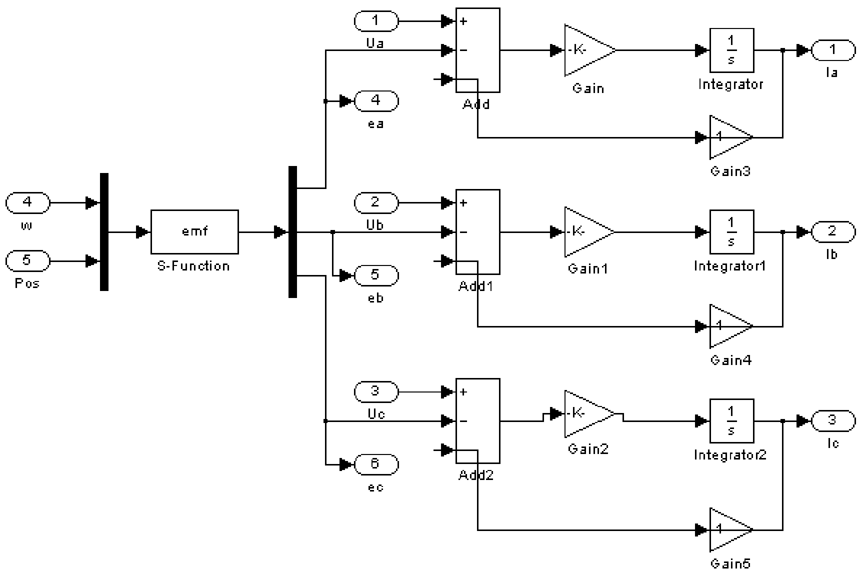

Fig. 2. BLCDM motor ontology modules.

2.1.2. Torque Measurement Module

According to the motor torque equation (3) and knowing the opposite of electromotive force, three phase stator current, rotational speed electromagnetic torque can be calculated. The torque calculation module is shown in Fig. 3.

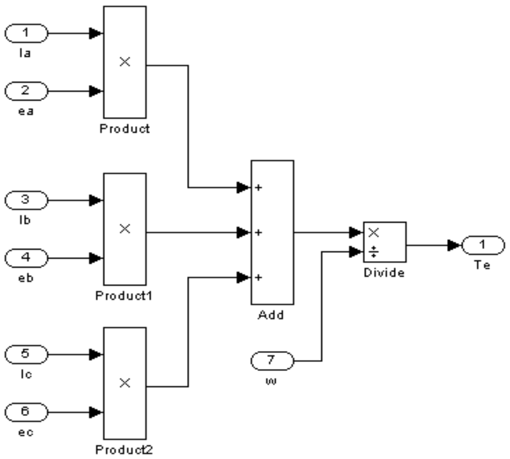

Fig. 3. Torque calculation module.

2.1.3. Voltage Inverter Module

The function of the inverter is that the DC voltage is converted to the adjustable voltage and adjustable frequency AC voltage. The voltage inverter module is shown in Fig. 4. The inverter input is the Pulse control signal which is the output of the current control module. The output is three-phase voltage. Voltage inverter modules are the general inverter bridge structures provided in Simulink.

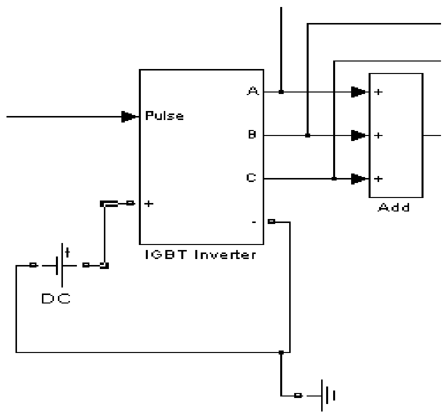

Fig. 4. Voltage inverter module.

2.1.4. Speed Adjustment Module

The function of the speed regulator is carrying on the design of fuzzy PID control algorithm based on the difference of a given speed and actual speed. The seed adjustment module is shown in Fig.5.

The output is used to control the current regulator. Among them, the output of the speed governor is the given value of the current regulator. According to the set of fuzzy rules of the fuzzy controller, the output is the PID parameter correction Δ K_P, Δ k_i, Δ k_d, this set of data and the initial values of PID preset additive operation can be concluded the current control of PID controller parameters K_P, k_i, k_d value, the final output is used to control the current regulator.

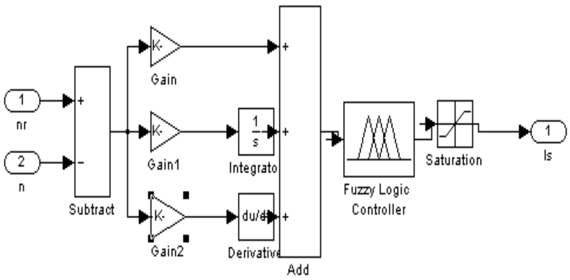

Fig. 5. Seed adjustment module.

2.1.5. Current Control Module

This current control module (Fig. 6) uses the current tracking control module. The Input of the current control module is the three-phase reference current value and feedback of the three-phase current value, the output of the control signals is the control signal of the switch tube. When the actual current is greater than the reference current and the deviation is greater than the given ring width, the corresponding MOSFET is shut off, and make it to the negative. The current will decrease slowly until the difference within the set ring width, and vice versa. So as long as choosing the appropriate hysteresis width, the actual current will constantly tracks the reference current.

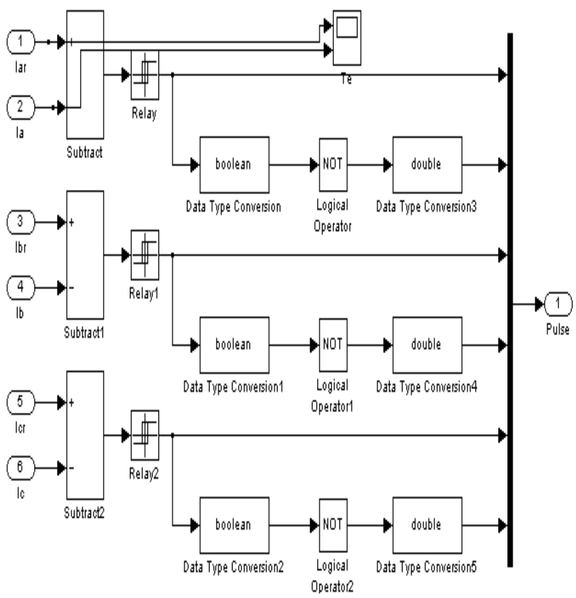

Fig. 6. Current control module.

2.2. The Design of the Fuzzy PI Intelligent Control Scheme

In order to improve the dynamic interference resistance of BLDCM speed regulating system. We further improve on the traditional PID control method. The fuzzy controller and PID controller compound speed regulator [7-10]. Its controller structure is shown in Fig. 7.

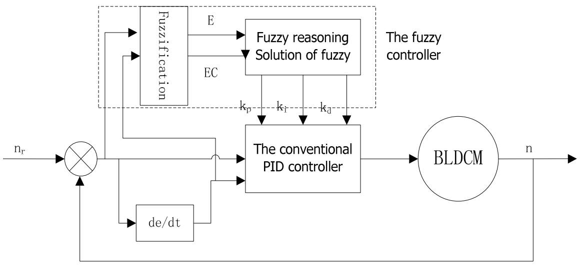

Fig. 7. BLDCM fuzzy PID control system structure.

First, calculate the error "E" and the rate of error change "EC" between the given rotate speed and the actual rotate speed of the motor. Using fuzzy control rules, get "E" and "EC" after inference. Then get "k_p" "k_i" and "k_d" by defuzzification. In the control process, online real-time modify the parameters of conventional PID controller. Finally, adjust brushless DC motor speed by the conventional PID controller.

1) When there is a large deviation |E|, no matter how EC symbol is. K_P and k_i should take larger to quickly reduce the deviation. If $E \times EC > 0$ (E and EC same sign), smaller k_d or make $k_d = 0$; If $E \times EC < 0$, we should take larger k_d, to prevent big deviation to continue.

2) When the deviation | E | is moderate, in order to prevent the system overshoot volume too big, we should take moderate smaller K_P and k_i. If $E \times EC<0$, then take larger k_d; If $E \times EC > 0$, the k_d should take moderate values, to prevent e any further big.

3) When the deviation | E | smaller or $E = 0$, in order to shorten the system adjusting time, preferable medium K_P and smaller k_i. If $E \times EC < 0$, then take smaller k_d; If $E \times EC > 0$, the k_d should be moderate and should not be too large, so as to weaken the system sensitivity to the oscillation, and reduce to adjust system time.

To improve the precision and tracking performance of the fuzzy controller, language variable values should be more. But with the thinner grades, the number of rules and the amount of calculation are greater, the actual debugging is more difficult and the real-time controller is worse. In this paper, all input and output variable fuzzy subsets are set to {NB, NM, NS, Z, PS, PM, PB}, respectively in negative Bige, negative, negative middle, negative small and zero, positive small, positive middle, positive big. The domain of fuzzy sets E and EC is [-3 3], ΔK_P, Δk_i, Δk_d fuzzy set theory domain for [6, 6]. ΔK_P, Δk_i, Δk_d obey the triangle distribution and can draw the curve of the membership function of fuzzy subset, as shown in Fig. 3.

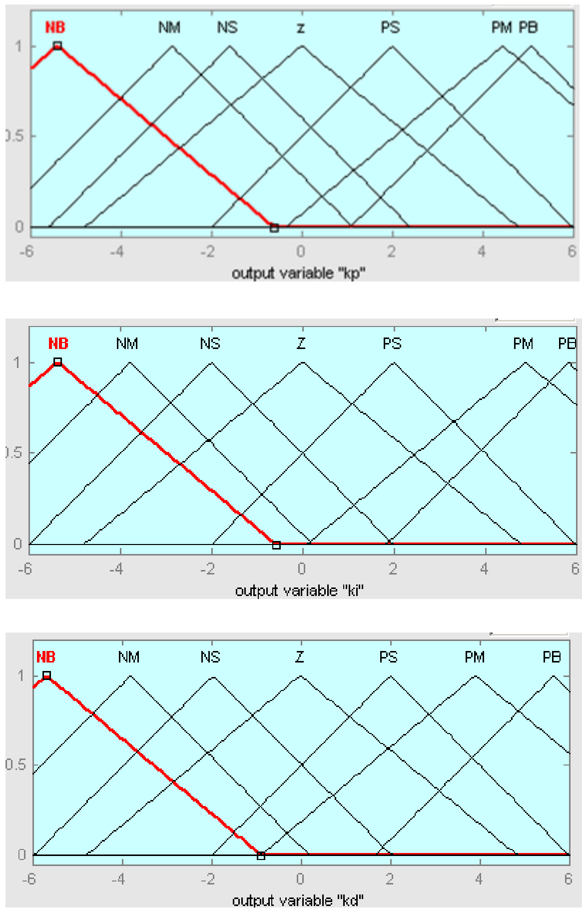

Fig. 8. Membership function of each variable.

Fuzzy controller use speed given value deviation rate and speed of feedback value deviation and EC as input, correction parameters ΔKp, ΔKi, ΔKd as output, the PID controller parameters Kp, Ki, Kd type (4)~(6), as shown in these Kp0, Ki0, Kd0 is the initial parameters of PID controller.

$$Kp = Kp0 + \Delta Kp \,, \tag{4}$$

$$Ki = Ki0 + \Delta Ki \,, \tag{5}$$

$$Kd = Kd0 + \Delta Kd \,, \tag{6}$$

Language value input and output language variables all are {NB, NM, NS, ZO, PS, PM, PB}. The membership function of fuzzy language variables adopts strong sensitivity of trigonometric function. On the basis of the knowledge on the PID control theory and long-term operation experience of ΔKp, ΔKi, ΔKd fuzzy control rules, fuzzy adjusting table that of ΔKp, ΔKi, ΔKd can be got by using fuzzy logic toolbox of MATLAB.

3. The Results of Simulation

A system simulation is tested in Matlab / Simulink software platform, system parameters: rated power of 1.5 kW; rated voltage of 220 V; 16 N m rated torque Rated speed; 1000 r/min; moment of inertia is 0.32 kg m^2; each phase resistance is 1 Ohm; each phase inductance is 0.002 H, and the load in the 0.3 s plus rated. Simulation of control is shown in Fig. 3. Through the above methods, the design parameters of fuzzy PID control in the parameter perturbation and disturbance simulation conduct tests. Simulation experiments with traditional PID control in the same parameters were compared [11-14]. The simulation curve is shown in Fig. 9, Fig. 10.

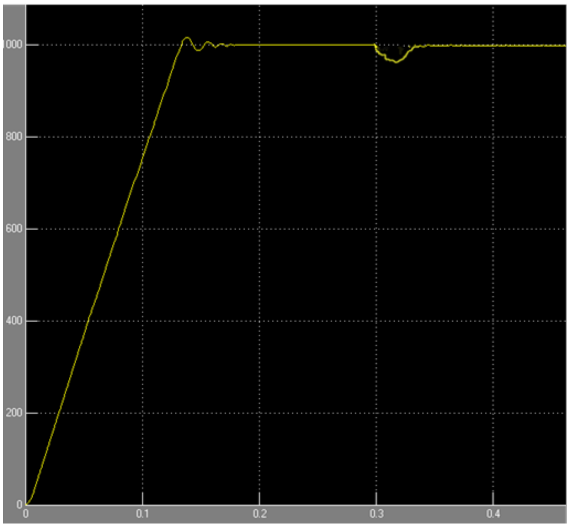

Fig. 9. Regular PID controller simulation curve.

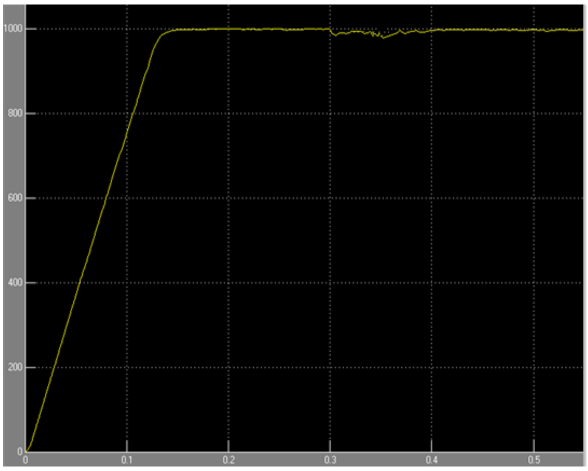

Fig. 10. Fuzzy PID controller speed simulation curve.

4. Experimental Analysis

We can obviously see: using fuzzy adaptive PID control of brushless DC motor is speed with fast response and no overshoot; Response curve fluctuations is smaller when system load sudden changes, and quickly back to the rated speed. Regulation time is short .System has a strong anti-interference ability, a good dynamic characteristic, and greatly get the robustness [15]. And the conventional PID control overshoot amount is larger when starting r, and there are large fluctuations, and load disturbance is bigger also, the speed decline about 5 %.

The simulation results show that the fuzzy PID control scheme which is proposed in this paper can improve the response speed of brushless DC motor speed control system, inhibit the overshoot and improve the control precision, enhance the system robustness and dynamic and static performance. Its control performance is superior to the conventional PID control. Function modules of the model can be easily for the modification and replacement. We can also analysis the motor and its control strategy for the future research with a new method.

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