Comparative Analysis of Different Speed Control Methods for DC Drives

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Abstract – *A comparison and analysis of various DC motor speed control techniques are presented in this study. In this research, the efficiency of proportional-integral-derivative (PID) controllers and fuzzy logic controllers (FLC) for regulating DC motor speed is contrasted. To evaluate the efficacy of each control approach, important performance indicators such overshoot, steady-state error, and settling time are examined through testing and simulation. The findings offer insightful information on how well PID and FLC work in a range of industrial settings. A steady-state inaccuracy of 48.8% is found when the study first assesses the performance of a DC motor without a controller, indicating the necessity for control techniques. When a PID controller is used, the necessary 1.9-second settling time is reached with zero peak overshoot and steady-state inaccuracy. These are outstanding results. Still, the research's usage of a fuzzy logic controller takes an interesting step, showing even more promising results. The fuzzy controller achieves a 0% steady-state inaccuracy, a 0% peak overshoot, and an amazing 1.16 seconds of settling time. The maximum steady-state inaccuracy of 1%, maximum peak overshoot of 5%, and maximum settling time of 2% are in contrast to the ideal parameters for a DC motor.*

Keywords – DC motors, fuzzy logic controller, performance analysis, PID controller, speed control

1. INTRODUCTION

Because of their controllability and versatility, DC motors are essential in many commercial and industrial applications. For DC motors to operate as intended and function at peak efficiency, effective speed control is crucial. Varying the field flux, adjusting the voltage, and modulating the voltage at the armature terminal are examples of conventional speed control techniques. However, the use of sophisticated control algorithms like PID and fuzzy logic controllers is frequently necessary for the accurate regulation of motor speed. [1-5]

In this work, the efficacy of FLC and PID controllers in regulating DC motor speed is compared. To assess how successful each control strategy is, the study looks into important variables like overshoot, steady-state error, and settling time. Electric energy is transformed into mechanical energy for spinning by a DC motor, which is an actuator. By applying varying voltage to the motor, accurate speed control is achieved. Applications where precise and variable speed are needed can benefit from this. It offered speed adjustment that was rapid. Small and medium power applications are best suited for DC motors since they can operate economically and effectively in these power ranges. It is employed because to its great dependability, adaptability, cheapest, robustness, and simplicity. Since loads in many applications might vary, a DC motor's wide range of control of speed and high beginning torque are essential. There are other ways to regulate the DC motor's speed, however in this study, we employ two techniques. PIDs can be controlled using one of two approaches: the fuzzy logic controller method or the traditional approach. The position and speed of DC motors are frequently controlled by PID controllers. because they combine the benefits of proportional integral and derivative to give the necessary control action. Despite having superior close-loop response characteristics, the controllers nevertheless produce satisfactory results; nonetheless, overshoot and a lengthy settling time are noted, necessitating human adjustment. In this research, we used MATLAB Simulink to tweak the parameters. In addition, we employed an alternative controller called a fuzzy logic controller to improve motor control even more. Using spoken language instead of mathematical formulas, The DC motor's speed is managed by the fuzzy logic controller. Non-linear, complex, and time-varying systems are difficult to analyze and regulate with conventional approaches. To address these concerns, Fuzzy Logic Controllers are utilized. It's referred to be human language. With a Basis of Fuzzy Logic Fuzzy Logic Controller converts the language control technique into an automatic control mechanism, which also eliminates the need for human tuning by building fuzzy rules based on expert experience or knowledge databases. This is where intelligence tuning shines, performing admirably. In satisfying these requirements, the fuzzy logic controller performs better than the PID controller. This research not only highlights the significance of control methods in optimizing DC motor performance but also establishes fuzzy logic as a superior approach in achieving the desired operational conditions. The findings contribute valuable insights to the field of DC motor speed control and provide a basis for further exploration and

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application of fuzzy logic controllers in similar systems. [5-24]

Prior research on DC motor speed control does not clearly compare fuzzy logic controllers (FLC) and PID controllers utilizing important metrics such as settling time and overshoot. By directly evaluating their performance under comparable circumstances, this study closes that gap.

2. MATHEMATICAL MODELING OF DC MOTOR

Different facets of PID controller tuning have been investigated in earlier DC motor speed control studies. [1], [10]. Additionally, studies have investigated the application of Fuzzy Logic Controllers in motor control systems [13-14]. A comparative analysis has been carried out to illustrate the benefits and drawbacks of every control strategy.

Since a DC motor running too fast or too slowly might have unfavorable effects, speed regulation is crucial. This speed is controlled by adjusting the supplied Voltage, but this voltage may not perform better result without controller so to save energy, safety and dynamic adjustment we introduced controller.

A DC motor's speed is adjusted in stages. First, we give it voltage, which makes electric current flow. A flux magnetic field is produced by this current. Afterwards, torque a force that twists are produced by this magnetic field. Changing this torque allows us to easily control and modify the DC motor's speed (figure 2). We're use Simulink, a computer simulation program, to compare two approaches in our research on Control DC motor's speed. fuzzy controllers and PID. The heart of our study is the DC motor model, which is like a digital version of the real motor. This model considers important factors like resistance, inductance, and inertia. By testing PID and fuzzy controllers on this model, we aim to figure out the best way to make the motor run smoothly and at the right speed. Our goal is to provide practical insights that can improve how DC motors work in different situations. The DC motor model is depicted in Figure 1. [15-20]

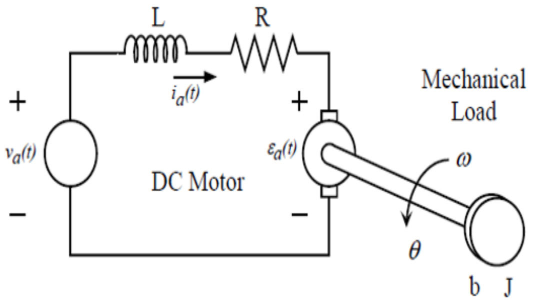

Figure 1: Prototype of DC drive.

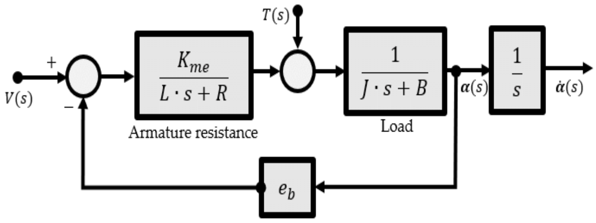

Figure 2: DC drive model in Simulink.

Table 1: Specification of the DC Drive.

Inductance of the armature (La)	0.5 Henry
Resistance to armature (Ra)	1 ohm
Back emf constant (kb)	0.01
coefficient of friction (Bm)	0.1Newton.meter.sec
The inertia of mechanics (j).	0.01 Newton.meter2
Rated speed	1500 rpm
Torque constant (Kt)	0.01

The DC motor circuit diagram is used to derive the mathematical modeling. In Figure 1, the circuit schematic is displayed.

Now, let's derive the transfer function:

- *Electrical equation:*

$$V(t) = Ra.i(t) + La\frac{di(t)}{dt} + Kb.w(t)$$

Taking the Laplace conversion:

$$V(s) = Ra.I(s) + La.s.I(s) + Kb.w(s)$$

- *Mechanical equation:*

$$J.s.w(s) = Kt.I(s) - B.w(s)$$

- *Combine equations:*

$$J.s.w(s) = Kt\frac{(V(s) - Kb.w(s))}{(La.s + Ra)} - B.w(s)$$

- *Solve for angular speed*

$$w(s) = \frac{Kt}{s^2\,(JLa) + s\,(JR + BLa) + BR + KtKb}V(s)$$

- *Derived transfer function:*

$$\frac{w(s)}{V(s)} = \frac{Kt}{s^2\,(JLa) + s\,(JR + BLa) + BR + KtKb}$$

Therefore, the derived transfer function is:

$$\frac{w(s)}{V(s)} = \frac{2}{s^2 + 12s + 20.02}$$

3. METHODOLOGY

Three speed control techniques for DC motors are assessed in this study:

3.1 Not Using Controller

In this instance, there is no controller present for the DC motor. Figure 3 displays the system response, and Table 2 displays the parameter values.

Table 2: Controller-free parameter values.

Maximum overshoot percentage	0
Error in steady state (%)	48.8
Timing of settlement (seconds)	1

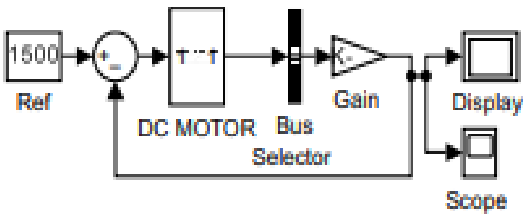

Figure 3: the DC motor with no controller model in Simulink.

3.2 Using the Controller

3.21 Using a PID Controller

PID control action is a combination of derivative (D), integral (I), and proportional (P) control actions. The error in steady states can be decreased using P Controller, but it cannot be completely eliminated. In proportion to the error itself, it offers a prompt reaction to the current error, which is the discrepancy between the intended and actual values. I Controller concentrates on the overabundance of previous mistakes. By progressively raising the control output, steady-state error can be reduced, but the system may experience an overshoot as a result. By taking into account the rate at which errors shift over time, the D controller predicts future errors. It helps dampen the system, lowering oscillation and overshoot, but it may also cause instability. PID controllers provide the intended close loop response and are employed in many different sectors. [2], [7], [9], [11]

When PID controllers are adjusted using a trial-and-error approach in this instance, with gains of Kp=100, Ki=100, and Kd=5, the system Simulink shown in figure 6 and in this case the parameters obtained is shown in table 3.

Table 3: Parameter values with PID Controller.

Maximum overshoot percentage	0
Error in steady state (%)	0
Timing of settlement (seconds)	1.9

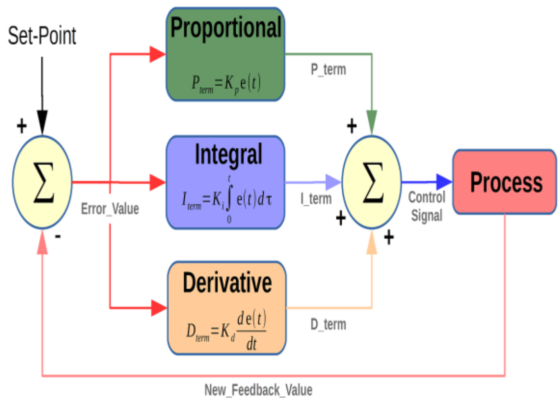

Figure 4: PID controller block diagram.

Figure 4 displays the block diagram for the PID controller and Simulink Figure 5 depicts a PID controller form.

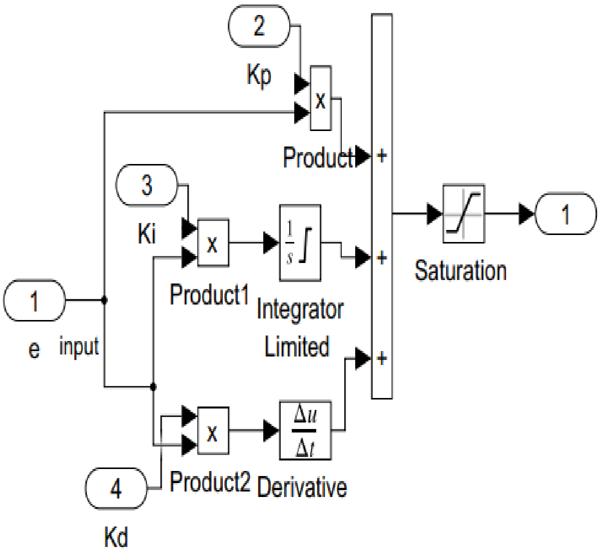

Figure 5: Simulink a picture of a PID controller.

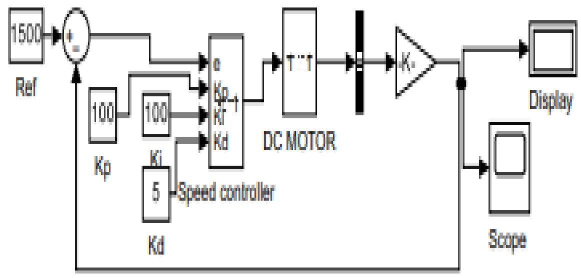

Figure 6: DC motor with a PID controller schematic in Simulink.

3.22 Utilizing a controller employing fuzzy logic (FLC)

The FLC uses language concepts as to modify that motor's power supply according to input features such as error and error change. Expert knowledge and system dynamics are used to define the controller parameters. The per uses inputs for error and error change to create a fuzzy logic controller.

I. For each input, use seven Gaussian membership functions, and for each output, use seven triangle functions.
II. Assign the input membership function range of (-1, 1) and the output function range of (0, 5).
III. Using the IF-THEN technique, create 49 rules for the fuzzy logic controller.
IV. Use the following parameters to get the system response:
   MAXIMUM OVERSHOOT = 0%,
   ERROR IN STEADY STATE = 0%,
   AND TIMING OF SETTLEMENT = 1.16 SEC.

The effectiveness of every technique is evaluated by testing and simulation. The four primary components of this fuzzy system are combined. A precise value, like

1500 RPM, was converted into a fuzzy value, like rapid or slow speed, by the fuzzification module. The Basis of rules describes the way to change a DC motor's power supply in response to unclear input. Variables including the desired speed, the rule may take into account both the current speed and its rate of speed variation. The rule-based system will increase power, for instance, if the required speed is high and the actual motor speed is low. engine of interference. The interference engine makes it easier to modify the DC Motor's power supply in accordance with the laws as they are understood. Defuzzification yields clear decisions. It converts the erratic result (varying degree of power) to a directive that can be utilized to regulate speed precisely. Figure 6 displays the fuzzy logic controller's block diagram. In a fuzzy logic system, there are two inputs: error and change in error. In a standard PID controller, the output voltage or speed is determined by a single input called error. Figure 7 displays a block design of a logic fuzzy controller coupled with a DC motor. [3], [15], [16]

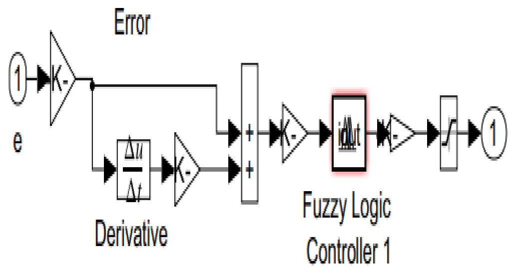

Figure 7: DC motor with logic fuzzy controller block diagram.

Procedures for creating fuzzy logic guidelines:

Step 1: determine the both the information being provided (Input) and the end result (output).
First input: error (E)
Second input: Error change (CE)
The voltage (i.e. speed) output
Step 2: Fuzziness Assignment to excitation and response [NS, ZE, NB, PM, PB, NM, NS] is the first input's error (E).
Second input: Error (I.e. CE) Change [NS, ZE, NB, PM, PB, NM, NS]
Output: voltage (i.e. speed) [NS, ZE, NB, PM, PB, NM, NS]
Step 3: Makes a Decision The 49 rules that are determined are displayed in Table 2.
In step four, set the output and input crisp values.

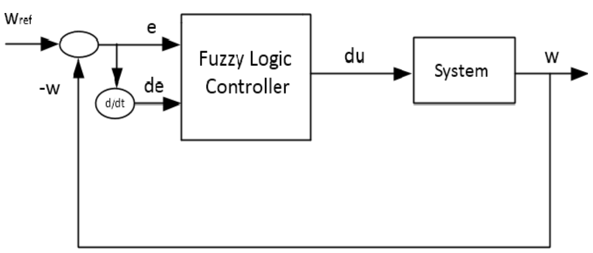

Figure 8: Block schematic of the system with fuzzy logic controller.

In this instance, the range for both input and output are (-1 to 1), and this range value (0 to 5) was chosen since it produces better results than other range values. It is crucial to verify the outcome using various input and output values. However, this value is most appropriate for me. A logic fuzzy controller connected to a DC drive system is shown in block schematic form in Figure 8.

Figure 9 shows the scheme of the excitation membership function, and Figure 10 shows the scheme of the response membership function.

Fuzzy logic rules are constructed by IF-THEN mechanism.

For instance, the outcome will be NB IF error (E) is NB (Negative Big) AND error change (CE) is NB. Table 4 displays all of the rules.

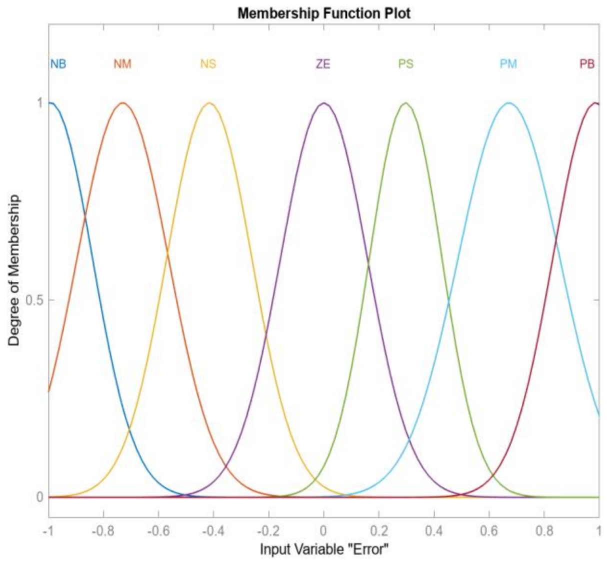

Figure 9: Input membership function plot.

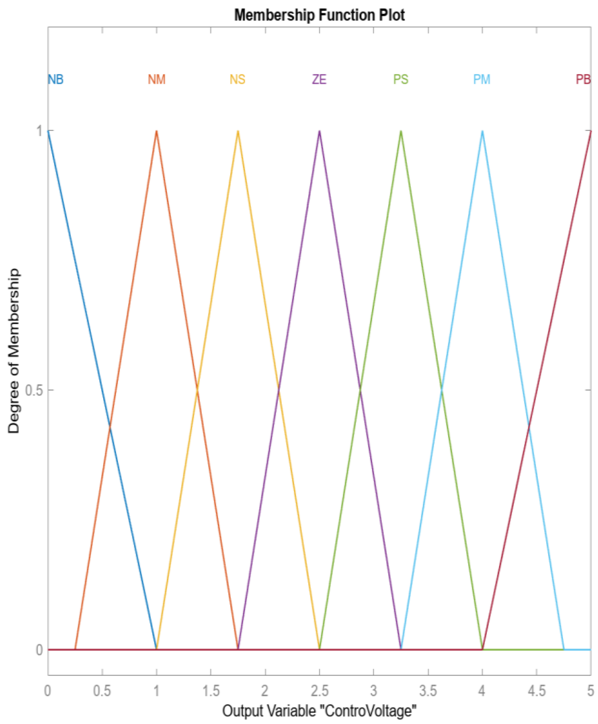

Figure 10: Output membership function plot.

Table 4: Fuzzy Logic rules

E CE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The Implementation of fuzzy with dc motor in Simulink shown in figure 11.

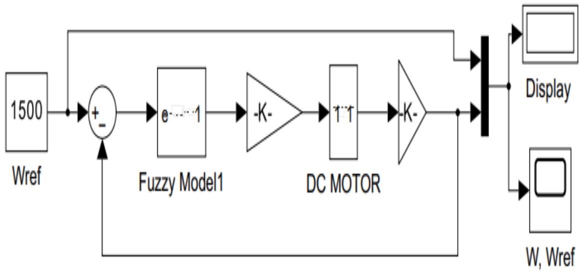

Figure 11: Implementation of fuzzy with dc motor in Simulink.

4. RESULTS AND DISCUSSIONS

The comparative analysis of speed control methods reveals significant differences in performance metrics. The PID controller demonstrates superior steady-state error reduction, while the FLC exhibits faster settling times.

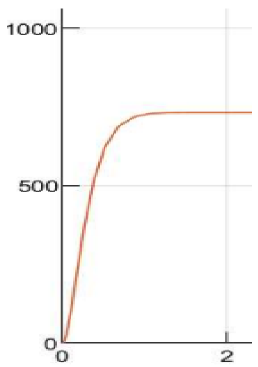

Figure 12: DC motor without controller.

In this scenario, the motor response does not satisfy the intended condition; the steady state error is excessive, and the settling time is also excessive, before introducing the control. DC motor without controller shown in figure 12.

When a PID controller is used in this situation, the response attains the intended value, there is no steady state error, and the settling time is suitable. Figure 13 depicts it.

Here, employing a fuzzy logic controller results in 0% steady state error, no overshoot, and a short settling period. Figure 14 illustrates it.

PID controllers are best suited for well-defined, linear systems requiring precise control, while fuzzy logic controllers excel in handling complex, uncertain, and nonlinear systems. The choice between them depends on the specific application requirements and the nature the system being controlled.

The Result of comparison for all cases (using without controller, with controller like PID and Fuzzy) is shown in table 5.

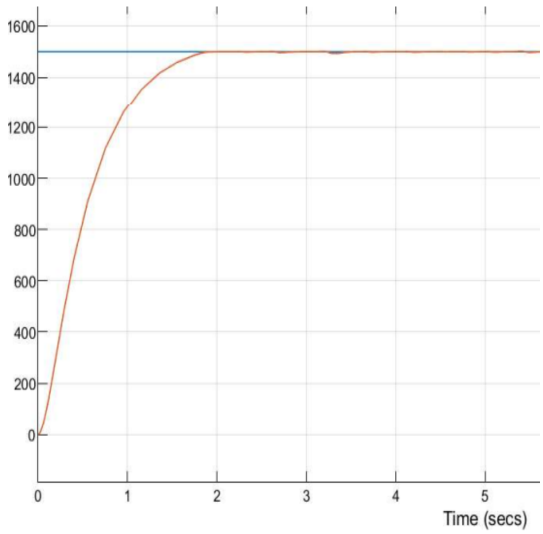

Figure 13: PID controller with DC motor.

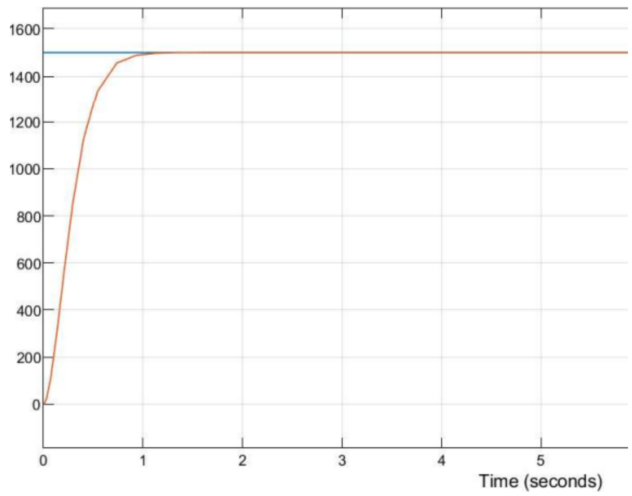

Figure 14: DC motor with fuzzy logic controller.

Table 5: Result of comparison.

Parameter	DC Motor without controller	PID	Fuzzy
Overshoot (%)	0	0	0
Steady state error (%)	48.8	0	0
Settling time(sec)	1	1.9	1.16

5. CONCLUSIONS

In conclusion, both PID and FLC offer effective means of regulating the speed of DC motors The choice between the two depends on specific application requirements and system dynamics. Future research may focus on hybrid control strategies and advanced optimization techniques to further enhance motor performance.

As we conclude from above table 5 the overshoot is always zero in all cases whether we use controllers or not but in case of DC Motor without controller there is a steady state error which is very large and thus our system become undesirable, so we need controller to correct it. So, introducing PID controller become more better as compared to the case in which no controller is used because steady state error becomes zero by using it. Fuzzy controller shows more better response characteristics in terms of settling time as compare to PID controller, in light of this, we can say that in this work, the fuzzy controller outperforms the PID controller in terms of settling time, while the PID controller outperforms the scenario in which no controller is used at all in terms of steady-state error and settling time. This work prepares controllers, which is its contribution.

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