Design of a Fuzzy P+ID controller for brushless DC motor speed control

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Abstract: The PID type controller has been widely used in industrial application due to its simply control structure, ease of design, and inexpensive cost. However, control performance of the PID type controller suffers greatly from high uncertainty and nonlinearity of the system, large disturbances and so on. This paper presents a hybrid fuzzy logic proportional plus conventional integral derivative controller (fuzzy P+ID). In comparison with a conventional PID controller, only one additional parameter has to be adjusted to tune the fuzzy P+ID controller. In this case, the stability of a system remains unchanged after the PID controller is replaced by the fuzzy P+ID controller without modifying the original controller parameters. Finally, the proposed hybrid fuzzy P+ID controller is applied to BLDC motor drive. Simulation results demonstrated that the control performance of the proposed controller is better than that of the conventional controller.

Keywords: PID controller, Fuzzy controller, Membership function, Brushless DC motor.

1. INTRODUCTION

PID controller is simple structure and is used widely in industry spot use much because of familiar advantage to engineers. But, when system becomes little more complicated or have serious nonlinearity, it is very difficult work that decide proper PID gains, and difficulty that must follow suit is if system same special quality changes while operating [1].

Presented control techniques are gain scheduling, adaptive PID techniques etc. It is solve these problem but these techniques are know following problem. In case change adaptation controller by PID controller structure and when adaptation PID controller that regulate automatically PID gains according to system special quality to on-line and Gain scheduling techniques to regulate PID gains according to system special quality in action point design controller, model degree of system, delay time etc. that suppose is different from actuality plant, good performance expect can [2]. So, recently fuzzy controller is designed [3][4].

It is applied variously difficult complicated system or rain fan shape system and is more tenacious than existent PID controller sometimes and show less sensitive performance in change of parameter that existent control techniques of fuzzy controller is applied.

But, while fuzzy controller also has adaptation special quality and soft control performance tenacious outside than traditional controller, but because worker must do decision of control rule choice and position function and scale coefficient much times are consumed and in case choice of control rule, incongruent, performance of controller causes worse result preferably.

Fuzzy P+ID controller that propose in this paper is structure that alternate P part of existent PID controller by fuzzy logic controller. Therefore, have all advantage of fuzzy controller that solid to disturbance and advantage of PID controller that structure is simple.

Proposed fuzzy P+ID controller has following characteristic. Only, because regulate existing PID controller adding single control parameter, need not to correct hardware part of existing device as that can design easily, and keep structure of PID controller. And fuzzy P+ID controller shows enough stability comparing with existing PID controller [5].

Therefore, proposed fuzzy P+ID controller can reduce much alignment time of controller than existent fuzzy controller because structure is simple and the calculation amount is few.

Finally, applied proposed fuzzy P+ID controller to BLDCM (brushless DC motor) and controller that propose in paper that see through various simulation showed than existent controller that control performance is superior.

Figure 1 displayed block diagram of BLDC electric motor drive system that apply proposed fuzzy P+ID controller.

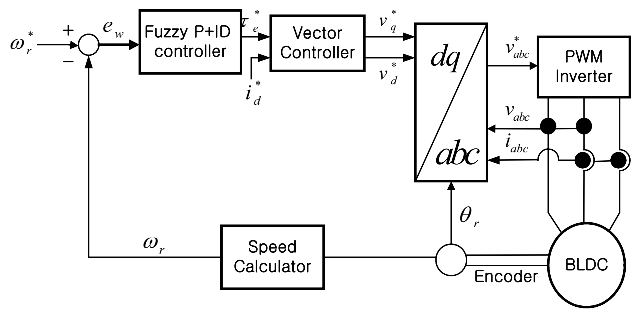

Fig. 1 Block diagram of BLDC motor drives

2. DYNAMIC STATE EQUATION OF BLDCM

Direct current motor that there is no brush that is used widely in use amount (small horsepower) motor control has form such as three phase permanent magnet synchronous motor. If express BLDCM's dynamic state equation in stator standard dq fixing coordinate system, is same with way (1) [6][7].

$$
\begin{aligned}
i_{qs} &= -\frac{r_s}{L_q} - \frac{L_d}{L_q}\omega_r i_{ds} + \frac{1}{L_q}V_{qs} - \frac{\lambda_m}{L_q}\omega_r \\
i_{ds} &= \frac{L_q}{L_d}\omega_r i_{qs} - \frac{r_s}{L_d}i_{ds} + \frac{1}{L_d}i_{ds} + \frac{1}{L_d}V_{ds} \qquad (1) \\
L_q &= L_{ls} + L_{mq}; L_d = L_{ls} + L_{md}
\end{aligned}
$$

Torque equation can express with way (2).

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left[\lambda_m i_{qs} + (L_d - L_q) i_{qs} i_{ds}\right] \tag{2}$$

$$= J\left(\frac{2}{P}\right)\frac{d\omega_r}{dt} + B\frac{2}{P}\omega_r + T_L$$

there ω_r **:** Mechanical angular velocity, J : Rotor inertia

T_L : Load toque, P : Number of pole

3. FUZZY P+ID CONTROLLER

3.1 The structure of fuzzy P+ID controller

PID controller has simple structure such as figure 2. Controller signal can calculate easily by P, I, association of D part.

$$u(t) = K_P e(t) + K_I \int e(t)dt - K_D \dot{y}(t) \tag{3}$$

K_P, K_I, K_D is each ratio, integral calculus, differential gains here. If change way (3) because do discreate, is expressed like way (4).

$$\Delta u(t) = u(k) - u(k-1) = K_P[e(k) - e(k-1)] \tag{4}$$

$$+K_I Te(k) - K_D \frac{y(k) - 2y(k-1) + y(k-2)}{T}$$

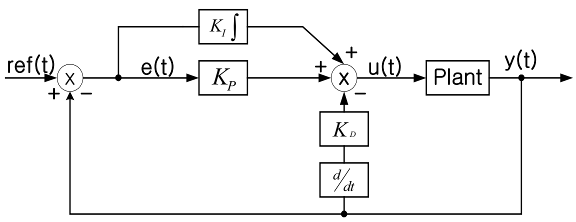

Fig. 2 The structure of PID controller

Reason that make use of much PID controller is because can regulate three controller parameters and design controller easily. And advantage of this controller design permits many applications. Therefore, we must design purge logic controller keeping advantage of PID controller that is such. There is fuzzy P+ID controller that have this purpose and design to figure 3.

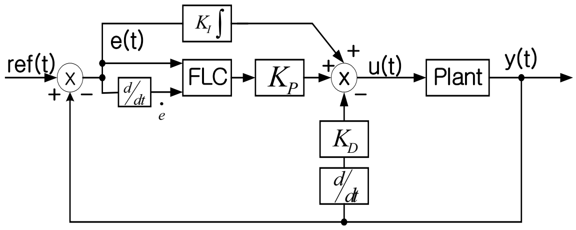

Fig. 3 The structure of Fuzzy P+ID controller

Apply output of fuzzy controller to way (4) and derive way (5) [8].

$$\Delta u(t) = u(k) - u(k-1) = K_P^* \Delta u_f(k) + K_I Te(k)$$

$$-K_D \frac{y(k) - 2y(k-1) + y(k-2)}{T} \tag{5}$$

K_I and K_D that way (5) displays output of fuzzy P+ID controller are same with existing PID controller and K_P^* spent value such as K_P too by comparison gains value of fuzzy controller. fuzzy P controller is most important because is concerned greatly overshoot of system response and improvement of rise time in fuzzy P+ID controller. In the meantime, integral controller removes stationary state error and differential controller is concerned in stability of system. $K_I^* \Delta u_f(k)$ that is P part of fuzzy P+ID controller used instead of $K_P \Delta e(k)$ of existing PID controller as see in figure 3. Improved fuzzy controller has input and $\Delta u_f(k)$ one output of $e(k)$ and two $\dot{e}(k)$. Fuzzy controller output is same with way (6).

$$\Delta u_f = FLC(e(k), \dot{e}(k)) = \Delta u_{f^i}(k) \tag{6}$$

$$(i = 1, 2, 3, 4, \cdots, 36)$$

3.2 Design of Fuzzy P+ID controller

Chose condition variable of fuzzy controller for speed control of BLDC electric motor by error (e) of the motor speed according to position command and change amount (de) about time of speed error, and the speed error change amount saved by speed error change between specimen cycle.

Selected Fuzzy Linguistic Variable by PB (Positive Big), PM (Positive Medium), PS (Positive Small), ZO (Zero), NS (Negative Small), NM (Negative Medium), 7 steps of NB (Negative Big). Also, used the membership function that each quantization value is with figure 4. And rule table that is applied in dissertation that see appeared in table.1

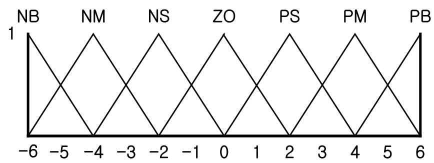

Fig. 4 Membership function

Table. 1 Control rule table

de \ e	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NM	NM	NM	NS	ZO	PS
NS	NB	NM	NS	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PM	PB
PM	NS	ZO	PS	PM	PM	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

Reasoning calculated control signal using expressed center of gravity mood (Center of gravity) MAX-MIN composition, rain purge anger like way (8) [9].

$$\Delta u_f(k) = \frac{\sum f_{i,j} \times u_{i,j}}{\sum f_{i,j}} \tag{8}$$

Must decide PID controller parameter that design fuzzy controller next. In this paper Ziegler and Nichols ' based on method fuzzy P+ID controller design. Can tail differential of system and integral part and increase gains of proportional parts until system response does critical shock and get comparison gains course sampling old publication of the moment that become critical shock, and decide PID controller parameter by way (9).

$$\begin{aligned} K_P &= 0.6K_{P(CRIT)} \\ K_I &= \frac{2.0K_P}{T_{(CRIT)}} \\ K_D &= (T+2)K_P + K_I T^2 \end{aligned} \tag{9}$$

4. SIMULATION RESULTS

Achieved simulation of BLDC electric motor in Matlab/ Simulink to estimate performance of fuzzy P+ID controller. Used model of BLDC electric motor that present in second table for this.

Table. 2 Parameters of brushless DC motor

Moment of Inertia (J)	0.35e-4	$kg \cdot m^2$
Stator Inductance (L)	10.9	mH
Stator Resistance (R)	4	Ω
Number of Pole (P)	4	Nm/A
Factor of Torque (K_T)	0.53	Nm/A

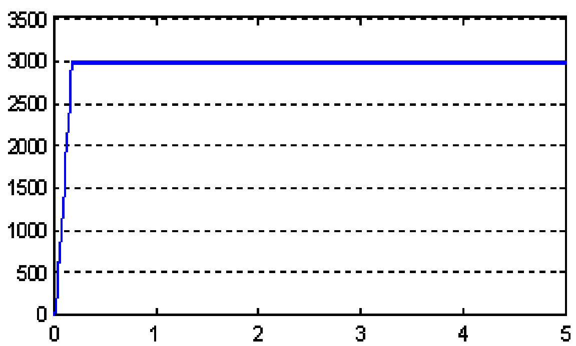

Fig 5. Velocity response 3000 [rpm]

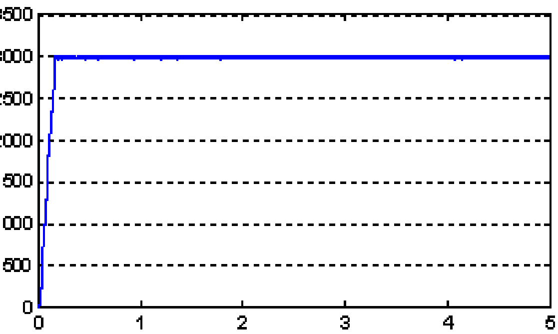

Fig 6. Change parameter of electric motor, velocity response

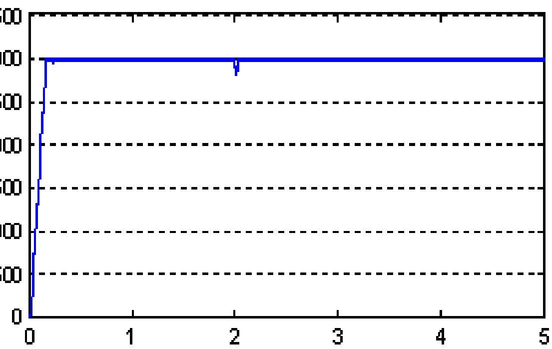

Fig 7. Velocity response at load torque

Figure 5 is velocity response waveform of presented controller. The standard speed being 3000 [rpm], show that follow well the command speed. Figure 6 parameter of electric motor velocity response waveform of when did change (J = 0.00004 $kgm^2 s$, R = 6 Ω) be. Can confirm through picture that presented controller is tenacious in parameter change.

Figure 7 is velocity response waveform of when approved load torque suddenly to 2[sec]. We can know through figure that recover the command speed in early time.

5. CONCLUSION

This paper achieved speed control of BLDC electric motor using fuzzy P+ID controller. Proposed controller can use without correcting hardware of existing PID controller because added only one parameter. Therefore, can use early alignment techniques to use to PID controller equally, and because basis structure is simple.

Presented fuzzy P+ID controller does not need control target's model and is tenacious in change of parameter, and arithmetic is simple advantage. Showed that performance of system that use controller that is presented through simulation is superior, also, showed that it is tough to electric motor parameter and load variation.

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