I-P-D TYPE FUZZY CONTROL FOR DC MOTOR

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ABSTRACT

In this paper we propose a parallel structure of I-P-D (Integral minus Proportional minus Derivative) type fuzzy controller based on the conventional PID control theory, used to control the speed of DC motor. The conventional PID controller exhibit poor performance when applied to DC motor, it fails to perform satisfactory under parameter variation or load changes. The parallel I-P-D type fuzzy controller are designed according to fuzzy rules so that system becomes fundamentally robust and the system shows better performance in transient state as well as steady state. The performance of the proposed control algorithm has been compared with the classical PID controllers on the basis of different performance indices. So by integrating the I-P-D type fuzzy controller to the DC motor were able to correct the error made by the DC motor and control the speed or position of the motor to the desired point or speed.

KEYWORDS: *DC motor, PID controller, I-P-D type fuzzy controller etc.*

I. INTRODUCTION

Generally, in many applications to perform various tasks requires a high performance motor drive system having good dynamic speed command tracking and load regulating response. A DC motor, because of their simplicity, reliability, flexibility and excellent control of speed for acceleration and deceleration have long been a backbone of industrial as well as home applications, where speed and position control of motor are required. DC motor is used as adjustable speed machine in which the motor should be precisely controlled to give the desired performance. For controlling the speed of DC motor there are several conventional and numeric controllers are present. The PID controller most popularly used control system in the world; over 90 % of the controllers in the industrial process control are of PID type because of its simplicity, stability, robustness, broad applicability and clear functionality. A PID controller will correct the error between the output and the desired input or set point by calculating and give an output of correction that will adjust the process accordingly.

However Drinkov et al. reported that PID controllers fail to perform satisfactorily under complexities such as parameter variations, oscillatory behaviour, and nonlinearity [1-3]. To overcome these difficulties various types of control methods can be applied with conventional PID controller such as adaptive and autotuning. Therefore to enhance the performance of conventional PID controller intelligent technique such as fuzzy logic is used. By combining PID controller with fuzzy logic we obtain same behaviour as that of conventional PID controller in presence of parameter variations. The fuzzy logic deals with human knowledge and expertise for handling nonlinear processes. FLC is extensively used in processes where systems dynamics is either very complex, plants having difficulties in deriving mathematical models or having performance limitations with conventional linear control methods.

Fuzzy logic was first proposed by L. A. Zadeh (1965) based on the concept of fuzzy sets. The first FLC algorithm implemented by Ebrahim (Abe) H. Mamdani (1974) was designed based on linguistic control protocol [4]. This type of fuzzy logic controller design depends on the experience and knowledge of the operator. To avoid such disadvantage of depending on the control experience of the

operator, Mac Vicar-Whelan (1976) first proposed some general rules [5] in fuzzy controllers. Tang et al. (1987) propose that system gives better results by using fuzzy logic with PID controller [6].
The application of fuzzy logic with PID controller can be classified as [9]:

1) The gains of the classical PID controller are tuned on-line and then the classical PID controller generates the control signal [7].
2) FLC is designed as a set of control rules, and the control signal is directly given [8].

The second type controller is PID-type fuzzy logic controller and it is analogous to conventional PID controller. Also Chen et al. proposes some fuzzy PI/PD controller, fuzzy PI + fuzzy D controller analogues to conventional PID controller. Kim and Oh (2000) propose fuzzy PI + fuzzy ID controller [15]. Tang et al. (2001) gives new controlling method fuzzy PI + D, in this controller derivative action is performed on control signal. Guzelkaya et al. propose new approach for tuning the coefficients of PID-type fuzzy logic controllers [11]. The self-organizing rule based fuzzy controller with an additional learning capability introduced by Kazemian (2001). Based on conventional PID control theory, Zhi-wei proposed a new PID-type fuzzy controller [10]. Chatrattanawuth et al. (2006) proposed fuzzy I–PD controller in which integral action is performed on error signal and proportional and derivative function is performed on controlled variables [14].
In this paper parallel structured I–P–D type fuzzy controller is proposed, in which parallel I–P–D controller is designed on the basis of fuzzy rules giving a parallel structured I–P–D type fuzzy controller [16]. In this type of controller integral action is performed on error signal while proportional and derivative action is performed on controlled variables so as to remove the spikes on control signal, which will be occurred due to proportional kick and derivative kick. Based on the conventional I–P–D, a parallel I–P–D type fuzzy controller is designed in the simulink environment of MATLAB. This controller is then applied to the DC motor, so that I–P–D type fuzzy controller will correct the error made by the DC motor and control the speed or the position of the motor and tracking the desired point or speed.
The organizations of this paper are as in section 2 deals with the DC motor model based on the different mathematical formulation. Problem with the tracking the performance of DC motor is eliminated by using conventional PID controller is stated in section 3. The application of fuzzy logic with parallel I–P–D controller stated in section 4. In section 5 the comparison of proposed I–P–D type fuzzy controller with conventional PID controller based on simulation results is stated.

II. DC MOTOR MODEL

When a separately excited DC motor is excited by a field current, an armature current flows in the circuit, the motor develops a back emf and a torque to balance the load at a particular speed.
A simple model of DC motor as shown in Figure 1,

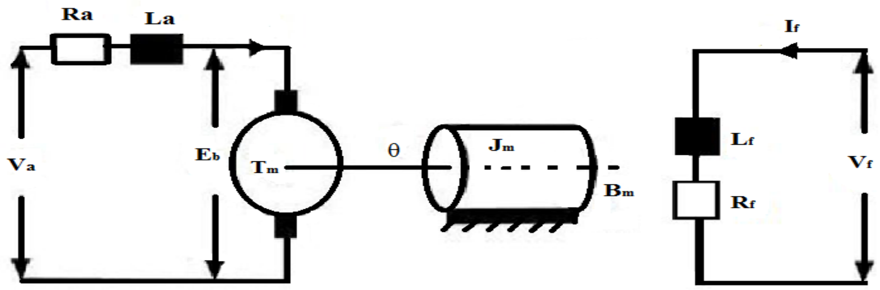

Figure 1. Separately excited DC motor model

In this figure V_a= armature voltage, E_b= back emf, I_a = armature current, R_a= armature resistance, L_a = armature inductance, T_m = mechanical torque developed, J_m= moment of inertia, B_m= friction coefficient of the motor and ω = angular velocity.
We know that,

$$\omega = \frac{(V_a - I_a R_a)}{K_a \emptyset} \quad (1)$$

where, ∅ = field flux per pole; K_a= armature constant.

Therefore the speed of DC motor can be controlled by,

1) Variation of armature resistance.
2) Variation of field flux.
3) Variation of armature terminal voltage.

But variation of resistance in armature circuit method suffers from the following drawbacks: A large amount of power is wasted in the external resistance and this control is limited to give speed below normal and increase of speed cannot be obtained. In variation of field flux method, the flux cannot usually be increased beyond its normal value because of saturation of iron, so speed control by flux is limited to weakening, which gives an increase in speed. It is applicable over only limited range, because if the field is weakened too much there is loss of stability. Therefore variation of armature terminal voltage is applied because armature terminal voltage is directly proportional to motor speed. So by varying armature terminal voltage speed of motor is varied.

The armature voltage equation and torque balance equation is given by

$$V_a = E_b + I_a R_a + L_a \frac{dI_a}{dt} \tag{2}$$

$$T_m = J_m \frac{d\omega}{dt} + B_m \omega + T_l \tag{3}$$

where, T_l is load torque.

The motor torque, T_m is related to the armature current I_a induced by the applied voltage,

$$T_m = K_a I_a \tag{4}$$

The back electromotive force (emf) E_b is related to speed is given by:

$$E_b = K_e \omega \tag{5}$$

Equation (2) and (3) can be rewrite as

$$L_a \frac{dI_a}{dt} + I_a R_a = V_a - K_e \omega \tag{6}$$

$$J_m \frac{d\omega}{dt} + B_m \omega = K_a I_a - T_l \tag{7}$$

Taking Laplace transform of the equation (6) and (7) we get,

$$(L_a s + R_a) I_a(s) = V_a(s) - K_e \omega(s) \tag{8}$$

$$s(J_m s + B_m)\omega(s) = K_a I_a(s) - T_l(s) \tag{9}$$

By eliminating $I_a(s)$ the following transfer function can be obtained, where the speed ω is the output and the voltage V_a is the input. Generally, T_l= 0 therefore

$$\frac{\omega(s)}{V_a(s)} = \frac{K}{(J_m s + B_m)(L_a s + R_a) + K^2} \tag{10}$$

III. CONVENTIONAL PID CONTROLLERS

3.1. PID Controller

PID controllers are commonly used to regulate the time-domain behaviour of many different types of dynamic plants. Different characteristics of the motor responses (steady-state error, peak overshoot, rise time, etc.) are controlled by selection of the three gains that modify the PID controller dynamics. First, taking a look at how the PID controller works in the closed-loop system.

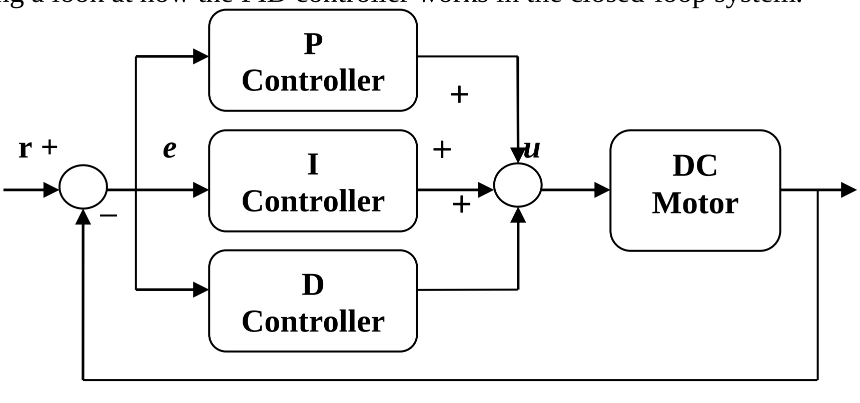

Figure 2. Conventional PID Controller.

The block diagram of classical PID control system is shown in Figure 2. The output of the classical continuous time PID controller, as shown in Figure 2, is given by

$$u_{PID}(t) = K_P\, e(t) + \frac{K_I}{\tau_I}\int e(t)dt + K_D\, \tau_D \frac{de}{dt} \tag{11}$$

where K_P = proportional gain, K_I = integral gain and K_D = derivative gain. τ_I is the integral time constant, τ_D is the derivative time constant and $u_{PID}(t)$ is the output of the classical PID controller.
Derivative action gives spike or kick to the controller output in the case of change in the error due to a new set point. Due to this controller to start taking corrective action immediately without waiting for the integral or proportional action to take effect. The negative derivative of the process variable lacks the spike present in the derivative of the error. With an extra derivative action, problems such as overshoot and hunting are reduced. However, issues like finding the appropriate parameter of PID controllers were yet to be solved.
In practice in PID controller proportional and derivative action, i.e., a sudden change in the PID controller output creates serious problems for actuator circuitry. So as to remove the spikes on the control signal, the PID controller structure is modified to integral minus proportional minus derivative (I–P–D) controller.

3.2. I–P–D Controller

The block diagram of the conventional parallel continuous time I–P–D control system is shown in Figure 3. Here, integral action is performed on error signal and proportional and derivative actions are performed on controlled variable. The output of the conventional parallel I–P–D controller is given by

$$u_{I-P-D}(t) = \frac{K_I}{\tau_I}\int e(t)dt - K_P\, y(t) - K_D\, \tau_D \frac{dy}{dt} \tag{12}$$

where $y(t)$ is the controlled variable signal, $e(t)$ is the error signal and $u_{I-P-D}(t)$ is the output of the conventional parallel I–P–D controller.

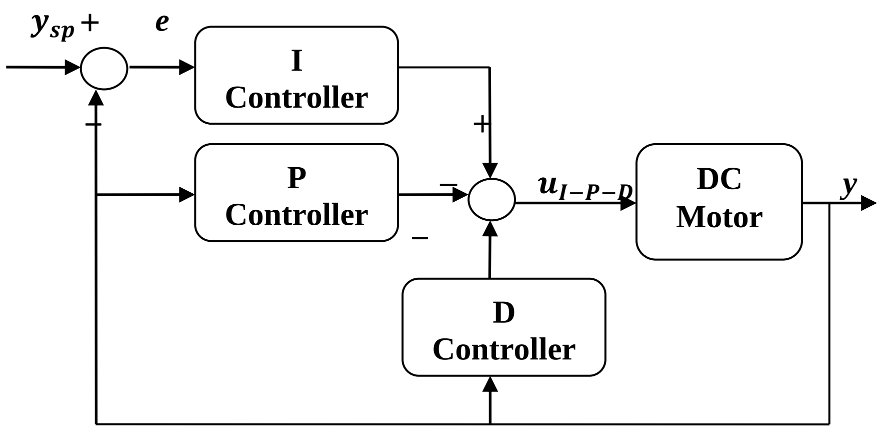

Figure 3. Conventional I–P–D Controller.

IV. I-P-D TYPE FUZZY CONTROLLER

PID control requirements model structure which is precise, and in practical applications, to different extent, most of industrial processes exist to the nonlinear model, thus by using conventional PID controller it is not possible to achieve precise control of the process. According to their own characteristics, we combine fuzzy control with I–P–D control [16], and provided as I–P–D type fuzzy controller shown in Figure 4.

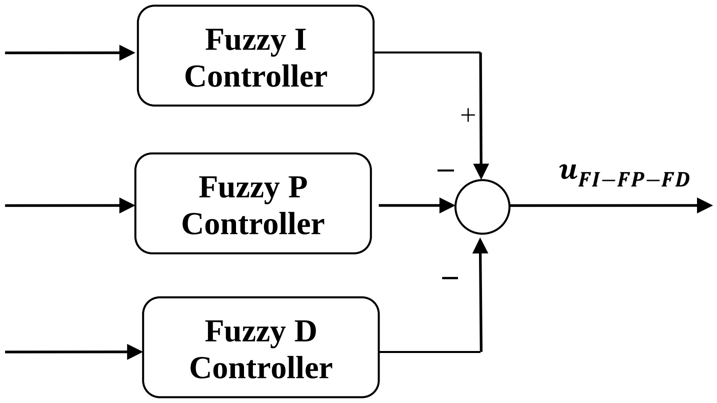

Figure 4. Typical I–P–D type fuzzy control system.

I–P–D type fuzzy controller takes the conventional controller and regulates the parameter. The characteristics of a fuzzy system such as robustness and adaptability can be successfully incorporated into the controlling method for better tuning parameters. I–P–D type fuzzy controller works on the control rules designed on the basis of theoretical and experience analysis. Fuzzy control tunes the parameters K_P, K_I and K_D by adjusting the other controlling parameters and factors on-line. This result as the precision of overall control higher and hence gives a better performance than the conventional controller. The I–P–D type fuzzy control system is shown in Figure 5.

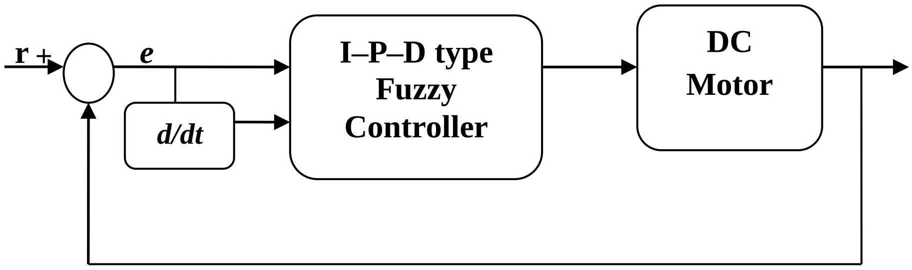

Figure 5. Structure of I–P–D type fuzzy control system.

The set value of speed is input to the control system, and the actual speed is output *y*. The fuzzy controller input variables are error and derivative of error and the output variables is a control signal given to DC motor.

In fuzzy logic controller fuzzy sets for both input variables are divided into five sections linguistic variables. For E and EC the variables are Negative big (NB), Negative small (NS), Zero (Z), Positive small (PS), Positive big (PB), the functions for linguistic variables are triangular membership functions and variation range are from -1 to 1. For output K_P, K_I and K_D the variables are Zero (Z), Positive small (PS), Positive medium (PM), Positive big (PB), Positive very big (PVB) and the variation range is from 0 to 1.

The principle behind regulating the I–P–D type fuzzy controller parameters [12] are,

1) When E is large, K_P should be large to speed up the system response and K_D should be small to avoid the over saturation at the same time K_I is to be zero prevents large overshoot and integral saturation.
2) When E and EC are in the medium at that time K_P should be smaller, K_I and K_D at suitable value giving smaller overshoot and to raise the system response.
3) When E is large, K_D can be small, and when E is small, K_D should be large which avoid the system oscillation.

The fuzzy control rules are formed according to this principle. Generally the fuzzy control rules are designed on the basis of theoretical and experience analysis and formed as

$$R_1\text{: if E is } A_1 \text{ and EC is } B_1 \text{ then U is } C_1.$$

$$R_2\text{: if E is } A_2 \text{ and EC is } B_2 \text{ then U is } C_2$$

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The fuzzy control rules for K_P, K_I and K_D [13] are shown in the TABLE I, TABLE II and TABLE III.

TABLE I. Fuzzy Control Rule of K_P

K_P		EC				
		NB	**NS**	**Z**	**PS**	**PB**
E	**NB**	PVB	PVB	PVB	PB	PM
	NS	PVB	PVB	PB	PB	PM
	Z	PB	PB	PM	PS	PS
	PS	PM	PS	PS	PS	PS
	PB	PS	PS	Z	Z	Z

TABLE II. Fuzzy Control Rule of K_I

K_I		EC				
		NB	**NS**	**Z**	**PS**	**PB**
E	**NB**	PVB	PB	PM	PM	PM
	NS	PVB	PB	PB	PM	PS
	Z	PM	PS	Z	Z	Z
	PS	PM	PM	PS	Z	Z
	PB	PS	Z	Z	Z	Z

TABLE III. Fuzzy Control Rule of K_D

K_D		EC				
		NB	**NS**	**Z**	**PS**	**PB**
E	**NB**	Z	Z	PS	PS	PB
	NS	Z	Z	Z	Z	PS
	Z	Z	Z	Z	Z	PB
	PS	PS	PS	PS	PB	Z
	PB	Z	Z	Z	PS	PB

V. SIMULATION RESULTS

The simulink model of DC motor built with the help of the mathematical equations discussed in Chapter 2 with the parameters values as L_a= 0.5, R_a= 1, K_e= 0.01, K_a= 0.01 and J_m= 0.01. Also the conventional PID controller and proposed I–P–D type fuzzy controller are built in simulink environment of MATLAB.

The step response of DC motor for conventional PID controller and I–P–D type fuzzy controller is shown in Figure 6.

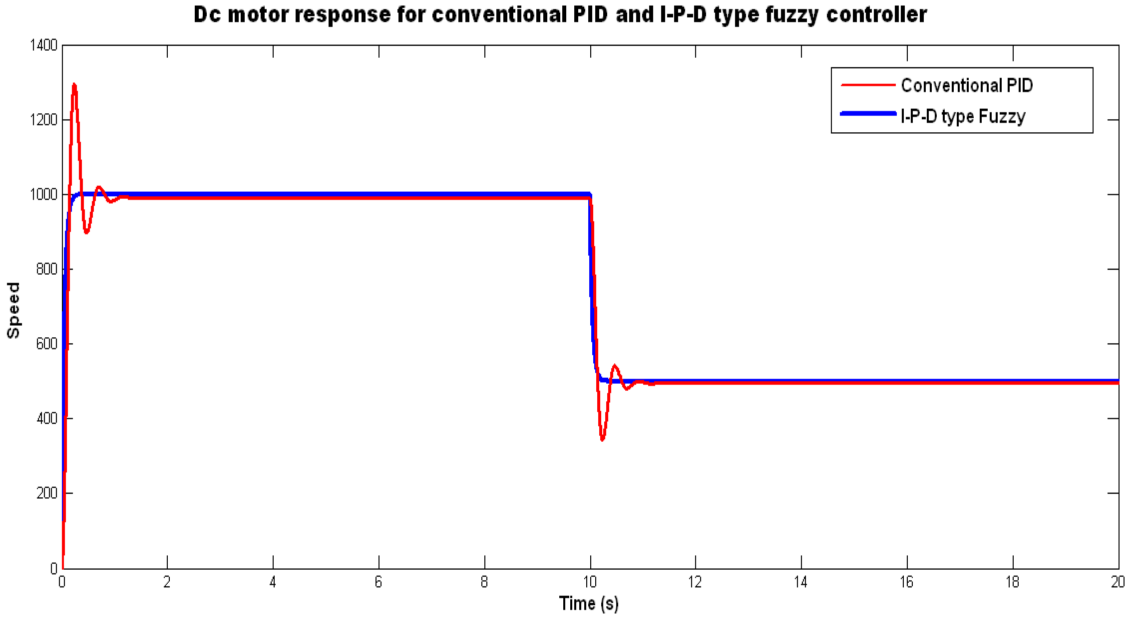

Figure 6. Step response of DC motor with PID controller and I – P – D type fuzzy controller.

From the Figure 6 the comparison between conventional PID controller and I–P–D type fuzzy controller are shown in below TABLE IV.

According to the use of above simulation resulted in better outputs, dynamic and static characteristics. The response of the system was also faster than in the conventional PID controller. The amount of overshoot for the output response was successfully decreased using the above techniques and the overshoot is reduced to zero.

The response of PID controller is quite slow but for I–P–D type fuzzy controller it is quite smooth and fast. In all the above cases, it is noted that integral square of error (ISE) and integral of absolute error (IAE) are minimum for I–P–D type fuzzy controller as compared to conventional PID controller.

TABLE IV. Comparison of PID Controller and I–P–D type Fuzzy Controller

Performance Indicators	Conventional PID Controller	I–P–D type Fuzzy Controller
Settling-time	1.8 sec	**1.0 sec**
Rise time	0.456 sec	**0.386 sec**
% Overshoot	29.4	Approx. set point speed
ISE	18.2907	**0.4437**
ITSE	182.90	**4.437**
IAE	7.2200	**0.6050**
ITAE	72.200	**6.050**

VI. CONCLUSIONS

Simulation results show the effectiveness and usefulness of I–P–D type fuzzy controller for set point tracking and load disturbance rejection. The I–P–D type fuzzy controller gives smaller overshoot and less rising and settling time and has better dynamic response properties and steady-state properties as compared with conventional PID controller. So by integrating the I–P–D type fuzzy controller to the DC motor were able to correct the error made by the DC motor and control the speed of the motor to the desired set point or speed. And the I–P–D type fuzzy controller enables the motor to reach the speed smoothly and within an acceptable period of time.

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