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Performance Simulation Of Various Intelligent Techniques For DC Motor Speed Control

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Abstract:*DC motor speed control is the important part of moving drive applications, home appliances and robot manipulators. Therefore, designing an adaptive, efficient, and more robust controller for DC motor speed control is a challenging task for the control engineers. In this paper, various intelligent techniques are designed and implemented for DC motor speed. Performance of intelligent techniques based on PID, fractional order PID, and fuzzy-PID are compared. PID controller parameters (Kp, Ki, Kd) and fractional order PID parameters (Kp, Ki, Kd, λ, μ) are optimally tuned by Genetic Algorithm. On other hand, fuzzy logic is used to tune each parameter of fuzzy-PID. Time domain specification of the speed response such as overshoot, undershoot, settling time, rise time and steady state error is obtained and compared for the considered controller. According to the simulation result, fuzzy-PID perform best regulate the speed for motor in compared with two others. Fractional order PID can increase and more rapidly stabilize the speed of motor for speed disturbance testing. PID controller shows better and more rapidly stabilize the speed of motor for load disturbance testing.*

Keywords:*DC motor, PID controller, fractional order, fuzzy logic,genetic algorithm, intelligent control.*

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I. Introduction

The DC motors are widely used in industry and commercial application such as tape motor, disk drive, robotic manipulators and in numerous control applications [1],[2]. DC motor speed control covers the simplicity, no difficulty of application, flexibility, high reliabilities and favorable cost. DC motor speed control offers an open research area to the control engineers because of advancement in intelligent control techniques. Naturally, PID is the first choice in DC motor speed control because they are standard industrial componens. The PID controllers represent software packages and commercial hardware modules, due to their simple structural construction and functionalities in patents [3]. A very important step in the use of PID controllers is the controller parameters tuning process. In a PID controller, each mode (proportional, integral and derivative mode) has a gain to be tuned, as a result of three variables involved in the tuning process. Several classical methods for tuning of the PID controllers are already proposed, i.e. Ziegler-Nichols method , Kappa-Tau, D-partitioning, OLDP method, Nyquist based design, K-B parameterization, Frequency Loop shaping, etc [4]-[6]. Control engineering is a dynamic field of research and practice, better performance was constantly demanded. In few decades, the field of control theory has been dominated with integer order controllers. With the innovation in the field of fractional calculus, it was evident that fractional order integral and differential can be used in control applications to offer more flexible PID controller design. Podlubny has proposed a generalization of PID controllers, namely the fractional order PID controller, involving conventional differentiator order 's' and integrator order '1/s' are replaced by 'sλ' and '1/sμ' respectively where 'λ' and 'μ' are the fractional order parameter [7],[8]. Some literature have attempted for an optimal fractional order PID design and develop tuning rules applied in various systems [1],[2],[9]-[11]. Petras presented a practical realization and implementation of digital fractional order PID control for a DC motor. The method used for fractional implementation was based on Bode's ideal closed loop [12]. A method for incorporating fractional order dynamics in an existing DC motor control system with internal PI or PID controller is presented by Aleksei et al. Results of experiment based on the control of a real test plant from MATLAB/Simulink environment are presented in [13]. Ying Luo et al. are proposed and designed for a class of fractional order systems with fractional order proportional integral and fractional order [proportional integral] controller. From the simulation and experimental results presented, both of the two designed fractional order controllers work efficiently [14].

For better performance, the tuning of parameters is an essential requirement for all controllers. With the advent in computational intelligence, various algorithms have evolved for optimization of different problems in the field of engineering. Several authors presented advanced optimization techniques in their works

[1],[15],[16]-[21]. In this paper, Genetic Algorithm (GA) has been used to tune parameters of PID and fractional order PID controllers [22]-[24],[25]. Suman and Giri present the speed control of DC motor utilizing GA based PID controller and gives the better results than all other the controller [19]. Moreover, GA applied in PID controller improves transient response compared to other tuning methods shown by average percent of overshoot reduction while keep the rise time and peak time almost unchanged and also improves the settling time [21]. From the literature it is clear that GA is a powerful tool for optimization and its application to a DC motor speed control needs to be explored.

After the effective use of fractional order PID controller, the research trend has been toward the use of fuzzy logic with PID controller. Fuzzy control theory usually provides nonlinear controllers that are capable of performing different complex nonlinear control action even for uncertain nonlinear systems [1],[26],[27]. Patil et al. deals that fuzzy controllers are more robust to plant parameter changes than classical PID controllers and have better noise rejection capabilities [28]. Combination of PID and fuzzy controller also has been compared with conventional PID and shown better result by improve the system characteristics. When disturbance of speed is applied, speed in self-tuning fuzzy-PID is not affected and it remain constant with less overshoot or undershoot [29],[30]. In this work, design self-tuning fuzzy-PID controller where the role of the fuzzy controller is to tune the PID controller parameters [15],[29]-[32]. The PID controller parameters are updated online according to error and change of error. This type of controllers is suitable for systems which exposed to external disturbances and parameters variation.

Base on some literature survey shows that control based on intelligent techniques are better than conventional. However, the best and more capable DC motor speed control based on various intelligent techniques needs to be explored. The first major contribution of this work is to explore the use of GA for tuning of all PID and fractional order PID parameters, and the use of fuzzy logic for tuning all fuzzy-PID parameters. The second contribution is to find out the performance of PID, fractional order PID and fuzzy-PID by compare it for some robustness testing consist constant model, load disturbance and speed disturbance.

This paper deals a simulation of DC motor speed contol using intelligent techniques designed by MATLAB/ Simulink. After that, DC motor performance is tested by comparing the speed response between PID, fractional order PID, and fuzzy-PID controller at various level of robustness testing.

This paper is organized as follows: Following a detailed literature survey in the first Section, the brief mathematical model DC motor is presented in Section 2. In Section 3, the brief Genetic Algorithm, design of PID, fractional PID, and fuzzy-PID are presented. The simulation and implementation of designed controllers are explained in Section 4. In Section 5, the simulation results and discussions for three conditions are presented in detail. Finally, the conclusions of the proposed work are highlighted in Section 6.

II. Mathematical Model of DC Motor

A separately excited DC motor speed control circuit is shown in Figure1. The equations describe the dynamic behavior of the DC motor are as equation (1)(2)(3) [33]:

$$V = e + R_a i_a + L_a \frac{di_a}{dt} \tag{1}$$

$$T_m = J\frac{d^2\omega(t)}{dt^2} + B\frac{d\omega(t)}{dt} \tag{2}$$

$$e = e(t) = K_b \frac{d\omega(t)}{dt} \tag{3}$$

Simplification and taking the ratio of ω(s)/v(s), will get the transfer function as equation (4):

$$\frac{\omega(s)}{V_a(s)} = \frac{k_b}{[JL_a S^2 + (R_a J + BL_a)S + (K_b^2 + Ra)]} \tag{4}$$

Where R_a is armature resistance, L_a is armature inductance, i_a is armature current, V_a is armature voltage, e is back emf, K_b is back emf constant, T_m is torque developed by the motor, ω(t) is angular speed of shaft, J and B are constants.

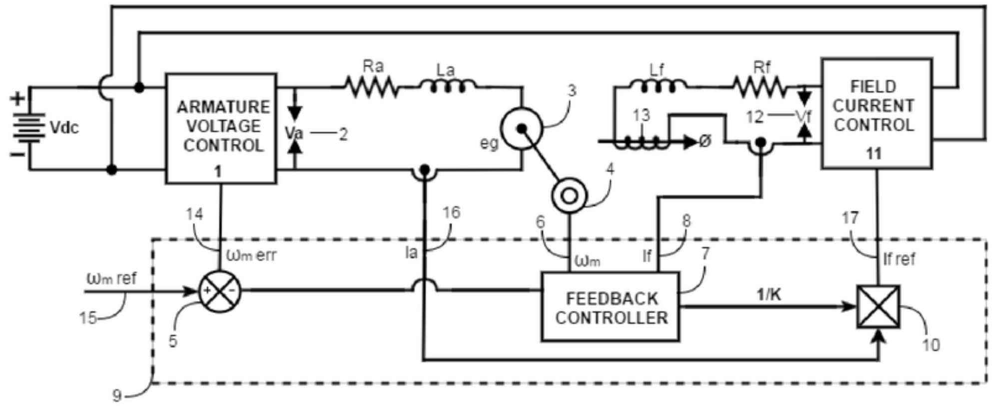

Figure 1. Equivalent circuit of a DC motor speed control system.

The separately excited DC motor in this study has the following parameters [34]: V_f 240 volts. R_a 0.5 Ω, L_a 0.01 H, V_a 280 V, K_b 1.23 V/(rad/s), J 0.05 Kg.m², B 0.02 Nm/s. Then, the overall transfer function is given in equation (5):

$$\frac{\omega(s)}{V_a(s)} = \frac{1.23}{0.0005\,S^2 + 0.0252\,S + 1.523} \tag{5}$$

III. Design of Controllers

This section presents the detailed description about the design of the controllers in order. First, a brief description of Genetic Algorithm. Second, design of PID controller. Third, design of fractional order PID controller. And the last, design of fuzzy-PID controller.

A. Design of Genetic Algorithm

Genetic Algorithm (GA) is a powerful search algorithm that performs an exploration of the search space that evolves in analogy to the evolution in nature [19]. GA consists of three fundamental operators: selection, crossover, and mutation. Given an optimization problem, GA encodes the parameter designed into a finite bit string, and then runs iteratively using the three operators in a random way but still based on the fitness function evolution. Finally, GA finds and decodes the solution to the problem from the last pool of mature strings [2]. The sequences of operation involved GA are described in Figure 2 [35].

GA based PID controller has been proposed for tuning optimized PID parameters in a continuous stirred tank reactor in [36]. Suman and Giri used GA to improve PID controller parameters for speed control of DC motor and list their points of interest over the traditional tuning strategies [20]. Intelligent optimization method for designingfractional order PID based GA presented in [22]. Simulation results show the proposed method is highly effective. Lazarevic et al. presents the new algorithms of fractional order PID control based on GA in the position control of a robotic system driven by DC motors and conclude that it gives better performance for robot control as compared to another controller method [23]. In this work, GA parameters in Table 1 is chosen for tuning PID and fractional order PID controller.

To evaluate control performance, the fitness function (J) was based on Integral Time Absolute Error (ITAE) criterion which has an advantage of providing lesser overshoot along with the less settling time [24]:

$$J = \int_0^T t\left|e(t)\right|dt \tag{6}$$

Where T is sample time, and e(t) is system error in time domain.

TABLE 1GENETIC ALGORITHM PARAMETERS

Parameter	Controller	
	PID	**Fractional order PID**
Population Size	100	50
Creation Function	Uniform	Uniform
Selection Function	Stochastic Uniform	Stochastic Uniform
Crossover	Arithmetic	Arithmetic

Function		
Crossover Probability	0.65	0.65
Generation	50	25
Initial Range	Lower [0 0 0] Upper [20 20 5]	Lower [0.5 1] Upper [1 1.5]

B. Design of PID controller

Fundamentally, PID controllers were composed of three basic control actions (K_p, K_i, and K_d)[37].

$$C(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \tag{7}$$

Moreover, in laplace form it can be described by the following transfer function in the s-domain [6]:

$$C(s) = K_p + K_i / S + K_d S \tag{8}$$

where $C(s)$ is controller in s domain, K_p is the proportional constant, K_i is the integral constant, K_d is the derivative constant. K_i and K_d respectively are defined as K_p/T_i and $K_p T_d$ in which T_i and T_d are integral and derivative time constant. PID controller can be defined in Laplace domain as shown in:

$$C(s) = K_p (1 + 1/T_i S + T_d S) \tag{9}$$

The function of each parameter of PID controller can be described as follows, the proportional part reduces the error response of system to disturbances, the integral part eliminates the steady state error, and the derivative part dampens the dynamic response and improves the system stability [38]. Because of this, choosing the right parameters becomes a crucial decision for putting PID controller into practice. Figure 3 shows the block diagram for tuning of PID parameters using GA.

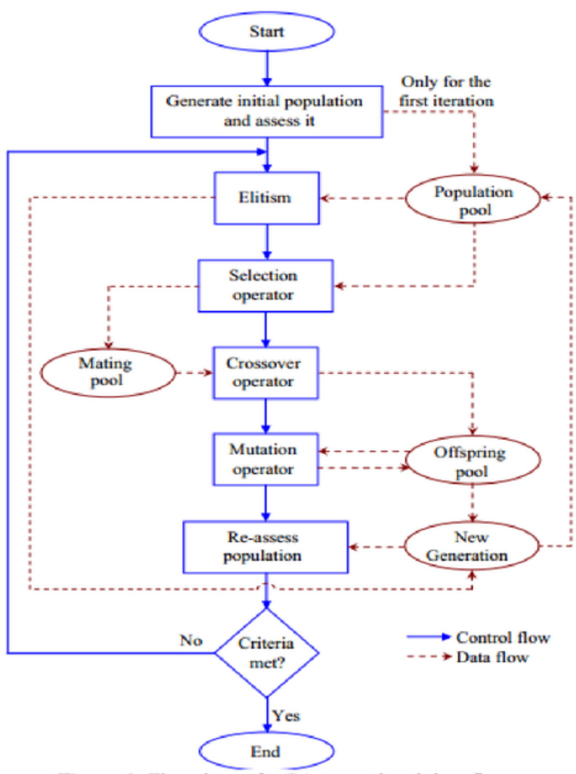

Figure 2. Flowchart of a GA control and data flow.

C. Design of fractional order PID controller

For the past decades, the fractional calculus has been used incombination with other control theory. This idea of the fractional calculus application to control theory has been described in many other works [8],[12],[39].The unique feature of fractional calculus is its ability of using the real number order of integral as well as differential operators instead of fixed integer order.The generalized differential-integrator definition is givenby [1]:

$$D_t^a f(t) = \begin{cases} \frac{d^a}{dt^a} f(t), & a > 0 \\ f(t), & a = 0 \\ \frac{d^a}{dt^a} = I^a f(t), & a < 0 \end{cases} \tag{10}$$

with*a* is the fractional order of operation. Various definitions of fractional order differentiator or integratorhas presented by many authors. The popular methodsis Riemann and Liouville (R–L)definitionas [12]:

$$D_t^a f(t) = \lim_{t \to 0} \left(\frac{1}{h^a} \right) \sum_{j=0}^{\infty} (-1)^j \binom{a}{j} \binom{n}{k} f(t - jh) \tag{11}$$

and another popular one is Grunwald–Letnikov (G–L) definition as:

$$D_t^a f(t) = \frac{1}{1 - \Gamma(n-a)} \frac{d^n}{dt^n} \int_a^t \frac{f(\Gamma)}{(t-\Gamma)^{a-n+1}} d\Gamma \tag{12}$$

For $(n - 1 < r < n)$ and where $\Gamma(.)$ is the gamma function.
The equation for the fractional order PID controller transfer function in the s-domain was [7]:

$$C(s) = K_p + K_i S^{-\lambda} + K_d S^{\mu} \tag{13}$$

whereλ is the integral order and μ is derivative order.Chopade et al. explained that fractional order PID is infinite order, in the sense of integral. Approximation from infinite to a finite dimensional system is needed [25]. In this paper, the Oustaloup's approximation for the fractionalorder implementation is used. The Oustaloup'sapproximation technique of fractional order controller is preferredover others because of its ability for real hardware implementationwith the use of higher-order infinite impulse response (IIR) typeanalog or digital filters for each fractional order differentiatorintegrator in the design of controller [40]. The approximating transfer function provided by Oustaloup's as [12]:

$$H(s) = C \prod_{k=-n}^{n} \frac{s + \omega' k}{s + \omega k} \tag{14}$$

where C is gain, ωk is zeros and poles of the filter. These can be calculated recursively as follows;

$$\begin{aligned} \omega' k &= \omega_b \left(\frac{\omega h}{\omega b} \right)^{\frac{k+n+0.5(1+r)}{2n+1}} \\ \omega k &= \omega_b \left(\frac{\omega h}{\omega b} \right)^{\frac{k+n+0.5(1-r)}{2n+1}} \\ C &= \left(\frac{\omega h}{\omega b} \right)^{-r/2} \prod_{k=-n}^{n} \left(\frac{\omega k}{\omega' k} \right) \end{aligned} \tag{15}$$

where $[\omega b, \omega h]$is the expected fitting range, $2n + 1$ represents the order of approximation.In this design, the value of n and frequency range is chosen as 5 and [1000, 0.001]respectively. Figure 4 shows the block diagram for tuning of fractional order PID parameters using GA.

D. Design of fuzzy-PID controller

It has been reported in many researches that fuzzy-PID controller parameters enhances its performance and increases the robustness of the system [26],[30],[32],[38],[41]-[43].In this case, the parameters of the PID controller are changed adaptively using fuzzy logic was desbribed in Figure 5. The controller consists of two parts: the first part is fuzzy logic (FLC) controller and the second part is PID. The PID controller parameters are updated on-line according to error and change of error.

The PID controller parameters are updated according to the following equation (16-18) [30],[32]. Therefore, they can be calibrated over the interval as follows:

$$K_{p2} = K_{p1} * K_p \quad (16)$$

$$K_{i2} = K_{i1} * K_i \quad (17)$$

$$K_{d2} = K_{d1} * K_d \quad (18)$$

where $K_{p1}$is proporsional modification coefficient. $K_{i1}$is integral modification coefficient. $K_{d1}$is derivative modification coefficient.

The structure of fuzzy logic is shown in Figure6. Pre-processing involves the scaling of input and output variables whereas the basic design of fuzzy logic involves:Fuzzification, Rule Base, Fuzzy Inference System and Defuzzification [44],[45].

1) Fuzzification

Known as the process where a numericalvariable (crisp variables) is transformed to a linguistic variable(fuzzy linguistic values). There are two inputs and three outputs to the controller Fuzzy-PID controller. PID controller parameters are updated on-line according to error (e) and change of error (Δe). In this paper, both e and Δe may be normalized (from -1 to 1), and the linguistic labels are {Negative Large, , Negative Medium, Negative small, Zero, Positive Small, Positive Medium, Positive Large}. The linguistic labels are referred to in the rules bases as {NL,NM,NS,ZE,PS,PM,PL}.

Three outputs of the controller are linguistic labels as {Zero, Medium Small, Small, Medium, Large, Medium Large, Very Large} and refereed to in the rules bases as {ZE,.MS, S, M, L, ML, VL} with normalized from (0,20) for Kp, Ki and may be normalized from (0,0.2) for Kd [9]. These are characterized by the triangular membership function plots. Figure 7-9 shown membership function plots of input (e,Δe) and output respectively.

2) Fuzzy Inference System

A decision-making logic that is simulates a human decision process.The rules are in "If Then" format and formally "If" side is called the conditions and "Then" side is called the conclusion. Usually this process utilizing rule base and tables. The rule base of fuzzy logic for K_p, K_i, K_d are simplified in Table 2-4. The input (e) and (Δe) has 7 linguistic labels. There are 7x7=49 possible rules in the matrix which are simplified into 25 rule-base by ignoring the medium label [30],[46].

3) Defuzzification

The defuzzification is a technique that has been used in this paper is the centroid of gravity, which is computationally inexpensive and easy to implement as shown in equation (17) [30]:

$$u(COG) = \frac{\sum_{i=1}^{n} u(xi)xi}{\sum_{i=1}^{n} u(xi)} \quad (19)$$

where*xi* is a point in the universe of the conclusion (i=1,2,3...) and *u(xi)* is the membership value of the element *xi*, *u(COG)* is the output of fuzzy control.The main contribution of these variable gains in improving the control performance is that they are self-tuned gains and can adapt to the rapid changes of the errors and the (changing) rates of the error signals caused by the time-delayed effects, nonlinearities, and uncertainties of the underlying system (plant, process) [45].

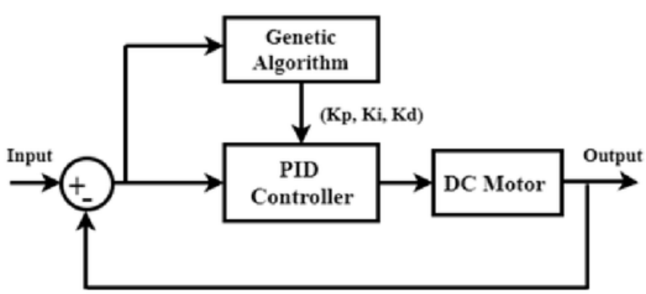

Figure 3. Block diagram of GA-PID.

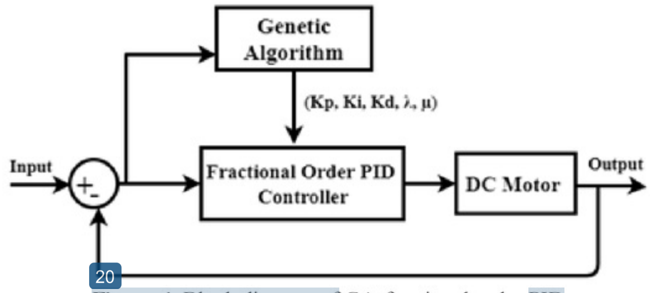

Figure 4. Block diagram of GA-fractional order PID.

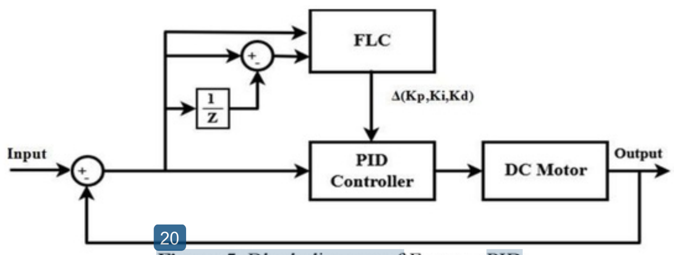

Figure 5. Block diagram of Fuzzy – PID.

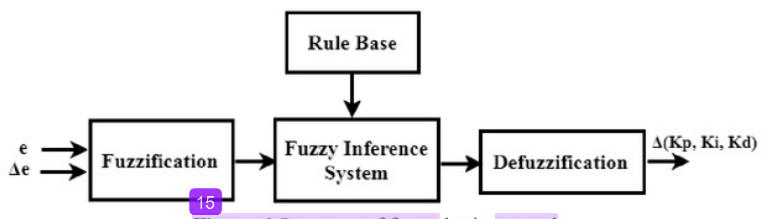

Figure 6.Structure of fuzzy logic control.

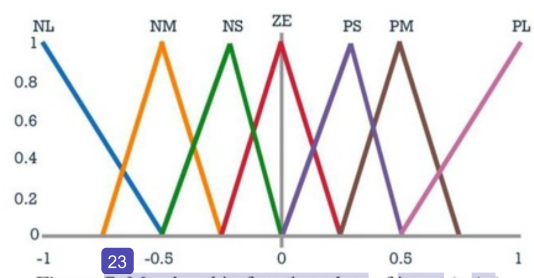

Figure 7. Membership function plots of input (e,Δe).

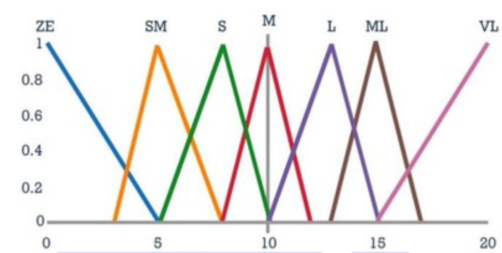

Figure 8. Membership function plots of output (Kp and Ki).

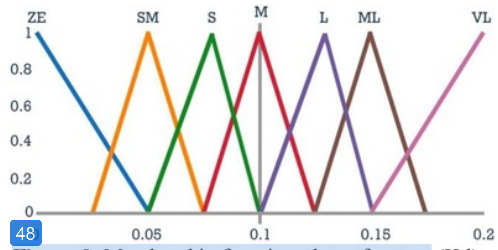

Figure 9. Membership function plots of output (Kd).

TABLE 2 THE RULE BASE OF K_{P1}

ΔE/E	[illegible]	NS	ZE	PS	PL
NL	VH	VH	VH	VH	VH
NS	H	H	H	MH	VH
ZE	[illegible]	ZE	MS	S	S
PS	H	H	H	MH	VH
PL	VH	VH	VH	VH	VH

TABLE 3 THE RULE BASE OF K_{I1}

ΔE/E	[illegible]	NS	ZE	PS	PL
NL	M	M	M	M	M
NS	S	S	S	S	S
ZE	MS	MS	ZE	MS	MS
PS	S	S	S	S	S
PL	M	M	M	M	MS

TABLE 4 the rule base of kd1

ΔE/E	NL	NS	ZE	PS	PL
NL	ZE	S	M	MH	VH
NS	S	H	MH	VH	VH
ZE	M	MH	MH	VH	VH
PS	[illegible]	VH	VH	VH	VH
PL	VH	VH	VH	VH	VH

TABLE 5 THE VALUE OF CONTROLLERS PARAMATER

Controller	Parameter	Value
PID	K_p	19.856
	K_i	19.61
	K_d	0.243
Fractional order PID	K_p	19.856
	K_i	19.61
	K_d	0.243
	λ	0.51
	μ	1.004
Fuzzy-PID	K_{pmin}	0
	K_{dmin}	0
	K_{pmax}	20
	K_{dmax}	0.2

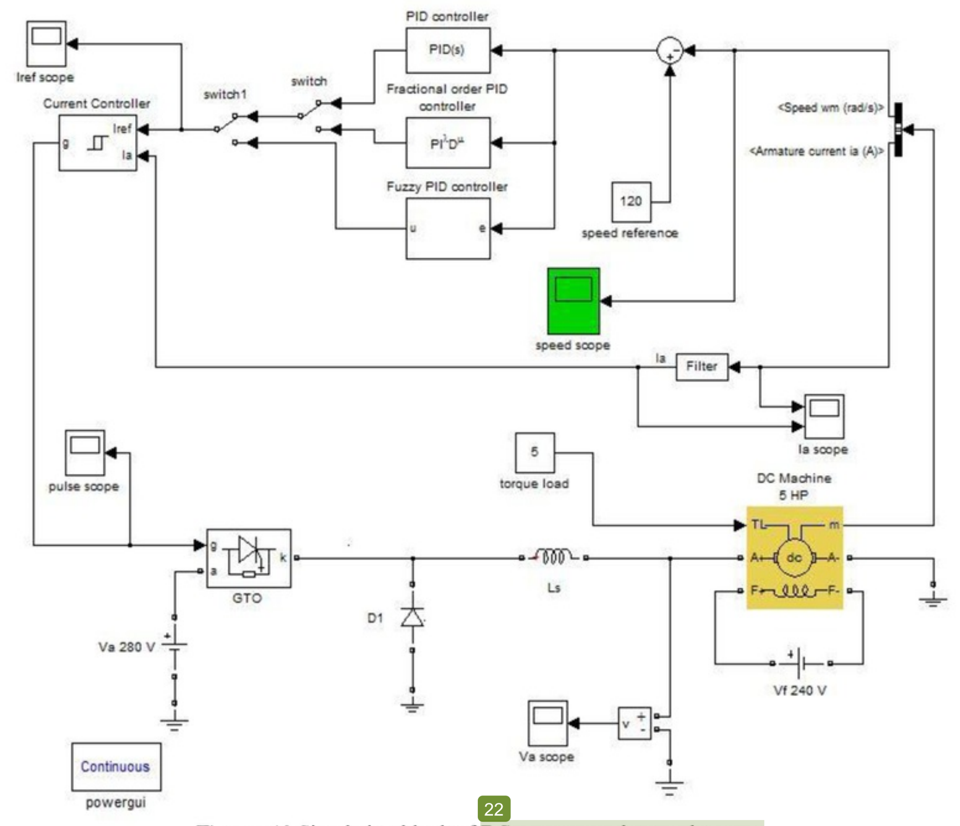

Figure. 10 Simulation block of DC motor speed control system.

IV. Implementation of Controllers

In this section, DC motor speed control by PID, fractional order PID, and fuzzy-PID controllers are implemented. The simulation was done with MATLAB R2012a. A Simulink model was obtained with SimPowerSystem, Fuzzy Logic, Optimization, and additional FOMCON toolbox as shown in Figure 10. The speed reference for initial condition is 120 rad/s and torque constraints for initial condition 5 Nm during the simulation. The Oustaloup's approximation was used with fifth order and range of frequency [1000,0.001] for the implementation of fractional order operator. The tuning of PID and fractional order PID controller was done with GA and the parameters set during the simulation are listed in Table 1.

The PID controllers were implemented as described in Figure 3 respectively. The fractional order PID controller was obtained by keeping the PID parameter's values and putting the values of fractional order parameters of integral and differentiator as described in Figure 4. On the other hand, fuzzy-PID was implemented by setting the rule base as unity in the design earlier. The tuned values of PID, fractional order PID, and fuzzy-PID controller are listed in Table 5.

V. Simulation Results and Discussions

In this section, testing results for PID controller, fractional order PID with GA tuning and fuzzy-PID are discussed.

A. Case A (constants condition)

Speed response characteristics of DC motor in Case A is explained. Case A is observed for torque load 5 Nm, reference speed of 120 rad/s and sampling time 2 second. The speed response value based the simulation result shows in Figure 11 and tabulated in Table 6. It can be seen that fuzzy-PID smoothly control DC motor with less overshoot (0.083%), settling time (0.069 s), and steady state error (0.41%). It is clear that fuzzy-PID has better performance compared two others.

B. Case B (disturbance of load)

Any DC Motor, as most of the application demands, it has to perform under varying load conditions. Therefore, the simulation results in Case B has been obtained for varying load conditions. First step, load torque is decreased from 20 Nm to 10 Nm at 2 second. Second step, load torque is increased from 10 Nm to 30 Nm at 4 second. The speed response value based the simulation result shows in Figure 12 and tabulated in Table 7 and Table 8.

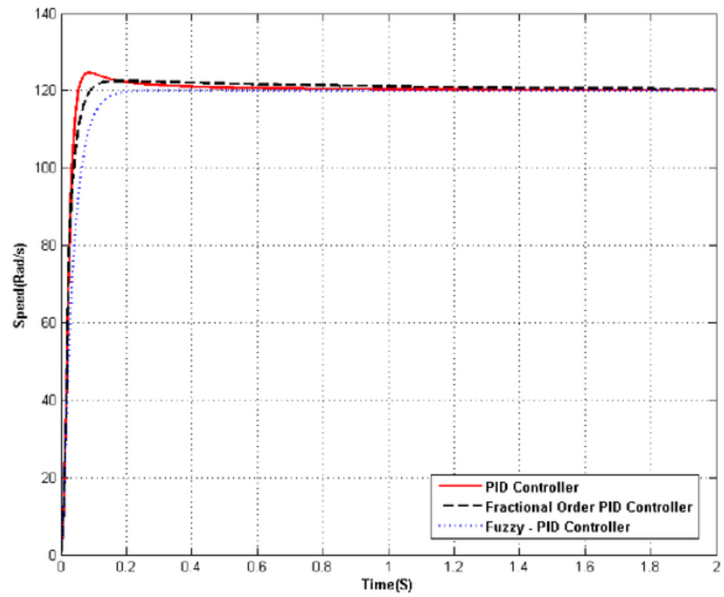

Figure 11. Speed response of Case A (constants condition).

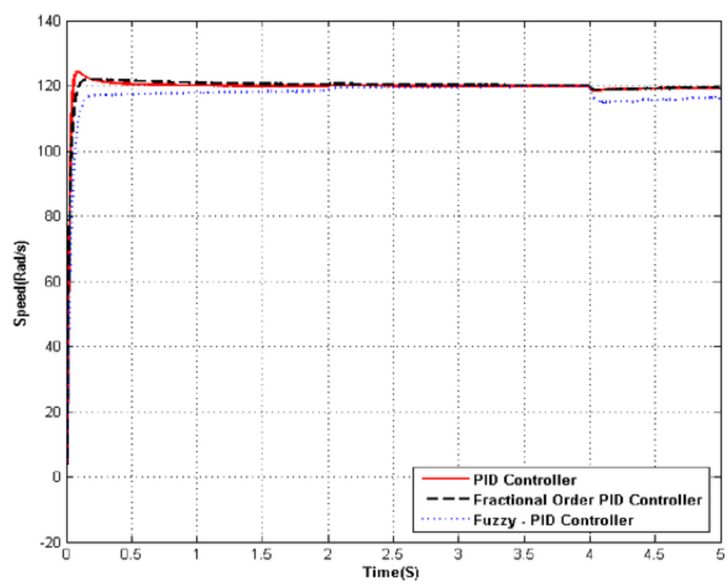

Figure 12. Speed response of Case B (disturbance of load condition).

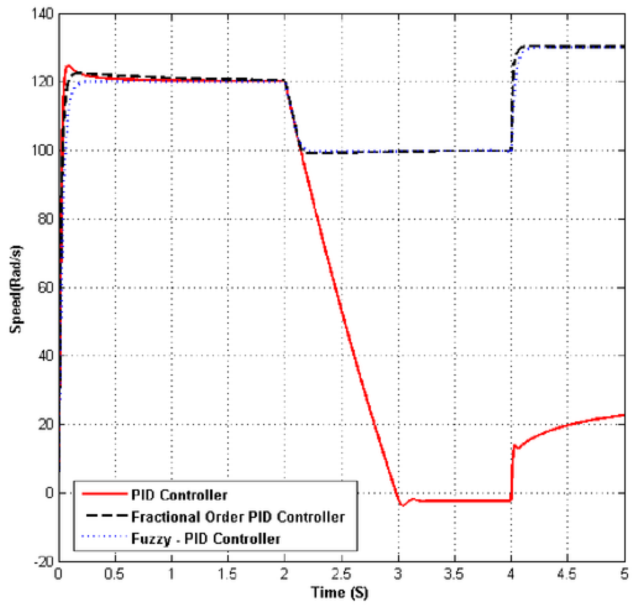

Figure 13. Speed response of Case C (disturbance of speed condition).

It shows that PID performances are less value at both step of load such as overshoot (0.016% and 0.08%), and rapidly stabilize system at both step of load with less rise time (2.025 s and 4.6 s). It is clear that PID has better performance compared with fractional order PID and fuzzy-PID in disturbance of load testing.

C. Case C (disturbance of speed)

In a process system, the DC motor can be operated at varying speed conditions. Therefore, the simulation results in Case C has been obtained for varying reference speed conditions. First step, reference speed isdecreased from 120 rad/s to 100 rad/s at 2 second. Second step, reference speed is increased from 100 rad/s to 130 rad/s at 4 second. The speed response value based the simulation result shows in Figure 13 and tabulated in Table 9 and Table 10.

It points out thatfractional order PID has less value at both step of speed such as undershoot 0.92% and overshoot 0.08%. Moreover, fractional order PID rapidly stabilize system at both step of speed with less rise time (2.11 s and 4.09 s). It is clear that fractional PID and fuzzy-PID in disturbance of speed testing.

TABLE 6 SPEED RESPONSE OF CASE A

Controller	Observed Parameters			
	Overshoot	Rise time	Settling time	Steady state error
PID	2.5 %	0.044 s	1.092 s	3.91 %
Fractional Order PID	2.083%	0.05 s	1.335 s	6.6 %
Fuzzy-PID	0.083%	0.08 s	1.069 s	0.41%

TABLE 7 SPEED RESPONSE OF CASE B 1ST STEP

Controller	Observed Parameters		
	Overshoot	Undershoot	Rise T
PID	0.016%	-	2.025 s
Fractional Order PID	0.41%	-	2.057 s
Fuzzy-PID	-	1.25%	2.15 s

TABLE 8 SPEED RESPONSE OF CASE B 2ND STEP

Controller	Observed Parameters		
	Overshoot	Undershoot	Rise T
PID	0.08%	-	4.6 s
Fractional Order PID	0.58%	-	4.7 s
Fuzzy-PID	-	4.16%	4.15 s

TABLE 9SPEED RESPONSE OF CASE C 1ST STEP

Controller	Observed Parameters		
	Overshoot	Undershoot	Rise T
PID	-	104%	2.10 s
Fractional Order PID	-	0.92%	2.11 s
Fuzzy-PID	-	0.96%	2.13 s

TABLE 10SPEED RESPONSE OF CASE C2nd Step

Controller	Observed Parameters		
	Overshoot	Undershoot	Rise T
PID	-	84.6%	4.5 s
Fractional Order PID	0.19 %	-	4.09 s
Fuzzy-PID	0.76 %	-	4.2 s

VI. Conclusions

This paper present design and implementation of DC motor speed control with various intelligent techniques namely PID, fractional order PID and fuzzy-PID controller. Genetics Algorithm optimally tunes the parameters of PID and fractional order PID controller. While parameters of fuzzy-PID controller is optimally tuned by fuzzy logic. The simulation for various intelligent controllers are designed and implemented on MATLAB/Simulink. Several test are carried out to investigate the performances of various intelligent control. These tests include performance of DC motor in constant condition, disturbance of load and disturbance of speed.Simulation result shows that PID controller has better performance with less value of overshoot and rapidly stabilizes system with less rise time at disturbance of load testing. Fractional order PID controller has less value of undershoot and overshoot, also rapidly stabilize system with less rise time at disturbance of speed testing. Then Fuzzy-PID controller has better performance compared two others in constant condition testing with less overshoot, settling time, and steady state error. Furthermore, a implemetation of various intelligent control techniques for AC motor been an area of active interest in the next work.

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