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Comparative Analysis of Speed Control Techniques of DC Motors with Matlab

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***Abstract*— In this paper, various speed control techniques for a dc shunt motor namely conventional method without using any controller, using a PID controller and speed control by Fuzzy Logic Controller have been discussed and a comparative analysis have been done between them. The models have been developed using MATLAB SIMULINK and the comparative analysis is based on the speed responses obtained by simulation of the models.**

***Keywords*— Speed Control, PID Controller, Fuzzy logic Controller, MATLAB, SIMULINK**

I INTRODUCTION

DC motor is a power actuator which converts electrical energy into mechanical energy. DC motor is used in applications where wide speed ranges are required. The greatest advantage of dc motors is speed control. The term speed control stands for intentional change of the drive speed to a value required for performing the specific work process. Speed control is either done manually by the operator or by means of some automatic control device. DC motors are most suitable for wide range speed control and are therefore used in many adjustable speed drives. Since speed is directly proportional to armature voltage and inversely proportional to magnetic flux produced by the poles, adjusting the armature voltage or the field current will change the rotor speed. Thus the conventional speed control techniques include the control of speed by three methods
(i) By varying the flux per pole. This is known as flux control method.
(ii) By varying the resistance in the armature circuit. This is known as armature control method.
(iii) By varying the applied voltage V. This is known as voltage control method.

Other than these, various controllers are used to have a better speed response of the DC motor.

Proportional-Integral-Derivative (PID) controller has been used for several decades in industries for process control applications. The combination of proportional, integral and derivative control action is called PID control action. PID controllers are commonly used to regulate the time-domain behavior of many different types of dynamic plants. These controllers are extremely popular because they can usually provide good closed-loop response characteristics. Though they give satisfactory results, an overshoot is observed and the settling time is more. Therefore manual tuning of PID controller is necessary.

For further improvement of the speed response characteristics of the DC motor, another controller called Fuzzy Logic Controller (FLC) has been developed. Fuzzy logic control is a linguistic control algorithm which uses general statements instead of the mathematical equations to define the control scheme of the responses. Due to this technique, a wide range of values are included in the set which leads to better rise time, less speed fluctuations and overshoots. With fuzzy logic controller, manual tuning is eliminated and intelligent tuning takes the centre stage with satisfactory performance.

DC motors is used in many industrial applications such as electric vehicles, steel rolling mills, electric cranes and robotic manipulators due to precise, wide, simple and continuous control characteristics.

II MODELLING OF DC MOTOR

The expression for speed of a DC motor is given as

$$N= [V-I_a(R_a + R)]/k\ \varphi$$

Therefore speed of DC motor can be varied by controlling the following quantities:

(i) External resistance in armature circuit R

(ii) Flux per pole φ

(iii) Voltage of the armature V

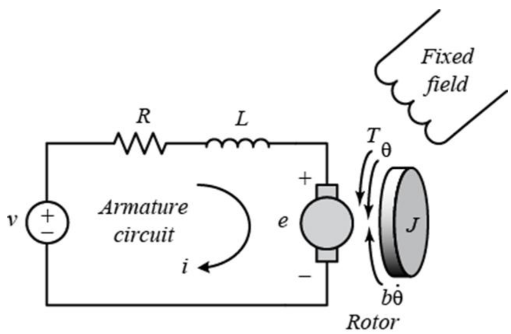

Fig1: DC Motor Model

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Here we assume that the input of the system is that voltage source (*V*) applied to the motor's armature, while the output is the rotational speed of the shaft d(θ)/dt. The rotor and shaft are assumed to be rigid. We further assume a viscous friction model, that is, the friction torque is proportional to shaft angular velocity.

In general, the torque generated by a DC motor is proportional to the armature current and the strength of the magnetic field. In this example we will assume that the magnetic field is constant and therefore, that the motor torque is proportional to only the armature current *i* by a constant K_t. This is referred to as an armature-controlled motor.

The armature voltage equation is given by:

$$V_a = E_b + I_a R_a + L_a (dI_a/dt) \quad (1)$$

The torque balance equation will be given by:

$$T_m = J_m(d\omega/dt) + B_m\omega + T_L \quad (2)$$

The overall transfer function of the above considered motor is given by,

$$\theta(s)/V_a(s) = k\phi/ (L_a J_m s^2 + R_a J_m s + k^2\phi^2) \quad (3)$$

For the DC motor with certain given parameters, the overall transfer function of the system is obtained as:

$$\theta(s)/V_a(s) = 0.5/ (0.002s2 + 0.050s + 0.629) \quad (4)$$

Using the above transfer function the SIMULINK model of dc motor has been designed as below:

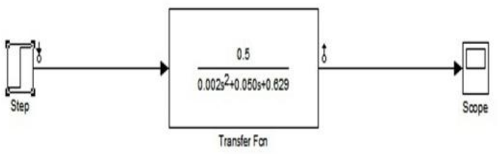

Fig2: SIMULINK Model for DC Motor

The design requirements of the systems may vary from one system to another. For our case, we want a fast response of the system to an error. The overshoot of the system should not be higher than 5% and the settling time should be smaller than 2 seconds.

The main design requirements are as follows;

Settling time should be less than 2 seconds;

Overshoot of the system should be less than 5%;

Steady state error should be less than 1%

III INCORPORATING PI CONTROLLER IN SIMULINK MODEL OF DC MOTOR

The combination of proportional, integral and derivative control action is called PID control action. PID controllers are commonly used to regulate the time-domain behavior of many different types of dynamic plants.

These controllers are extremely popular because they can usually provide good closed-loop response characteristics.

The block diagram incorporation PID controller to the existing dc motor model is shown below:

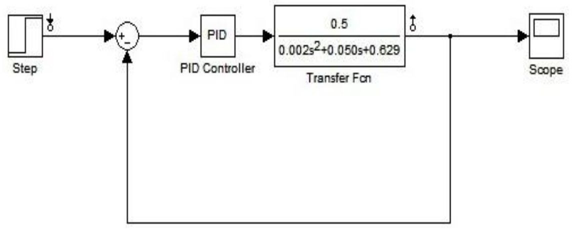

Fig3: SIMULINK Model of DC Motor with PID controller

Here by varying the values of the parameters of the PID controller Kp, Kd and Ki, different responses are obtained for the system.

III FUZZY LOGIC CONTROLLER (FLC)

Fuzzy logic is a method of rule-based decision making used for expert systems and process control that emulates the thought process of human beings. The basis of fuzzy logic is ‘fuzzy set theory’ which was developed by Lotfi Zadeh in the 1960s.

Generally, a fuzzy system has four modules.

i) Fuzzification

ii) Fuzzy Inference

iii) Rule base

iv) Defuzzification

The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called **Fuzzification.** In others words, means the assigning of linguistic value, defined by relative small number of membership functions to variable.

Under inference, the truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. Mostly MIN or PRODUCT is used as inference rules. In MIN inference, the output membership function is clipped off at a height

For the rule bases a classic interpretation of Mamdani was used. Under rule base, rules are constructed for

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outputs. The rules are in "If Then" format and formally the If side is called the conditions and the Then side is called the conclusion. A rule base controller is easy to understand and easy to maintain for a non- specialist end user and an equivalent controller could be implemented using conventional techniques.

Defuzzification is a process in which crisp output is obtained by the fuzzy output. Two of the most common techniques are the CENTROID and MAXIMUM methods. In the CENTROID method, the crisp value of the output variable is computed by finding the variable value of the centre of gravity of the membership function for the fuzzy value. In the MAXIMUM method, one of the variable values at which the fuzzy subset has its maximum truth.

Here we have considered two inputs to the fuzzy controller, input1(e) and input2(ce). We consider the output as output1. We have used three triangular membership functions for each of the input and output variables namely: **Low(L)**, **Medium(M)**, **High(H)**. The input1 variables range from 0 to 0.2, input2 variables range from 0 to 0.8, output1 variable range from 0 to 0.8.

The fuzzy rules are now defined as **"If (input1 is L) and (input2 is L) then (output1 is L)"** which can be depicted in the rule table below:

Table1: Fuzzy Inference Rule Table

e/ec	L	M	H
L	L	M	M
M	L	M	H
H	M	M	H

IV SIMULINK MODEL OF DC MOTOR WITH FLC

For the purpose of advanced speed control, we implement the FLC in SIMULINK. The SIMULINK model is shown below.

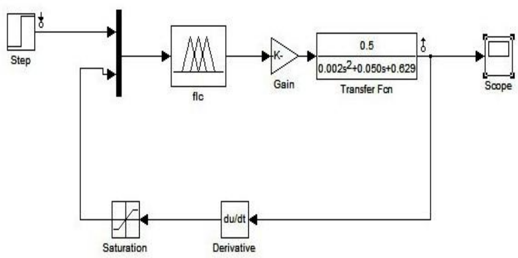

Fig4: SIMULINK Model of a DC Motor with FLC

V RESULTS OBTAINED

For the purpose of comparative analysis of the various speed responses of the DC motors, we simulate all the three Simulink models i.e. without using any controller, using PI controller and using FLC. Then we combine all the three responses in a single plot.

By considering a 1rad/sec step reference, the response obtained by the DC motor speed analysis is shown below:

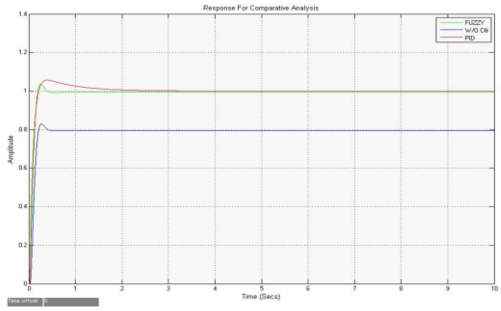

Fig5: Speed Responses Combined on a Single Plot

From the graph, the following results can be obtained

Table2: Comparative Analysis

	Rise Time(s)	Settling Time(s)	% Overshoot	Steady-state value
Without any controller	0.121	0.337	3.46	0.795
With PID	0.4183	1.417	4.8	1
With FLC	0.120	0.3748	3.7	1

V CONCLUSION

This work finally gives a comparative analysis between the Simulink responses obtained for speed of a dc motor without controller, with PI controller and with FLC. After observing the responses we can finally draw the following conclusions:

i) The settling time of the fuzzy logic controller is lower as compared to the PID controller. Though the settling time without the use of any controller is better than the fuzzy logic controller, it does not attain the steady state value of the step reference of 1rad/sec. As such its steady state error is very high which does not satisfy the design requirements.

ii) The percentage overshoot of the Fuzzy logic controller is the lowest. The lower overshoot leads to lesser vibrations and variations in the attainment of the desired speed response by the fuzzy logic controller.

iii) The rise time is the lowest for the Fuzzy logic controller. This leads to the fast response to the desired value.

iv) The PID and Fuzzy logic controller attains the steady state value of 1, thus eliminating the steady state error.

The PID controller though reduces the steady state error, shows significant overshoot and higher settling time. The Fuzzy Logic Controller has the least settling time and the overshoot value is reduced to acceptable limits. Thus we can conclude that the Fuzzy Logic Controller shows the best speed response characteristics. It shows higher flexibility, control, better dynamic and static performance compared with conventional controller and PID controller. Moreover it satisfies the design parameters as mentioned above with conventional controller and PID controller. Moreover, it satisfies the design parameters as mentioned above. Thus Fuzzy Logic Controller is the preferred choice for the controlling the speed response of the DC Motor.

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Appendix

Meaning of the different parameters used are
V_a is the armature voltage (Volts)
E_b is back emf the motor (Volts)
I_a is the armature current (Ampere)
R_a is the armature resistance (Ohm)
L_a is the armature inductance (Henry)
T_m is the mechanical torque developed (Nm)
J_m is moment of inertia (Kg/m²)
B_m is friction coefficient of the motor (Nms)
ω is angular velocity

The default values of the parameters are

Armature resistance (R_a) = 0.5Ω
Armature inductance (L_a) = 0.02 H
Armature voltage (V_a) = 200 V
Mechanical inertia (J_m) = 0.1 Kg.m2
Friction coefficient (B_m) = 0.008 N.m/rad/sec
Back emf constant (k) = 1.25 V/rad/sec
Motor torque constant (k) = 0.5 Nm/A
Ki=100
Kd=10
Kp=100
Step response=1 rad/sec