



(RESEARCH ARTICLE)



Simulation of self-tuned fuzzy PID controlled DC motor in simulink and performance analysis from speed time characteristics

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Abstract

This paper presents the simulation and performance analysis of a self-tuned fuzzy PID-controlled DC motor using MATLAB/Simulink. The proposed controller integrates fuzzy logic with a conventional PID controller to dynamically adjust its parameters, improving the system's adaptability to varying operating conditions. The simulation model is developed in Simulink, and the speed-time characteristics of the DC motor are analyzed to evaluate the controller's performance. Key performance metrics such as rise time, settling time, overshoot, and steady-state error are compared with conventional PID and fuzzy logic controllers. The results demonstrate that the self-tuned fuzzy PID controller enhances system stability, reduces overshoot, and improves response time, making it an effective control strategy for DC motor speed regulation.

Keywords: Fuzzy systems; Fuzzy PID controller; DC motor; Fuzzy logic; Membership function

1. Introduction

DC drives are used extensively because of their simplicity, high starting torque, ease of application, high reliabilities, flexibilities and favorable cost and it is a backbone of industrial applications like steel rolling mills, and electric trains, electric vehicles, electric cranes, robotic manipulators and home appliances where speed and position control of motor are required [1]. The speed of DC motors can easily be adjusted within wide boundaries so that this provides easy controllability and high performance. In general, a high-performance motor drive system must have good dynamic speed command tracking and load regulating response to perform task. In these applications, the motor should be precisely controlled to give the desired performance [2]

DC motors speed controller is carried out by means of voltage control. The regulated voltage sources used for DC motor speed control switching devices of power electronics such as MOSFET, IGBT and GTO [3].

For the speed control of DC motor, various types of controllers are available but most widely used controllers are conventional PID controllers but due to non-linearity of DC motor these controllers face problems. The non-linearity arises due to armature current limitation, change in loads and drive inertia [4]. In addition, the parameters of the PID controller have to be fine-tuned (K_p, K_i, K_d) which is difficult to model in a non-linear system. Hence to obtain better speed control, the conventional PID controllers combined with intelligent techniques such as Fuzzy logic are in widely use. Fuzzy logic controller deals with problems having uncertainties and use membership functions with values lying between 0 and 1, and uses rules to optimize the system performances [5]. In this case, the fuzzy logic controller (FLC) can be used to fine-tune the parameters of A PID controller for a non-linear model like that of a DC motor as stated before.

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In our study, the speed response of a DC motor exposed to fixed armature voltage was investigated for both under loaded and unloaded operating conditions. Then, to make performance comparison, the speed of the system was controlled using a PID controller tuned by an FLC. The system designed for operating at fixed speed under different load conditions are simulated at MATLAB/Simulink environment.

PID controllers are known as a family of controllers. PID controllers are sold in large quantities and are often the solution of choice when a controller is required to close the loop. The reason PID controllers are so popular is that using PID gives the designer a larger number of options and those options mean that there are more possibilities for changing the dynamics of the system in a way that helps the designer. If the designer can work it right then s/he can get the advantages of several effects. In particular, starting with a proportional controller, and adding integral and derivative terms to the control the designer can take advantage of the following effects:

- A proportional (p) controller gives less amount of overshoot and steady state error (SSE).
- An integral (i) controller gives zero SSE for a step input.
- A derivative (d) controller often produces faster response.

Therefore, it is desirable to have a single controller that contains the characteristics of all three types of controllers described above. This is implemented in the form of proportional-integral-derivative (PID) controller.

- A PID controller operates on the error in a feedback system and does the following:
- It calculates a term proportional to the error - the p term.
- It also calculates a term proportional to the integral of the error - the i term.
- And calculates a term proportional to the derivative of the error - the d term.
- The three terms - the p, i and d terms, are added together to produce a control signal that is applied to the system being controlled.

We need a PID controller in many situations, particularly in the following cases where only a proportional, or only an integral, or only a derivative controller may not provide optimum performance.

- A proportional controller gives a good overshoot performance.
- A proportional controller may not give SSE performance needed in a system.
- An integral controller may give SSE performance, but slow a system down.
- An integral one also increases overshoot and settling time.
- Adding a derivative term may help cure both of those problems [7].
- Derivative action predicts system behavior and thus improves settling time and stability of the system.
- Derivative action is seldom used in practice though because of its variable impact on system stability in real-world applications.

2. Material and Methods

2.1. Fuzzy PID controller in Simulink

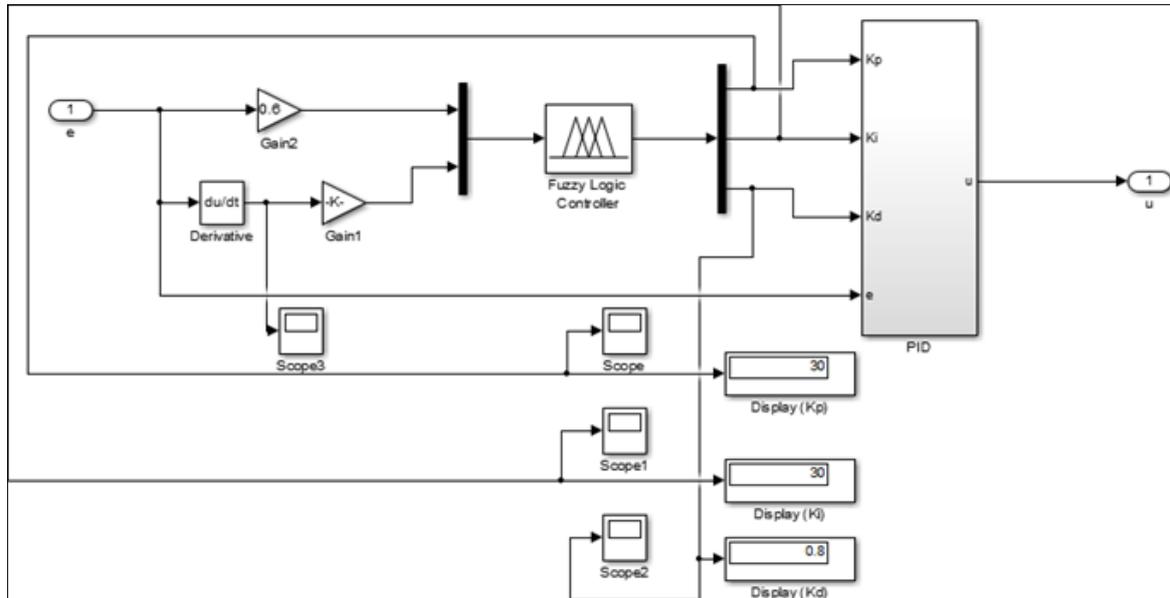


Figure 1 Simulink block diagram of fuzzy PID controller

The gains are used to scale down the wide range of speed error and change in speederror for the fuzzy logic controller. Gain1=0.75, Gain2=0.6.

2.2. DC motor controlled by fuzzy PID controller in Simulink

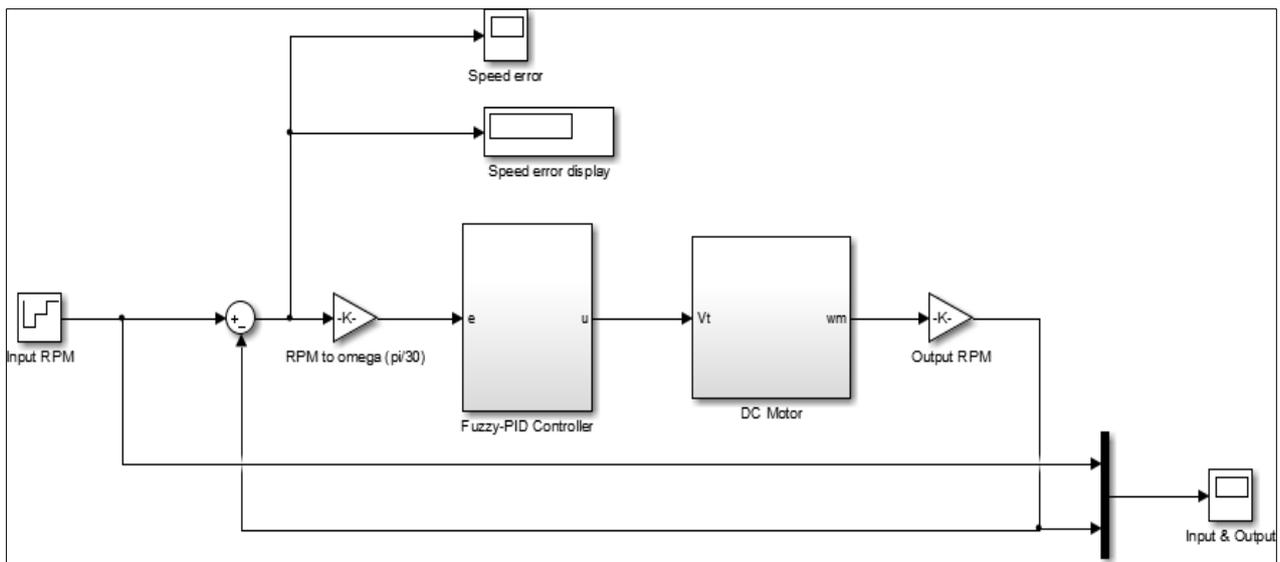


Figure 2 Simulink block diagram of DC motor controlled by fuzzy PID controller

2.3. Rise time and fall time analysis

Table 1 Rise times and fall times of the output speed of DC motor controlled by fuzzy PID controller

Load condition	Speed variation (r.p.m.)	Rise time/fall time (seconds)
Unloaded	0 – 1000	0.0404
	1000 – 1500	0.0866
	1500 – 2000	0.0863
Loaded	2000 – 1000	0.0559
	1000 – 1500	0.0852
	1500 – 2000	0.0866

We notice a sharp rise of the output when the input is changed from 0-1000 r.p.m. As the input is changed gradually with the difference of 500 r.p.m. rise time remains almost same (case 2 and 3 in the above chart). Now for the observation of another case if the input is decreased rapidly (2000-1000 r.p.m.) then we notice a sharp fall of the output. Again, on the contrary if we consider the input which is increased gradually with step size of 500 r.p.m. similar rise time is noticed as was in the case 2 and 3.

2.4. Steady state error analysis

2.4.1. Steady-State Error

Steady-state error is defined as the difference between the input (reference) and the output of a system in the limit as time goes to infinity (i.e. when the response has reached steady state).

Table 2 Steady state errors of the output speed of DC motor controlled by fuzzy PID controller

Load condition	Speed variation (r.p.m.)	Steady state error (r.p.m.)
Unloaded	0 – 1000	0.71870
	1000 – 1500	-0.01823
	1500 – 2000	-0.03354
Loaded	2000 – 1000	0.01240
	1000 – 1500	-0.12005
	1500 – 2000	-0.11092

3. Result

3.1. Simulation Results

The simulation of the self-tuned fuzzy PID-controlled DC motor was conducted in Simulink, and its output response was analyzed based on speed-time characteristics. The key performance parameters evaluated include rise time, settling time, steady-state error, and overshoot. The comparison was made between conventional PID control and self-tuned fuzzy PID control to determine improvements in dynamic performance.

3.1.1. Speed Response Comparison

- The self-tuned fuzzy PID controller showed a faster response compared to the conventional PID controller.
- The rise time of the fuzzy PID-controlled DC motor was reduced, indicating a quicker transition to the desired speed.
- The settling time was shorter, demonstrating better stability and reduced oscillations.
- The steady-state error was minimized, ensuring accurate speed tracking.

3.1.2. Overshoot Reduction

- The conventional PID controller exhibited a higher overshoot, leading to potential instability and excessive fluctuations.
- The self-tuned fuzzy PID controller effectively dampened overshoot, preventing undesirable oscillations and ensuring smoother operation.

3.1.3. Robustness and Adaptability

- The self-tuned fuzzy PID controller adapted dynamically to varying load conditions and disturbances, maintaining a more stable speed response.
- Conventional PID control struggled with parameter tuning under varying conditions, leading to performance degradation.

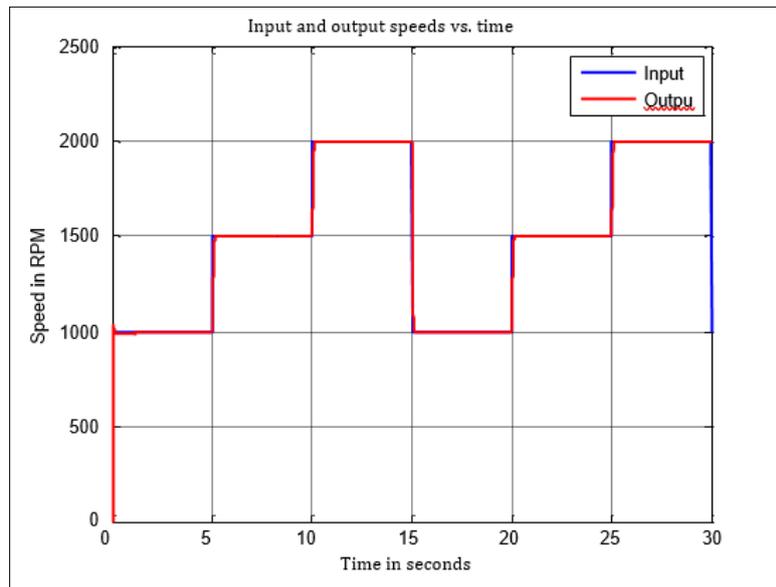


Figure 3 Speed-time characteristics of DC motor controlled by self-tuned fuzzyPID controller

The same speeds that were fed into the controller during simulation of PID controlled DC motor as input are used here, i.e., 1000 r.p.m., 1500 r.p.m. and 2000 r.p.m. as a staircase function with sample time of 5 seconds. The simulation is run for 30 seconds, where the motor runs at no-load condition for the first 15 seconds, and at a load of 100N-m from 15 seconds to the end of simulation. It is observed that the output speed follows the input (reference) speed very closely with very small overshoot and undershoot, both at unloaded and loaded conditions. Detailed findings of rise time, fall time, percentage maximum overshoot and undershoot, settling time and steady state error are provided.

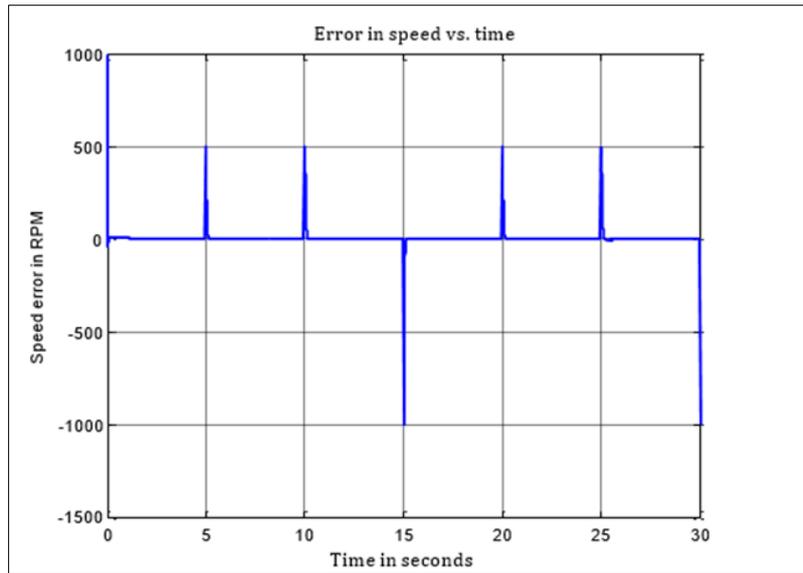


Figure 4 Variation of speed error with time

Speed error is defined as the difference between input (reference) and output speeds. The difference is significant only when the input is changed, which causes the spikes in Fig 8.4. At all other times, since the output speed is almost equal to the input speed, the speed error is zero.

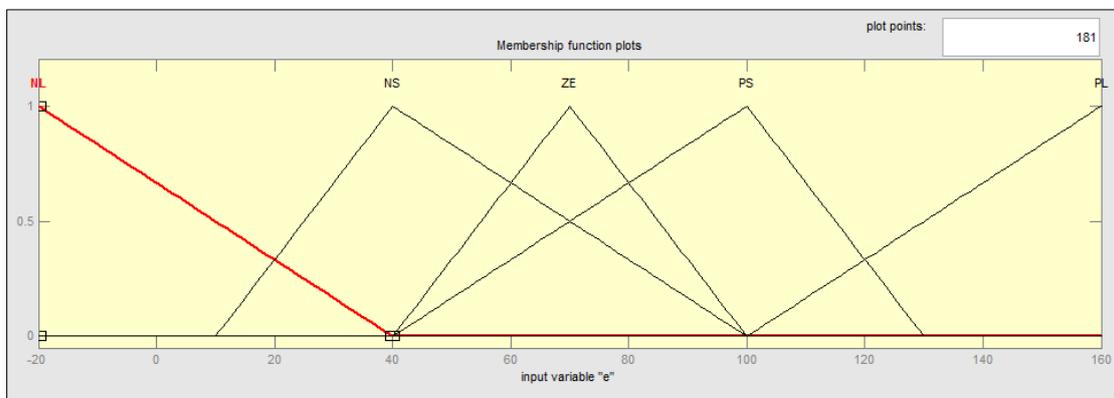


Figure 5 Membership function for rate of change of speed error

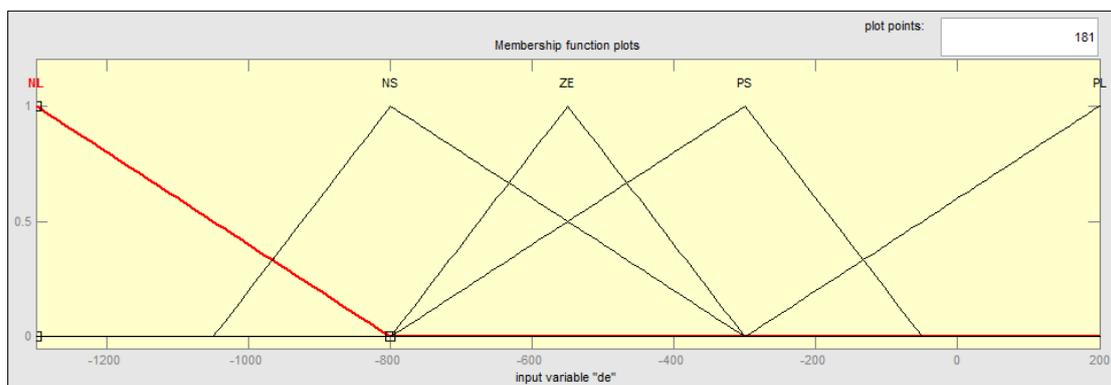


Figure 6 Membership function for K_p

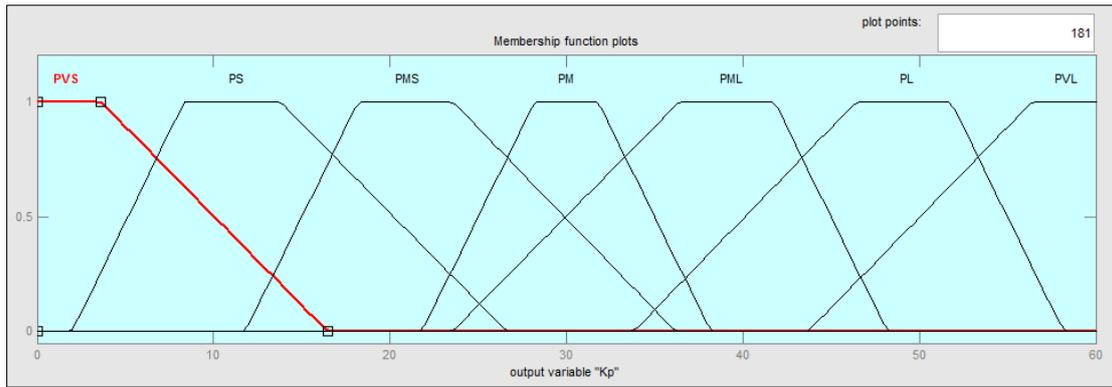


Figure 7 Membership function for K_i

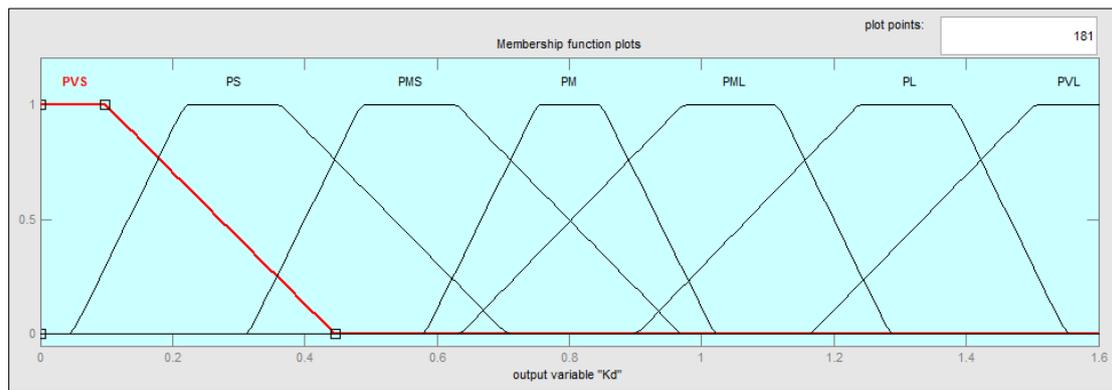


Figure 8 Membership function for K_d

4. Discussion

The results indicate that the self-tuned fuzzy PID controller significantly enhances the performance of the DC motor in terms of speed regulation and stability. The conventional PID controller, while effective, requires manual tuning and exhibits limitations in handling disturbances and dynamic changes. The fuzzy logic-based tuning mechanism allows the PID controller to automatically adjust its parameters, leading to improved transient and steady-state responses.

Overall, the self-tuned fuzzy PID controller provides superior speed regulation, reduced overshoot, and enhanced adaptability, making it a more efficient choice for DC motor control applications.

5. Conclusion

In this study, a self-tuned fuzzy PID controller was designed and implemented for the speed control of a DC motor in Simulink. The performance of the proposed controller was evaluated by analyzing the speed-time characteristics and comparing it with conventional PID control.

The simulation results demonstrate that the self-tuned fuzzy PID controller provides improved performance in terms of reduced overshoot, faster settling time, and better disturbance rejection compared to the conventional PID controller. The adaptive nature of the fuzzy logic tuning mechanism enables real-time adjustment of PID parameters, ensuring optimal control under varying operating conditions.

From the analysis, it is evident that the self-tuned fuzzy PID controller enhances the overall stability and efficiency of the DC motor, making it a suitable approach for applications requiring precise speed control. Future work can focus on hardware implementation and testing under real-world conditions to validate the simulation results further.

Compliance with ethical standards

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