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Research Paper

Design Self-Tuning Fuzzy PID Control System for BLDC Motor Speed

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Abstract

Brushless DC (BLDC) motors has been widely used for many industrial applications such as automobile, medical and aerospace industry because of high efficiency, high torque, low volume, less electrical noise, longer life and low maintenance. In this Paper we used BLDC motor and designed a self-tuning fuzzy PID controller to control a BLDC motor speed. However, speed control system used in conventional PID controller has simple, stable and highly reliable algorithm but the speed control system of brushless DC motor is a complex nonlinear system, so it is difficult to use conventional PID control. The performance of self-tuning fuzzy PID controller, which tuned on-line the PID controller gains has been compared with the typical PID. A selftuning fuzzy-PID controller is proposed that combines the fuzzy controller with the conventional PID controller and has the advantages of two methods. Simulations and results on Matlab software show the effectiveness of proposed self-tuning fuzzy PID give better control performance than conventional PID controller.

Keywords: Brushless DC (BLDC) motors; Speed motor; Conventional PID controller; Self- tuning fuzzy PID controller.

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Introduction

In recent years the development of high performance motor drive is very important in industrial as well as other purpose applications such as automotive, computer, steel rolling mills, electric trains, robotics, medical and aerospace industry [1]. Electric motors are classified into two different categories: DC (Direct Current) and AC (Alternating Current). Electric motors consist of a stator (stationary field) and a rotor (the rotating field or armature) and operate through the interaction of magnetic flux and electric current to produce rotational speed and torque [2]. Brushless DC motor is a new kind of special motor. It is developed on the traditional DC motor. Thus brushless DC motor plays an important role in both aerospace and machinery manufacture [3]. BLDC motor have many advantages than induction motor such as a better speed-torque characteristic, high dynamic response, long operating life, noiseless operation which can be considered the most dominant electric motor [4]. In early years, Proportional-Integral (PI) controller is widely used in electric drive fields due to its fast and efficient response [5]. PI controller is a linear controller that implements a simple and functional structure which makes it easy to adapt in a real system. For a nonlinear system, using PI controller might not be the best option due to its limitation [6]. PI controller has been at disadvantages from slower response, oscillation and larger overshoot when comparing with the artificial intelligence-based-control methods of fuzzy logic, neural network and FPGA [7]. Since 1965, the University of California cybernetics expert Zadeh proposed fuzzy since its theories and methods of improving, just a few decades, the fuzzy control (Fuzzy Control) is widely used in the natural and social sciences and engineering control field [8]. Fuzzy logic has a natural language skills similar to the human brain, is very suitable for describing complex nonlinear systems. Fuzzy control does not depend on accurate mathematical model of controlled object [9]. FLC controller has advantages over PI controller such as the auto-tuning technology that can manually set by researcher, can be used for a broad range of operating conditions and has a precise control performance [10]. However, despite all the benefits offered, FLC still suffers from longer design time cycle due to the many parameters and number of rules to tune [11,12]. To improve the ability of fuzzy control, this paper presents a model that is based on fuzzy PID control of brushless DC motor speed control system. Parameters used in this paper can be adjusted real time using self-tuning fuzzy PID controller. The simulation results show that the control system is fast response, small overshoot and robustness, and the dynamic characteristics is better than traditional PID control.

The paper is organized as follows: The first section gives the introduction about work. The second section describes the design of PID and fuzzy-PID controller. The third section is about the simulation and result work based on Matlab/Simulink environment. The fourth or final section presents the conclusions of the entire work.

DESIGN OF PID AND FUZZY PID CONTROLLER

PID controller

PID controllers are used in more than 95% of closed–loop operation in industrial process [13]. PID controller transfer function takes one of the two formats:

$$G_{PID}(s) = K_P + K_I / s + K_D s \quad (1)$$

$$G_{PID}(s) = K_P (1 + 1 / T_I s + T_D s) \quad (2)$$

Where K_P, K_I and K_D are the proportional, integral, and derivative gains respectively.

$$T_I = K_P / K_I \qquad T_D = K_D / K_P \quad (3)$$

The function of each part of a PID controller can be described as follows, the proportional part reduces the error responses of the system to disturbances, the integral part eliminates the steadystate error, and finally the derivative part dampens the dynamic response and improves the system stability [14]. The problem in the PID controller is to choose the three parameters to be suitable for the controlled plant. There are many methods to define the parameters of PID controller such as try and error and Ziegler-Nichols methods [15]. The values of the PID are tuned by Ziegler-Nichols methods. PID controller is shown in figure (1).

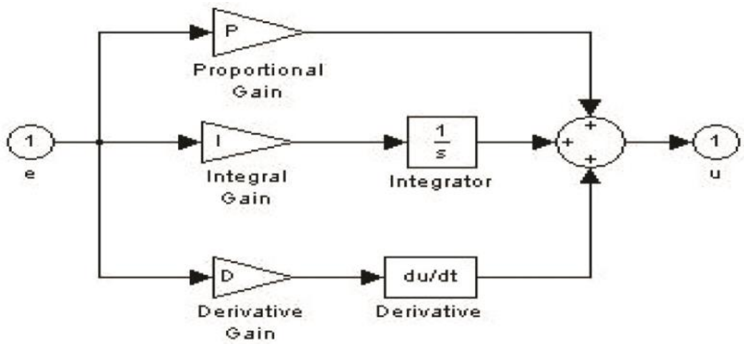

Figure 1: Block diagram of PID controller

Fuzzy controller

Fuzzy logic control (FLC) is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy. Fuzzy sets were described using following linguistic labels Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB). These fuzzy control rules were framed to attain the finest performance of fuzzy logic controller [16]. So that there are at most 49 fuzzy rule. The set of rules were assigned as shown in below tables and the basic structure of fuzzy control system is shown in figure (2).

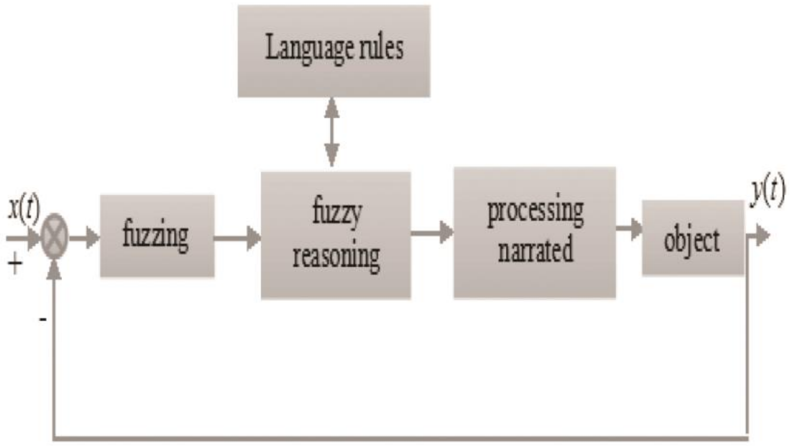

Figure 2: Block diagram of fuzzy controller

TABLE 1: FUZZY RULES FOR KP.

KP		ERROR						
		NB	NM	NS	Z	PS	PM	PB
CANGE OF ERROR	NB	B	S	S	S	S	S	B
	NM	B	B	S	S	S	B	B
	NS	B	B	B	S	B	B	B
	Z	B	B	B	B	B	B	B
	PS	B	B	B	S	B	B	B
	PM	B	B	S	S	S	B	B
	PB	B	S	S	S	S	S	B

TABLE 2: FUZZY RULES FOR KD.

KD		ERROR						
		NB	NM	NS	Z	PS	PM	PB
CANGE OF ERROR	NB	S	B	B	B	B	B	S
	NM	S	B	B	B	B	B	S
	NS	S	S	B	B	B	S	S
	Z	S	S	S	B	S	S	S
	PS	S	S	B	B	B	S	S
	PM	S	B	B	B	B	B	S
	PB	S	B	B	B	B	B	S

TABLE 3: FUZZY RULES FOR KI.

KI		ERROR						
		NB	NM	NS	Z	PS	PM	PB
CANGE OF ERROR	NB	S	M	B	B	B	M	S
	NM	S	M	M	B	M	M	S
	NS	S	S	M	M	M	S	S
	Z	S	S	S	M	S	S	S
	PS	S	S	M	M	M	S	S
	PM	S	M	M	B	M	M	S
	PB	S	M	B	B	B	M	S

Self-tuning fuzzy PID controller

Fuzzy PID controllers are classified into two types: the direct action fuzzy control and the fuzzy supervisory control. Tuning the parameters of a PID controller is very important in PID control. Ziegler and Nichols proposed the well-known method to tune the coefficients of a PID controller and improve the performance by optimization the PID parameters using different optimization techniques but cannot guarantee to be always effective [8]. For this reason, this paper investigates the design of self-tuning for a PID controller. The controller includes two parts: conventional PID controller and fuzzy logic control (FLC) part, which has self-tuning. The proportional, integral and derivate (K_P, K_I and K_D) are the gains of PID controller which, tuned online to force the system to follow the specified reference point [17]. The traditional PID control method has no steady state error and it is easy to implement, so it has been widely used in many fields. But the speed control system of brushless DC motor is a complex nonlinear system, the requirements to the control parameters change along with the system state, so it is difficult to use traditional PID control. The fuzzy controller has an advantage in dynamic performance than the traditional PID controller, but it has the steady state error. The fuzzy-PID control combines the fuzzy control with the traditional PID control, it takes advantages of excellent dynamic performance of fuzzy control and the excellent static performance of traditional PID control, so it can obtain a better control effect [18]. The structure fuzzy self-tuning PID controller of is shown in figure (3) [19].

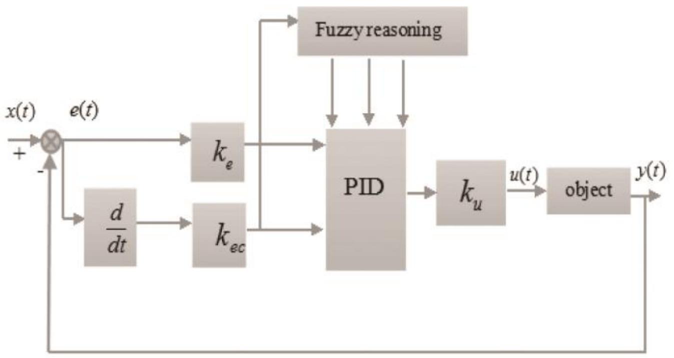

Figure 3: Structure of self-tuning PID fuzzy controller.

SIMULATION AND RESULTS

Brushless DC motor Consists of Three-phase stator windings, permanent magnet rotor, the inverter, the rotor magnetic pole position detector and other groups [20]. The BLDC motor works on speed and current control mode.

The transfer function is one of the most important concepts of control theory, and the transferfunction-based mathematical models are widely used in automatic control fields. The DC motor has been simulated in the MATLAB/ SIMULINK environment [15]. BLDC motor and block diagram of DC motor on Matlab Simulink is shown in figure (4) and (5).

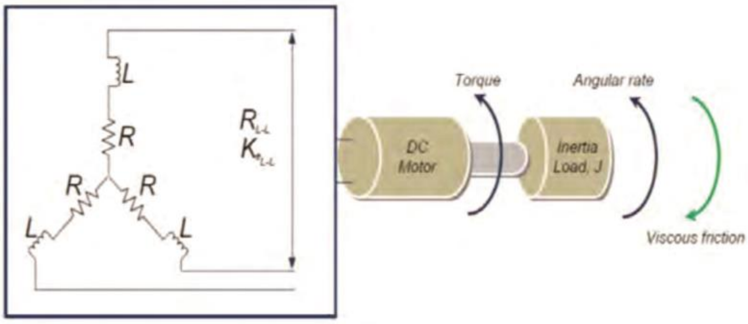

Figure 4: Brushless DC motor.

The transfer function of the BLDC motor is defined as follows:

$$G(s) = 1 / S^3 + 3\,S^2 + 2\,S \qquad (4)$$

For comparison, the speed control system is operated in conventional PID and self-tuning fuzzyPID control separately, the proposed simulation model of speed-loop of self-tuning fuzzy PID control is shown in figure (5).

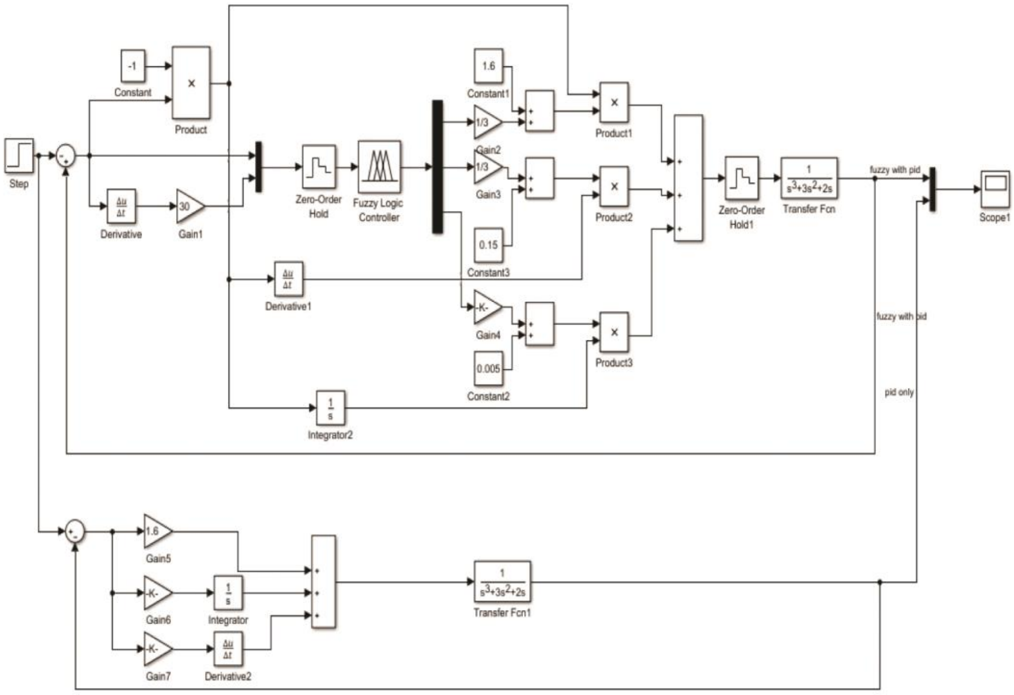

Figure 5: The simulation model of the control system on Matlab software.

Figure (6), (7) and (8) shows the membership functions of KP, KI and KD respectively.

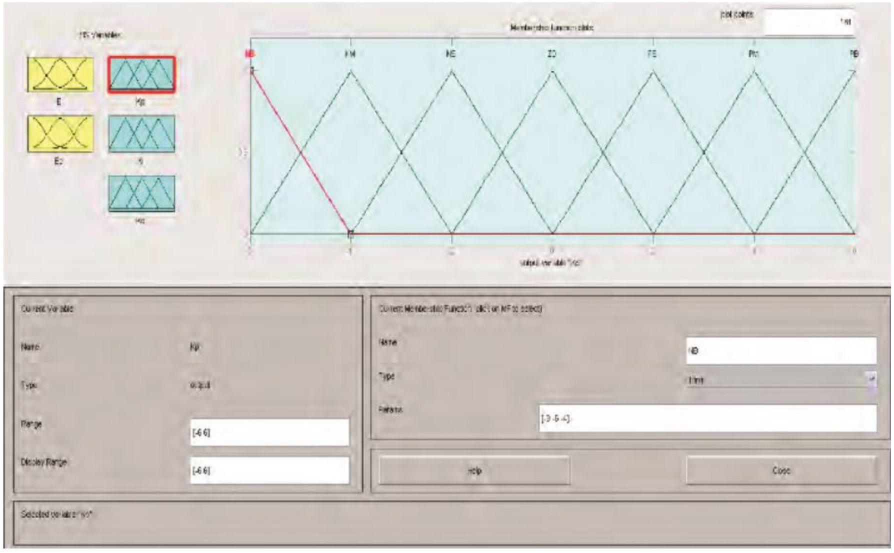

Figure 6: Membership functions of KP output.

Figure 7: Membership functions of KI output.

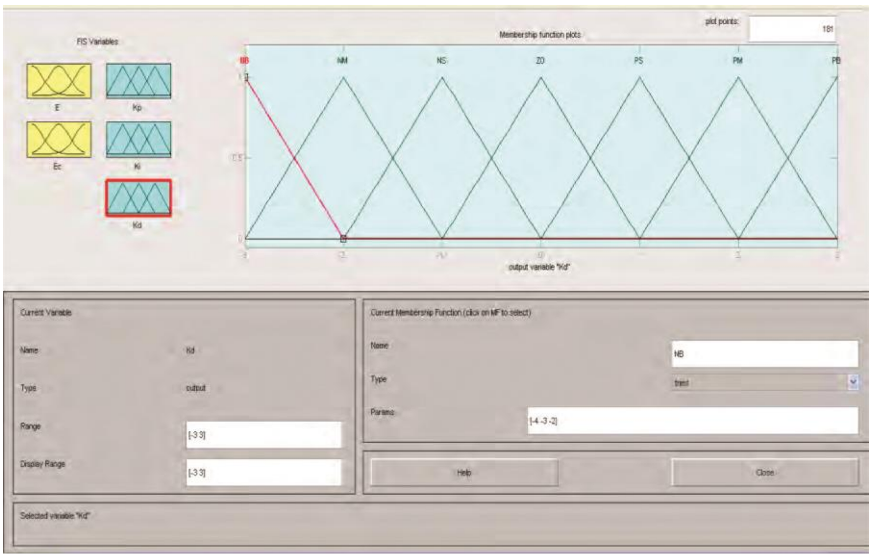

Figure 8: Membership functions of KD output.

After designing the rule, we can get the surface viewer in figure (9), (10) and (11) that represent the rule of FLC.

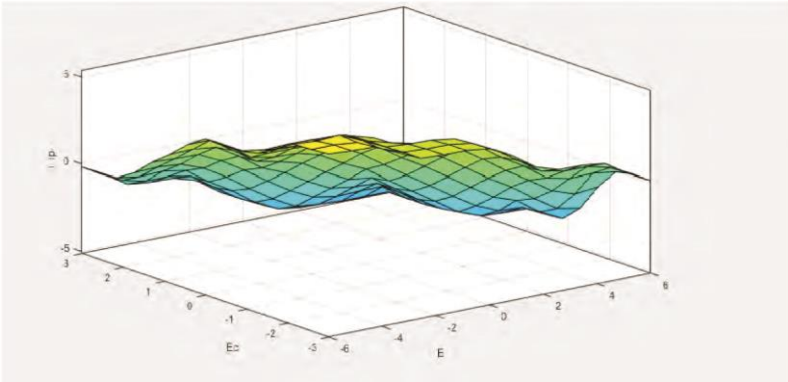

Figure 9: Rule surfaces of KP.

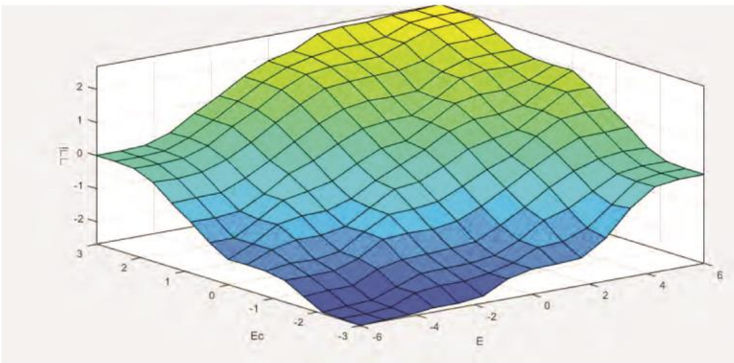

Figure 10: Rule surfaces of KI.

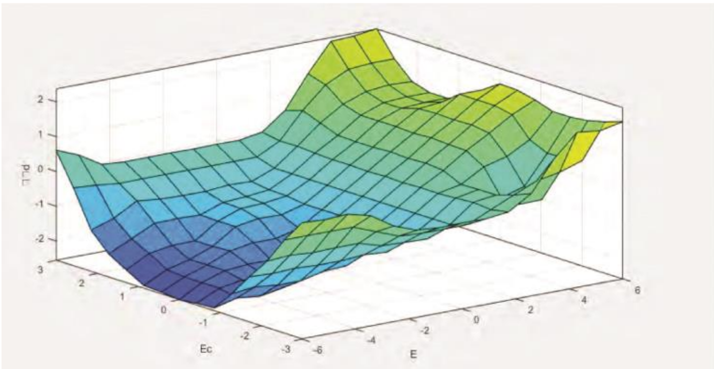

Figure 11: Rule surfaces of KD.

Finally, performance of Fuzzy PID controller and PID controller of BLDC motor is shown in figure (12).

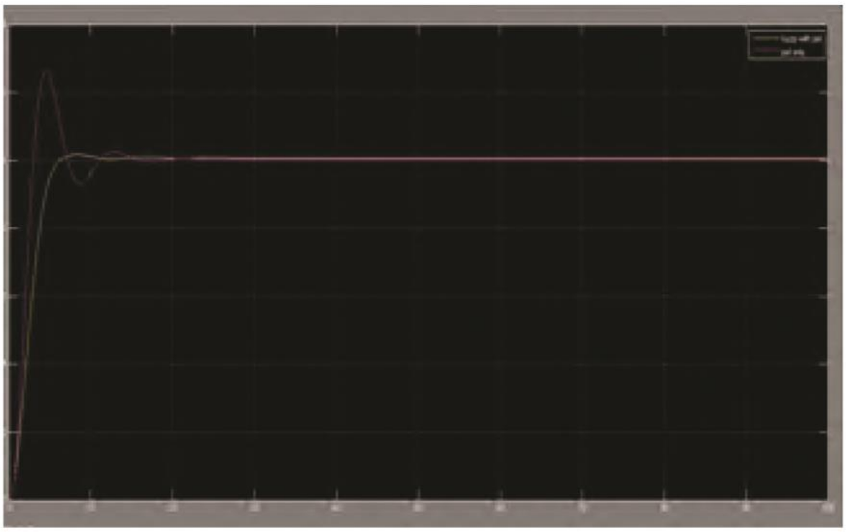

Figure 12: Performance of Fuzzy PID controller and PID controller of BLDC motor.

We compared simple PID and Fuzzy-PID controller. The controller of self-tuning fuzzy PID controller consists of two parts PID controller and fuzzy logic controller, which tuned on-line the PID controller gains. The simulation results in figure 12 show that the controller which combined PID and Fuzzy had a better performance, including a small amount of overshoot and a fast response speed.

Conclusions

This paper designs a simulation model of self-tuning-fuzzy PID control system for BLDCM in MATLAB software. Design of the PID controller has been successfully implemented but it still has an overshoot. So, a fuzzy-PID controller is proposed which combines the fuzzy controller with the conventional PID controller and has the advantages of two methods. The simulation results show that the dynamic and static performance of the proposed fuzzy-PID controller are all excellent, the overshoot is lesser, the system respond to be more quickly and the static precision is high, better stability and the system has strong robustness, the simple PID control method is difficult to get such good performance. At the same time, the controller combines PID and other methods, such as neutral network control will be considered in future work.

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