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Analysis and Design of A Fuzzy-PID Controller for DC Motor

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***Abstract*--In this project we have designed a DC Motor for which speed can be controlled by using various controllers like P, PI, PID, Fuzzy. By using different controllers, we can compare various performances of the DC Motor. Initially the speed of the motor is controlled by using a PID controller and the gains of the controller i.e., proportional, integral and derivative gains are adjusted by the rules of a fuzzy logic controller. A fuzzy logic controller consists of fuzzy rules which are used to control both the input and output of the system. A fuzzy logic controller alone can also be used to control the speed of a motor, but a combination of both Fuzzy and PID gives us a better performance rather when compared to an individual PID and Fuzzy. A comparison is made among all the controllers mentioned above and finally concluded that a combination of Fuzzy-PID gives us better performance among all.**

Keywords: DC motor, PID controller, Fuzzy controller, Fuzzy logic, Fuzzy-PID

I. INTRODUCTION

DC Motors are widely used in industrial processes because of its high reliability, flexibility and its minimal cost. These motors are used in industrial applications, home appliances, and in robot manipulators where the control of speed and position are required. Many control techniques were invented through which we can control the equipment and obtain the desired performance. A better control technique can be chosen for a deigned circuit so that the performance characteristics of the motor are improved with its use. Here our aim is to calculate the various performances of a DC motor which are the rise time, peak time, settling time, and overshoot and to control the speed of the same. For this, initially, we have designed a separately excited DC motor for which there is no speed control and then implemented a conventional PID controller with the inputs as proportional gain Kp, integral gain Ki, and derivative gain Kd. The PID controller is manually tunned and it's a bit difficult to obtain accuracy. At times the PID causes an overshoot due to its drawbacks of larger time delay and its distributed parameters, therefore, the invention of logical techniques like the Fuzzy-Logic controller approach are invented.

Fuzzy logic controller is a mathematical tool that is necessary to handle the uncertainty due to vagueness. FLC's are more robust when compared to a PID controller. The fuzzy logic was implemented by Lofti. A. Zadeh in 1965 which was a generalization of the classical set theory. It deals with human relating concepts and approximations.

II. MODELLING OF A DC MOTOR

A separately excited DC motor has an independent voltage which is supplied to the field and armature windings is used to control the performance of the motor. By using the traditional approach, we can control the motor by using either the field control or the armature voltage control method.

Armature voltage control method is more advantageous when compared to field control method as it retains its maximum torque capability and allows to vary the speed below its rated speed.

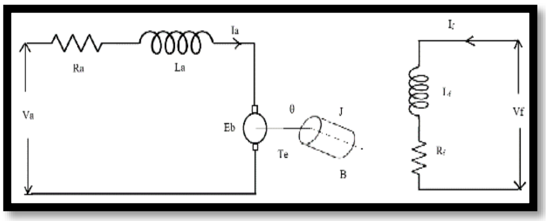

Fig.1. DC motor representation

Let V_f be the fixed voltage applied at the field and I_f be the field current.

The linear model consists of both mechanical and electrical equations.

The electrical equation is given by,

$$E_b \propto \frac{V_a - I_a R_a}{\emptyset}$$

$$E_b = \frac{V_a - I_a R_a}{K_a \emptyset}$$

Where $\emptyset$ is the flux per pole

K_a is the armature constant

The armature voltage is given by,

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

By applying Laplace transformation, we get,

$$V_a(S) = E_b(S) + I_a(S) R_a + sL_a I_a(S)$$

The mechanical system differential equations are given by,

$$T_e = J\frac{d\omega_r}{dt} + B\omega_r + T_L$$

By applying Laplace transformation, we get,

$$T_e(S) = sJ\omega_r(S) + B\omega_r(S) + T_L(S)$$

The back emf of the motor is proportional to the speed of the motor and is given by,

$$E_b = K_b \omega_r$$

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The motor equation is proportional to the armature current and is given by,

$$T_e = K_T \omega_r$$

Where ω_r is the speed of the motor
J is the moment of inertia
B is the friction of the motor
T_e is the electromagnetic torque
T_L is the load torque
K_T is the motor torque constant
K_b is the back emf constant

The block diagram representation of the armature-controlled DC motor system is represented as,

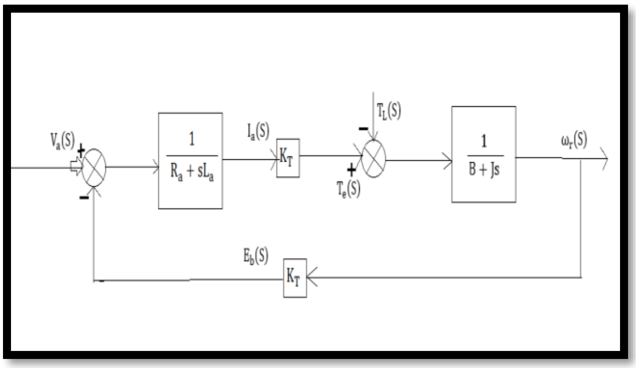

Fig.2. Armature-controlled DC motor system

Hence the overall transfer function is given as,

$$\frac{\omega_r(S)}{V_a(S)} = \frac{\frac{K_T}{(R_a + sL_a)(B + Js)}}{1 + K_b\left[\frac{K_T}{(R_a + sL_a)(B + Js)}\right]}$$

$$\frac{\omega_r(S)}{V_a(S)} = \frac{K_T}{(R_a + sL_a)(B + Js) + K_b K_T}$$

The Simulink representation of a DC motor is shown below.

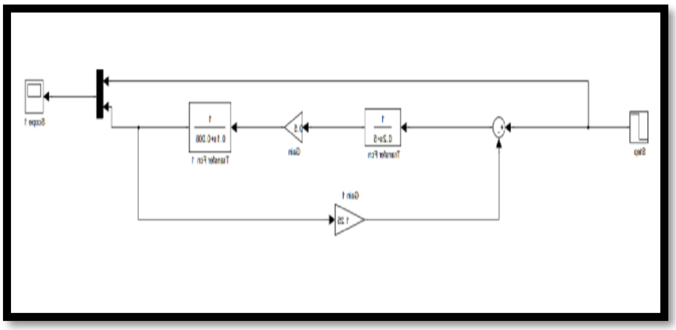

Fig. 3. Speed control of DC Motor without controller

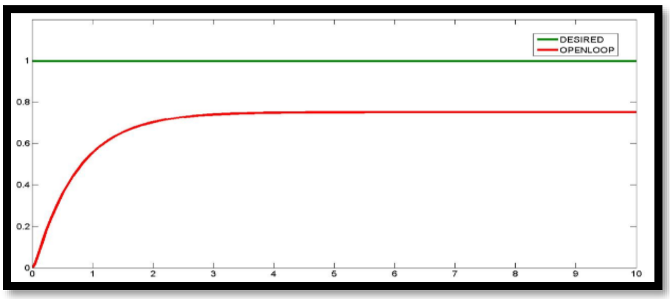

Fig. 4. Simulink output of DC motor without controller

III. METHODS OF TUNING

The speed of a DC motor can be controlled by using different tunning techniques.

- PID Controller
- Fuzzy Logic Controller
- Fuzzy-PID Controller

A. *PID Controller*

A PID controller is a closed loop controller with a feedback system which is extended in a wide range of industrial applications. By adjusting the values of the proportional gain, derivative gain and integral gain we can control the overall performance of the system. The input of this controller is the error e(t) which is the difference between the actual value and the desired value, whereas the output u(t) is obtained from the calculated values of Kp, Ki and Kd. The block diagram representation of a conventional PID controller is represented as,

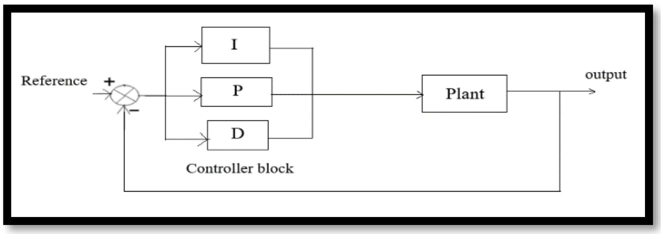

Fig. 5. Block Diagram of PID Controller

For a better characteristic performance, the PID is tunned either manually or automatically. Here we have used manual tunning to obtain the values of Kp, Ki and Kd. The simulink representation of the PID controller is shown below,

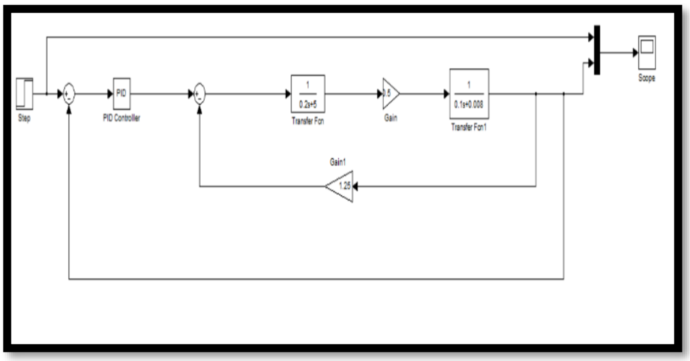

Fig. 6. Speed Control of Dc Motor Using PID Controller

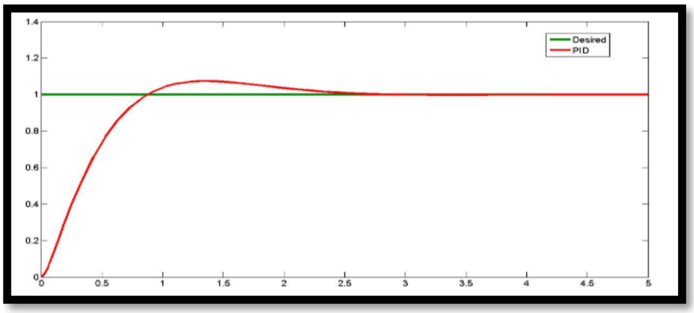

Fig. 7. Simulink output of PID controller

B. *Fuzzy controller*

Fuzzy logic controller is an efficient control technique used to solve a control problem. It depends upon the fuzzy inference rules which works on the condition of IF-THEN rules. These rules are easy to compute rather than a

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mathematical model. The fuzzy IF-THEN rules are defined by continuous membership functions. These rules are used to implement the necessary control action to be taken by the variables. Each rule is represented as IF X AND Y THEN Z. The structure of a fuzzy logic controller has the following components. They are.,

- Fuzzification
- Fuzzy rule-base
- Fuzzy inferencing
- Membership function
- Defuzzification

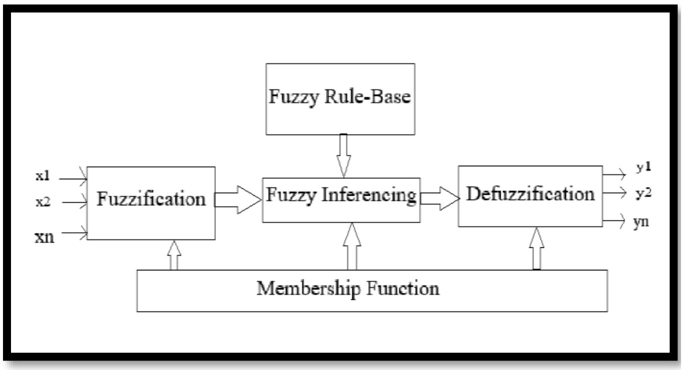

Fig. 8. Block diagram representation of Fuzzy Logic controller

1) *Fuzzification:* In this process, the crisp values are transformed into linguistic variables. The membership functions are calculated for each part of the crisp value.
2) *Fuzzy Rule-Base:* The rules are given in the format of IF-THEN in which IF is a set of CONDITIONS and THEN is a set of CONSEQUENTS. The fuzzy rule base is knowledge based in the form of a dimensional table. The rules are chosen depending upon the input variable and the output variable. The fuzzy rules vary depending upon the input variable.
3) *Fuzzy Inferencing:* The data obtained from the fuzzification process is combined with the rule base values and fuzzy reasoning process is done.
4) *Membership Function*: The input data is transformed in the range of 0 to 1 in the universe of discourse U to fuzzy set. These membership functions exist in different shapes such as., trapezoidal, triangular or curved.
5) *Defuzzification*: In this process, the fuzzy values are computed back to the real-world data. It is the reverse process of the fuzzification.

The Simulink representation of a Fuzzy Logic controller is represented as shown below.

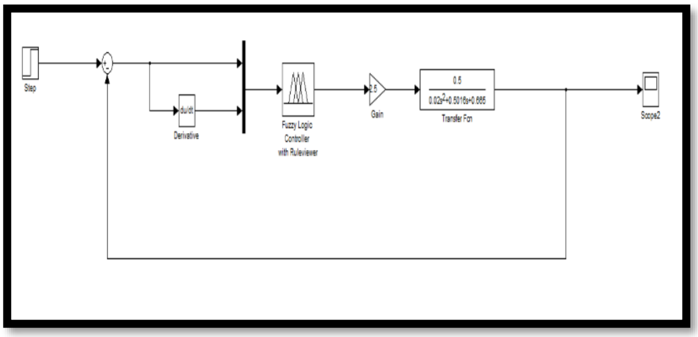

Fig. 9. Speed Control of Dc Motor Using Fuzzy Controller

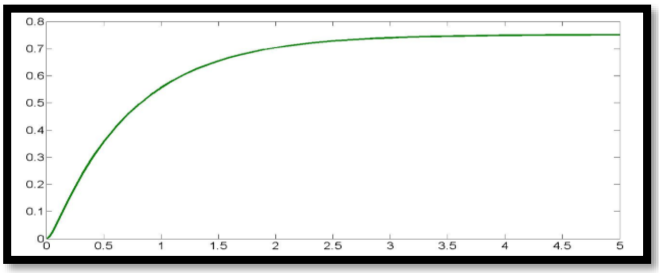

Fig. 10. Simulink output of fuzzy controller

C. Fuzzy-PID Controller

A combination of fuzzy logic controller and PID controller is implemented for the DC motor. The inputs of the fuzzy controller are the error and change in error, whereas, the outputs are the inputs of the PID controller which are the gains kp, ki, and kd. By implementing the fuzzy rules for each of gain values we have observed that at kp=30, ki=12 and kd=5 we have obtained the desired response.

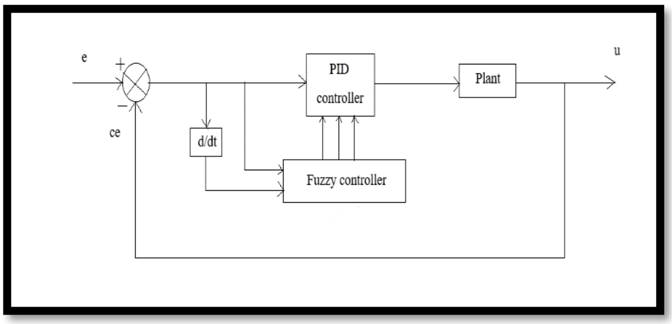

Fig. 11. Block diagram representation of FUZZY-PID controller

The Simulink representation of the fuzzy-PID system is designed as shown below.

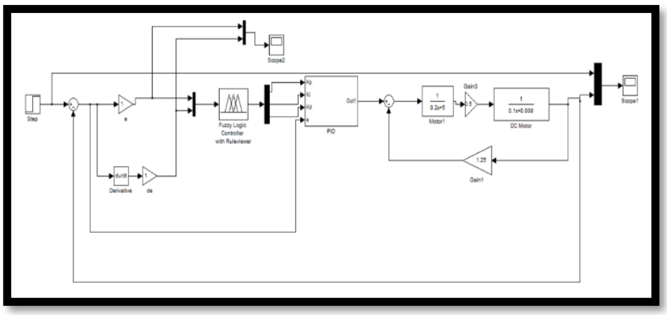

Fig. 12. Speed control using Fuzzy-PID controller

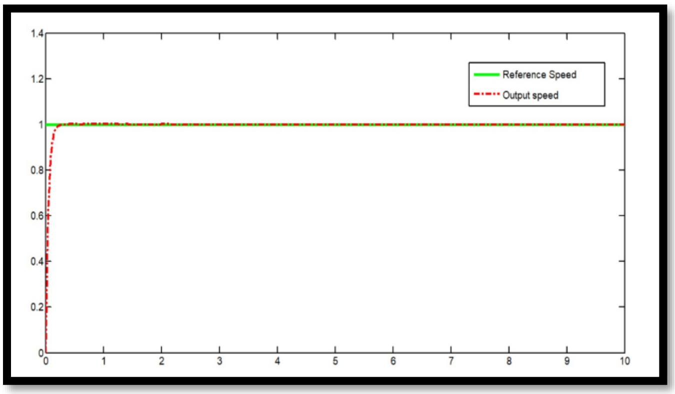

Fig. 13. Simulink output of Fuzzy-PID controller

IV. CONCLUSION

In this paper, we have designed various control techniques like the PID, Fuzzy and a Fuzzy-PID for the control of DC motor's speed. By using MATLAB-SIMULATION, we have obtained the output results and observed that rather than a conventional PID controller and an FLC, it is better to opt for a combination of the two which is the Fuzzy-PID controller. The proposed method gives more precise and accurate performance characteristics. An FLC has higher flexibility, controllability and better dynamic performance than a PID. Hence, a combination of Fuzzy-PID gives an appropriate control for the designed motor.

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