Modeling and Analysis of Controllers for DC Motor Drives

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Abstract

This paper deals about mathematical modeling and analysis of PID controller, Fuzzy PD controller and Fuzzy PI controller for DC motor drives. Dynamic responses of speed, torque, speed error and the time domain specification of speed response are simulated using simulink toolbox of MATLAB environment for the above controllers. Results are analyzed and comparison has been made among the controllers designed for DC motor drives.

Key Words: DC Motor, Electric Drive Simulation, Fuzzy PI controller, Fuzzy PD controller, Matlab/Simulink, Proportional Integral derivative controller.

1. Introduction

DC motors have long been the primary means of Electrical traction. DC motor has at torque/speed characteristics compatible with most mechanical loads. The speed control methods of a dc motor are simpler and less expensive than those of A.C Motors and speed control over a large range both below and above rated speed can be easily achieved. Modern intelligent motion applications demand accurate speed and position control. Many machine and control schemes have been developed to improve the performance of DC motor drives. Some simulation models based on state space equations, Fourier-transforms model and variable sampling have been proposed for the analysis of DC motor drives [1].

During the past decades, the process control techniques in the industry have made great advances. Numerous control methods i.e, adaptive control, neural control, and fuzzy control have been extensively studied. Among them, the best known is the Proportional-Integral-Derivative (PID) controller, which has been widely used in the industry because of its simple structure and robust performance in a wide range of operating conditions [2]. But PID controller gives oscillatory response during disturbance.

Emerging intelligent techniques have been developed and extensively used to improve or to replace conventional control techniques because these techniques do not require a precise model. One of intelligent techniques, fuzzy logic developed by Zadeh [3] is applied for controller design in many applications [4]. A fuzzy logic controller (FLC) was proved analytically to be equivalent to a nonlinear controller when a nonlinear defuzzification method is used [5]. Also, the results from the comparisons of conventional and fuzzy logic control techniques in the form of the FLC and fuzzy compensator [6] showed that fuzzy logic can reduce the effects of nonlinearity in a DC motor and improve the performance of a controller. Performance evaluation of Fuzzy PI/ Fuzzy PD controller is analyzed in real time [7, 8] and comparative analysis between Fuzzy PI, Fuzzy PID and PID controller is explained for linear, nonlinear and time delay systems [9]. The different defuzzification method along with different fuzzy controllers is demonstrated for time invariant system and it conclude that the centroid defuzzification method is outperformed for non linear system [10]. From the literature survey, the Fuzzy logic control is the optimum control for DC motor drive.

In this paper mathematical model of PID/Fuzzy PD/Fuzzy PI controlled DC motor has been presented. The performance indexes i.e., rise time, settling time, percentage peak overshoot, steady state error and recovery time are evaluated for the above controllers.

This paper is organized as given below. DC motor drive strategy is presented in the proceeding section. In section 3, control development for PID, Fuzzy PI and Fuzzy PD controller is presented. In section 4, simulation results and discussion is explained. In section 5, conclude the remarks of the proposed controller.

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2. DC Motor Drive strategy

The schematic diagram of a DC motor is illustrated in Figure 1. The fundamental equations governing the operation of the armature controlled DC motor are as follows [11, 12],

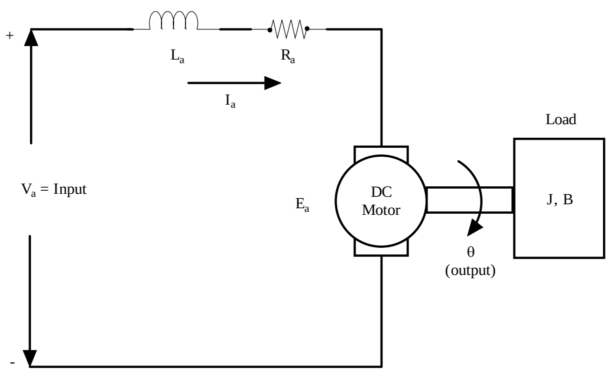

Figure 1. Schematic diagram of a DC motor.

$$i_a R_a + L_a \frac{di_a}{dt} + e_b = V_a \qquad (1)$$

Where i_a is the armature current, R_a is the armature resistance, L_a is the self inductance of the armature, e_b is back emf and V_a is the supply voltage.

Torque of the dc motor is proportional to the product of flux and current. Since flux is constant in this system, the torque is proportional to i_a alone.

$$T = K_t * i_a \qquad (2)$$

Where K_t is torque constant.

The differential equation governing the mechanical system of motor is given by

$$J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} = T \qquad (3)$$

Where J is the moment of inertia of motor and load, θ is angular displacement of shaft and B is the frictional coefficient of motor and load.

The back emf of DC machine is proportional to speed of shaft

$$e_b = K_b * \frac{d\theta}{dt} \qquad (4)$$

Where K_b is back emf constant.

On taking Laplace transform of the system differential equations with zero initial condition we get.

$$\frac{\theta(s)}{V_a(s)} = \frac{K_t}{(R_a + sL_a)(Js^2 + Bs) + (K_b K_t s)} \qquad (5)$$

The block diagram of armature controlled dc motor is shown in figure 2.

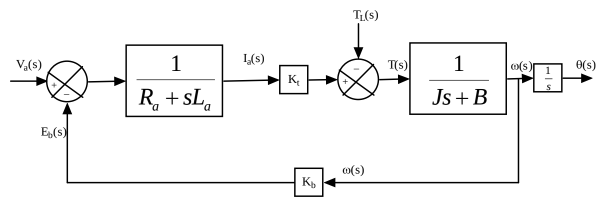

Figure 2.Block diagram of armature controlled DC motor.

3. Control Development

In this section, mathematical model of PID, Fuzzy PD and Fuzzy PI controller is explained,

3.1. PID controller

The block of PID controller of conventional PID control is shown in figure 3. The mathematical model in time domain is as follows [13],

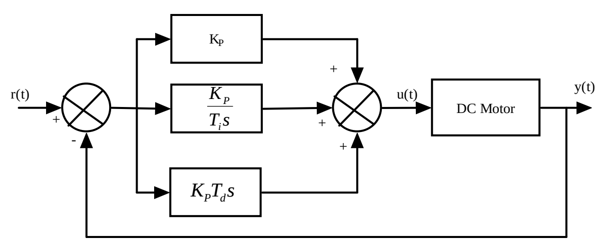

Figure 3.Block diagram of PID controller.

$$u(t) = K_P\left[e(t) + \frac{1}{T_i}\int_0^t e(t) + T_d\frac{de(t)}{dt}\right] \qquad (6)$$

Where e(t) is the error signal, u(t) is the controlled input to the DC motor, K_P is proportional gain, $K_i = K_P/T_i$ denotes integral constant and $K_d = K_P T_d$ denotes differential constant. The increased K_P enhance the response speed of system and improve control precision, but the over much of K_P will results in stability of the system. K_i can remove steady state error of the system. K_d can improve the dynamic performance of system.

3.2. Fuzzy PD controller

Figure 4 shows the block diagram representation of Fuzzy PD controller, which consists of structural parameters of fuzzification module, inference engine, knowledge base, defuzzification module and external parameters as normalization and denormalization factors. A fuzzy PD controller takes two inputs, error and rate and produces one output [14].

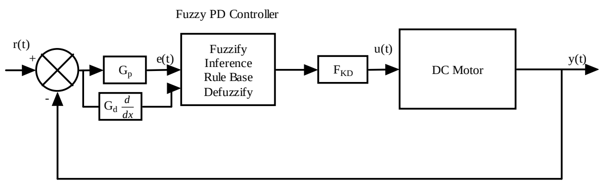

Figure 4.Block diagram of Fuzzy PD controller.

The mathematical model for Fuzzy PD controller in time domain is as follows,

$$u(t) = \frac{1}{M}\left[G_P e(t) + G_d \frac{de(t)}{dt} \right] \tag{7}$$

Where M denotes the universe range, G_P and G_d denote the input normalization factor. Apply fuzzification to input variables and after defuzzification we get equation

$$u(t) = F_{KD} * MD\left\{ F\left\{ \frac{1}{M}\left[G_P e(t) + G_d \frac{de(t)}{dt} \right] \right\} \right\} \tag{8}$$

Where F_{KD} denotes the denormalization, MD denotes the defuzzification of the output and F denotes the Fuzzification of input. Membership function for input and output is shown in figure 5. The rule base for Fuzzy PD controller is shown in figure 6.

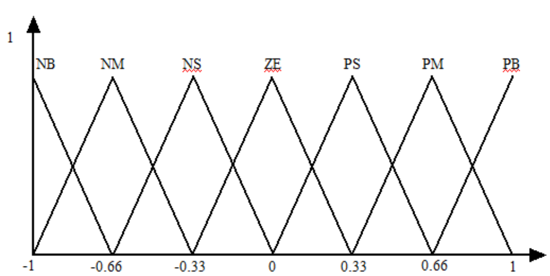

Figure 5. Membership functions for e(t) ce(t) and u(t).

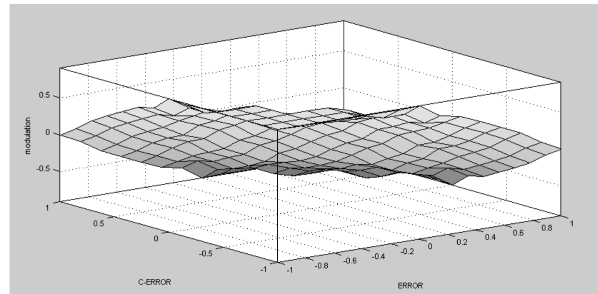

Figure 6. Rule base for Fuzzy PD controller.

3.3. Fuzzy PI controller

The same process applied to fuzzy-based proportional derivative controllers is applied to the fuzzy-based proportional integral controller. Figure 7 shows the block diagram of Fuzzy PI controller.

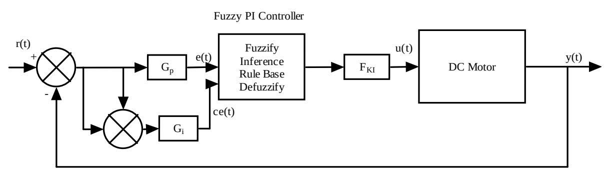

Figure 7.Block diagram of Fuzzy PI controller.

The mathematical model for Fuzzy PI controller in time domain is as follows [15],

$$u(t) = \frac{1}{M}\left[G_P e(t) + G_i \int e(t)dt \right] \tag{9}$$

Where M denotes the universe range, G_P and G_i denote the input normalization factor. Apply fuzzification to input variables and after defuzzification we get equation

$$u(t) = F_{KI} * MD\left\{ F\left\{ \frac{1}{M}\left[G_P e(t) + G_i \int e(t)dt \right] \right\} \right\} \tag{10}$$

Where F_{KI} denotes the denormalization, MD denotes the defuzzification of the output and F denotes the Fuzzification of input. Membership function for input and output is shown in figure 5. The rule base for Fuzzy PI controller is shown in figure 8.

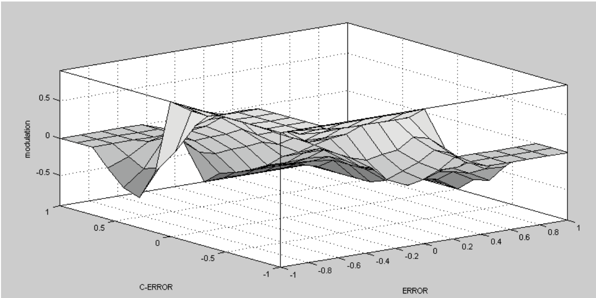

Figure 8. Rule base for Fuzzy PI controller.

4. Simulation Results and Discussion

In order to validate the control strategies as described, digital simulations were carried out on a DC motor drive system using MATLAB/SIMULINK, where the parameters used for the DC motor drive system is given in Table I.

Table I
The Parameter of DC Motor Drive System

Specifications	Value
Armature resistance Ra (ohm)	2
Armature inductance La (H)	0.1
Back emf constant (V/(rad/sec))	0.3
Torque Constant (N-M/A)	0.3
Moment of Inertia (Kg-m_2/rad)	0.1
Friction factor (N-M/(rad/sec))	0.01

Figure 9 shows simulation result of Speed, torque and error response of DC motor Drive based on the rotor position at 100 rad/sec. Performance indexes like rise time, settling time, peak over shoot and steady state error for speed response at no load condition is evaluated and tabulated in Table II.

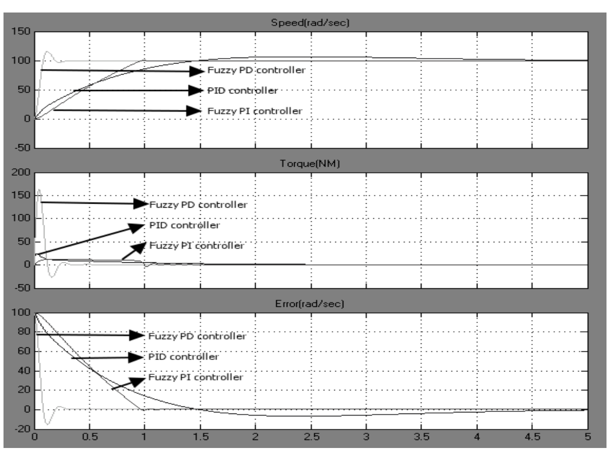

Figure 9. Speed, torque and error response of DC motor Drive based on the rotor position at 100 rad/sec

Table II
The Performance indexes at no load condition

Parameters	PID	Fuzzy PD	Fuzzy PI
Rise time(sec)	1.07	0.1	0.9
Settling time(sec)	4.75	0.4	1
Peak over shoot (%)	6.74	20	2
Steady state error (rad/sec)	0.2	0.35	0.1

Figure 10 shows simulation result of Speed, torque and error response of DC motor drive when load change from no load to full load after 5 sec. Performance indexes like peak over shoot steady state error and recovery time for speed response is evaluated and tabulated in Table III.

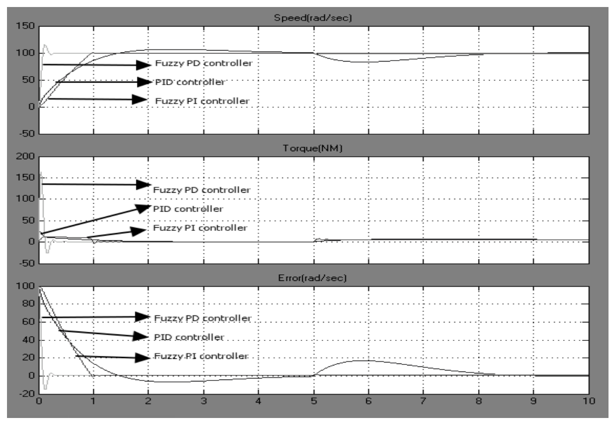

Figure 10. Speed, torque and error response of DC motor Drive when load change from no load to full load condition.

Table III
The Performance indexes at load change from no load to full load condition

Parameters	PID	Fuzzy PD	Fuzzy PI
Peak over shoot (%)	25	3	1
Steady state error (rad/sec)	0.3	0.35	0.1
Recovery time (sec)	9	5.1	5.2

Figure 11 shows simulation result of Speed, torque and error response of DC motor Drive when load change from full load to no load after 5 sec. Performance indexes like peak over shoot steady state error and recovery time for speed response is evaluated and tabulated in Table IV.

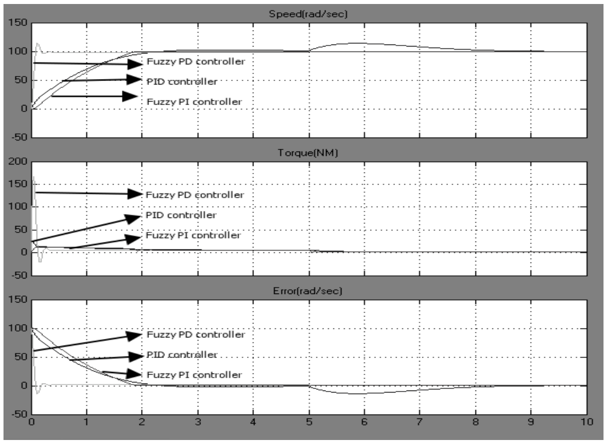

Figure 11. Speed, torque and error response of DC motor Drive when load change from full load to no load condition.

Table IV
The Performance indexes at load change from full load to no load condition

Parameters	PID	Fuzzy PD	Fuzzy PI
Peak over shoot (%)	23	3	2
Steady state error (rad/sec)	0.25	0.3	0.2
Recovery time (sec)	8	5.2	5.3

Figure 12 shows simulation result of Speed, torque and error response of DC motor Drive when speed change from 100 rad/sec to 75 rad/sec after 5 sec. Performance indexes like peak over shoot steady state error and recovery time for speed response is evaluated and tabulated in Table V.

Figure 13 shows simulation result of Speed, torque and error response of DC motor Drive when speed change from 75 rad/sec to 100 rad/sec after 5 sec. Performance indexes like peak over shoot steady state error and recovery time for speed response is evaluated and tabulated in Table VI.

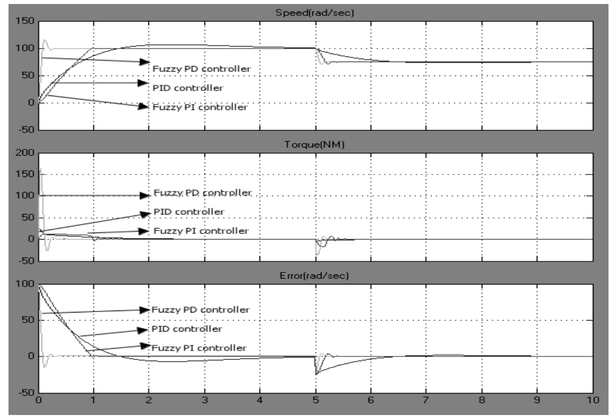

Figure 12. Speed, torque and error response of DC motor Drive when speed change from 100 rad/sec to 75 rad/sec.

Table V
The Performance indexes at speed change from 100 rad/sec to 75 rad/sec

Parameters	PID	Fuzzy PD	Fuzzy PI
Peak over shoot (%)	3	3	1
Steady state error (rad/sec)	0.2	0.3	0.1
Recovery time (sec)	7	5.1	5.2

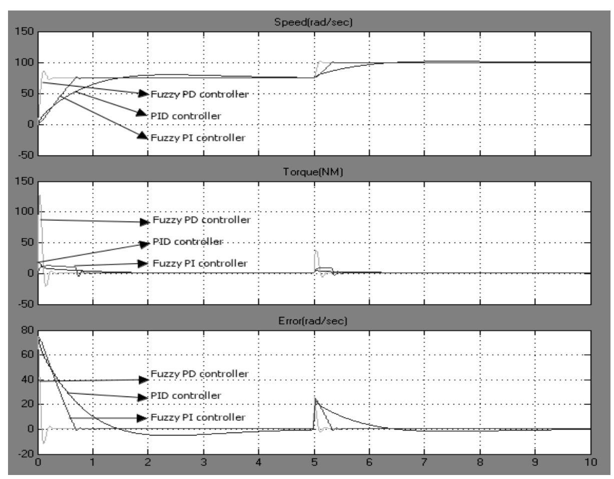

Figure 13. Speed, torque and error response of DC motor Drive when speed change from 75 rad/sec to 100 rad/sec.

Table VI
The Performance indexes at speed change from 75 rad/sec to 100 rad/sec

Parameters	PID	Fuzzy PD	Fuzzy PI
Peak over shoot (%)	6.74	4	1
Steady state error (rad/sec)	0.2	0.35	0.1
Recovery time (sec)	8	5.1	5.3

From the table II – VI, it shows peak over shoot, steady error, settling time and recovery time for speed response under Fuzzy PI controller gives good results than other two controllers.

5. Conclusion

In this paper, a comprehensive analysis of DC motor drive system has been performed by using PID, fuzzy PD and fuzzy PI controller. The simulation model which is implemented in a modular manner under MATLAB/SIMULINK environment allows that many dynamic characteristics such as speed, torque and speed error can be effectively considered. Furthermore, the control algorithms, Fuzzy Logic Controllers and PID controller have been compared by using the developed model. The results show that Fuzzy PI controller improves the performance indexes and also maintain stability of the system than PID and Fuzzy PD controller.

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