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A Simple Approach to DC Motor Modeling and Comparative Implementation of PI and FLC for its Speed Controlling

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ABSTRACT: Brushless DC motor rapidly gained popularity due to its high efficiency and accurate control characteristics. For any industrial and domestic application it is necessary to control the speed accurately. This paper is presenting to make an attempt for modeling a DC motor by its electrical equivalent circuit for its simplicity and also the comparative implementation of the widely used controller that is Proportional-Integral controller (PI) and Fuzzy logic controller for controlling of the dc drives. The DC motor modeling, the control structure, comparison, evaluation and simulation is done by Matlab/Simulink. The drawbacks of the conventional PI controller for the speed control can be overcome using Fuzzy Logic controller. The results obtained from simulation shows that the fuzzy logic controller is better than PI for controlling the DC drive for a reference change or for changes in load.

KEYWORDS: DC Motor, DC motor's equivalent circuit, DC motor modeling, PI controller, Fuzzy logic controller.

I. INTRODUCTION

The speed controlling is a major factor for DC motor using in many applications which contains robotic manipulators, electric trains, electric cranes, steel mills and electric vehicles. For easy controlling and good performance a wide range speed controlling is required for DC motors.

The PI controller is the most common controller using in industries and also widely using with dc drives for controlling it in a feedback manner. In the case of nonlinear systems such as DC drive it undergoes some problem because in dc drives the non-linearity may occur in the form of armature current changes, variation in motor inertia, load variation etc. The quick step response is one of the most performance factor of a controller. [2] And the step response is desire to be with less settling time and less overshoot. So because of these limitations the fuzzy logic controller is used with dc drives which control these drawbacks. Fuzzy logic controller give better response to a system because it admit human intelligence into the process. Here in this study fuzzy logic controller (FLC) and the PI controller both are used with DC motor model to compare the results of both for speed controlling.

II. MODELING OF MOTOR

The main aim of modeling is to find the applied voltage, torque, current, and speed related differential equations The Fig.1 shows the motor's electrical equivalent circuit with general mechanical system of DCmotor that show the mechanical parameters and the mechanism coupled to it [4]. The terms shown in Fig.1 are explained in Table.2.

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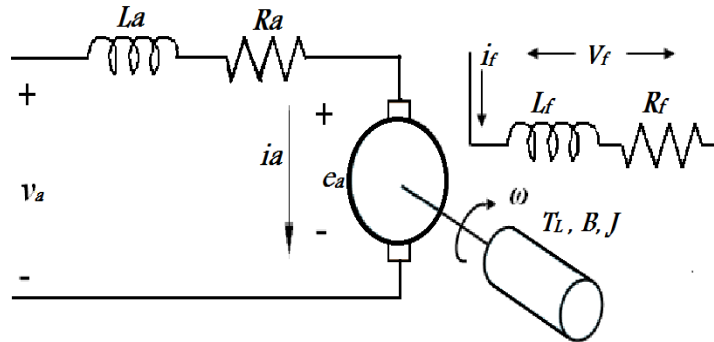


Fig.1. DC motor's Electrical equivalent circuit

To obtain the equation from armature side, the Kirchoff law is applied to armature circuit and the following equation is obtained for the input voltage.

$$V_a = L \left(\frac{di_a}{dt} \right) + R i_a + E_a \quad 1$$

The armature current is obtained from above equation as shown in below equation.

$$\frac{di_a}{dt} = (V_a - R i_a - E_a) / L \quad 2$$

Where

$$E_a = K_e K_t I_a \quad 3$$

From applying Kirchoff law on field circuit the following equations are derived for the input field voltage applied.

$$V_f = L \frac{di_f}{dt} + R i_f \quad 4$$

$$\frac{di_f}{dt} = (V_f - R_f i_f) / L \quad 5$$

The mechanical system is described in following equations.

$$T_e = T_L + J \left(\frac{d\omega}{dt} \right) + B\omega \quad 6$$

$$\frac{d\omega}{dt} = (T_e - T_L - B\omega) / J \quad 7$$

Where

$$T_e = K_t \cdot 2 I_a \quad 8$$

All the terms used in above expressions are explained in Table.2.

The model of DC motor from equation (2), (5) & (7) is obtained by Simulink which is shown in Fig.2.

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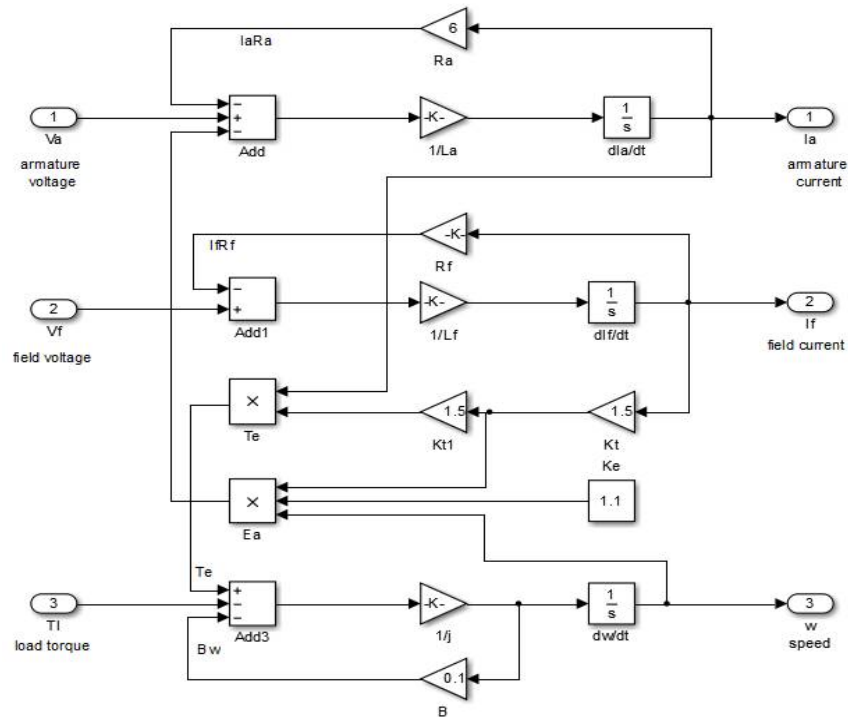


Fig.2. Simulink model of DC motor's Electrical equivalent circuit

III. CONTROLLERS

The controllers used are designed by Simulink. The main aim of the controller is to maintain the output speed of motor according to reference speed desired. To obtain the required reference a limitation is required for controller according to the rating of the motor. In this paper the PI and FLC controller are used.

A. PI Controller

The Proportional-Integral (PI) controller is the most using and famous controller from the past decade used in industrial applications. In PI the control law is given by the following equation:

$$T = K_p e + K_i \int e dt \tag{9}$$

Where T shows the output, K_p shows the proportional gain, K_i shows the integral gain and e is for instantaneous error. In control variable for the elimination of steady state error, for a good performance and to obtain or maintain the good controlled results the PI controller gains (K_p and K_i) are changed according to some rules even in the case of nonlinear drive or in the presence of variation in parameters. To simulate high variation in the speed command of the controller the value of error is increased to a high value at starting time. The system can become destabilized if the variation in the command speed become very high and this can be occur if the gains of the controller cross a certain value. A limiter is used at the output of PI to solve this problem. The speed error can be bounded to a limits by the limiter by which the variation in speed become smooth even if the gains are too high. By this without overshoot, without steady state error, the motor gain the reference speed with rapid rejection of load disturbances and with control on variation in motor parameters.

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B. Fuzzy Logic Controller

Fuzzy logic controller (FLC) tries to implement the human’s knowledge about controlling a system. The Fuzzy Logic controller (FLC) is consist of four main units. The basic FLC system is shown in Fig.3.

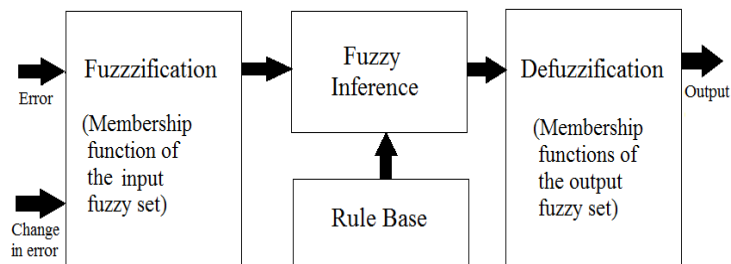


Fig.3. Fuzzy Logic Controller

The four units are Fuzzification which convert the input non-fuzzy data to suitable linguistic variables. The second is fuzzy inference which make a decision for input according to a set of rules provided by the third unit which is rule base. The forth unit is defuzzification which convert the output fuzzy signal to a non-fuzzy output suitable to apply to a plant or to a system. [5] In this study the Mamdani type of fuzzy logic controller is used. Two inputs of FLC are speed error (e) and the change in speed error. By comparing the actual and reference speed the error is calculated. The major important thing in FLC is the if-then rules and the design of membership function for the input and output. [2] In this study the five membership functions are used for input and output which is shown in Fig. 4. Where MN is for more negative value, N is for Negative value, Z is for Zero value, P is for Positive value, and MP is for more positive value. In this study five membership functions are used, and of triangular shape for simplicity.

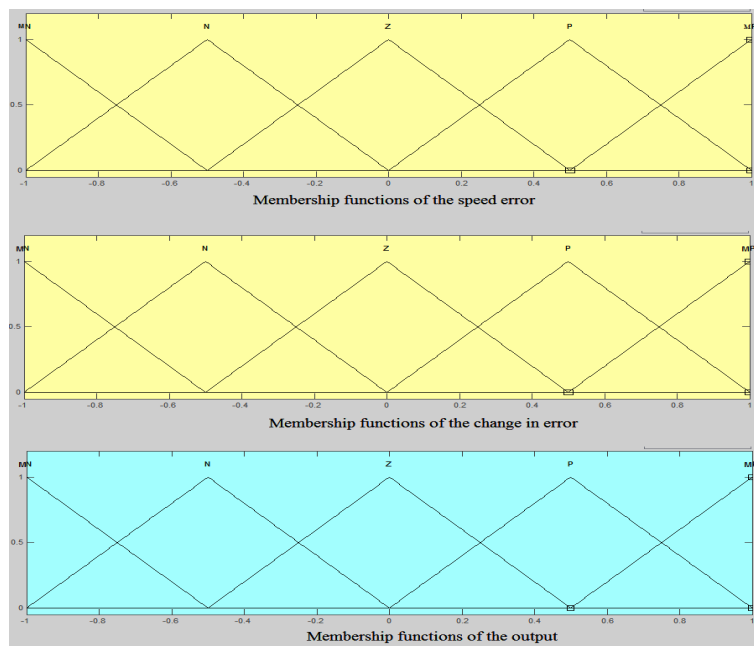


Fig. 4. FLC’s Membership functions for input & output

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Now the rules will be defined. The 25 rules will be used in this study for controller simplicity and for its fast response. These rules are defined in Table 1.

Table 1. FLC Rule Table

Membership Functions		Change in Error				
		MN	N	Z	P	MP
E R R O R	MN	MN	MN	N	N	Z
	N	MN	N	N	Z	P
	Z	N	N	Z	P	P
	P	N	Z	P	P	MP
	MP	Z	P	P	MP	MP

IV. SIMULATION & RESULTS

The Simulink is used for simulation of the system.

A. Simulation of DC Motor model with PI Controller

DC motor model with PI controller is simulated by Simulink as shown in Fig.5.

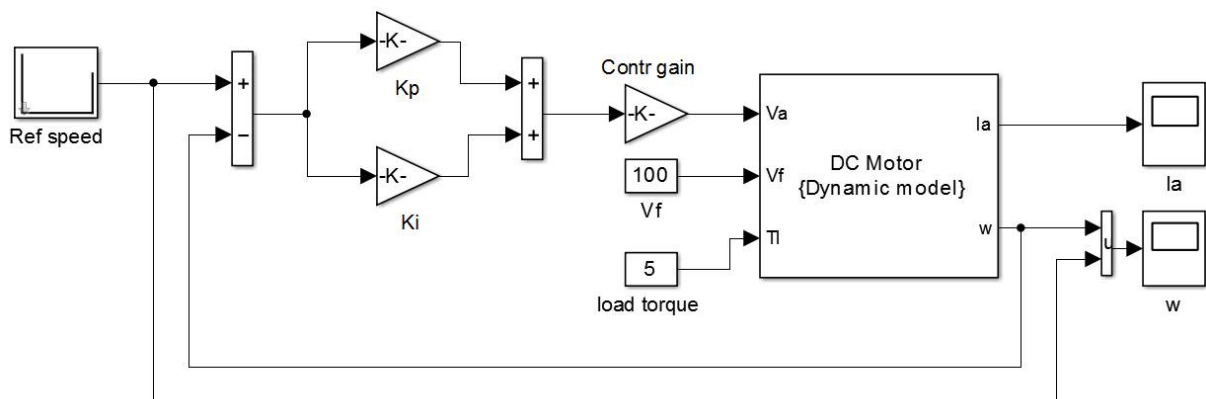


Fig. 5. Simulink diagram of DC Motor model controlled by PI controller

The circuit is simulated for a reference of 100 rad/s for up to 0.5 sec, -50 rad/s for 0.5 to 1 sec and 50 rad/s for 1 to 1.5 sec of time. The simulation result is shown in Fig.6.

From Fig.6 we can observe that PI controller give good result for speed control of DC motor. It gain the required speed quickly but it has some ripples after these ripples the output become smooth and equal to reference required input. These ripple and settling time is changed with changes in proportional or integral gain value, and this is better results which can be obtained by PI controller.

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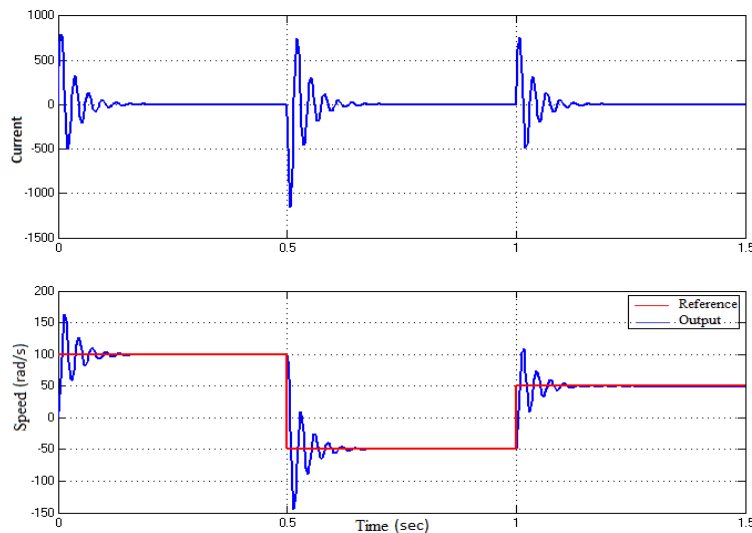


Fig.6.Simulation result for PI controller

B. Simulation of DC Motor model with Fuzzy Logic Controller

DC motor with Fuzzy logic controller is simulated by Simulink as shown in Fig.7.

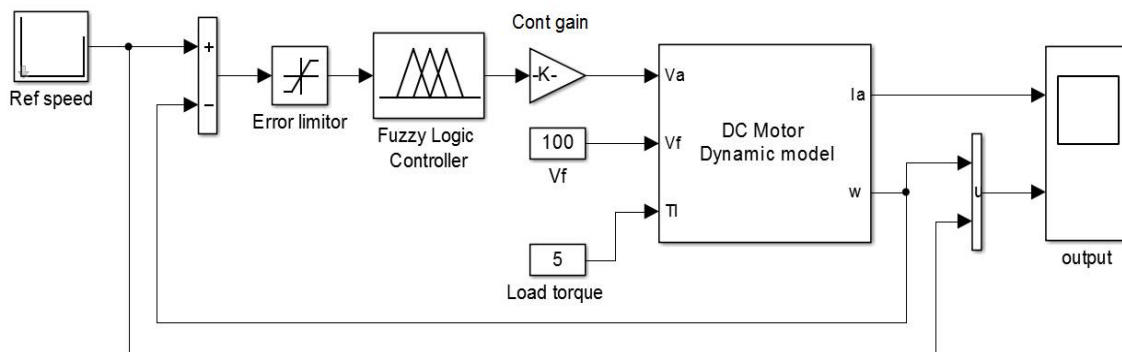


Fig.7.Simulink diagram of DC Motor model with Fuzzy Logic Controller

The circuit is also simulated here like for PI controller for a reference of 100 rad/s for up to 0.5 sec, -50 rad/s for 0.5 to 1 sec and 50 rad/s for 1 to 1.5 sec of time. The simulation result is shown in Fig.8.

The input to FLC is applied through limiter to maintain the input within the range for FLC and the output of FLC is applied to motor by a gain named as controller gain. From Fig.8 it is cleared that the Fuzzy logic controller give good result than PI controller for controlling of DC motor. It take a little more time than PI controller to gain the required reference speed but it have very little ripples than PI controller and the output become stable and smooth very quickly.

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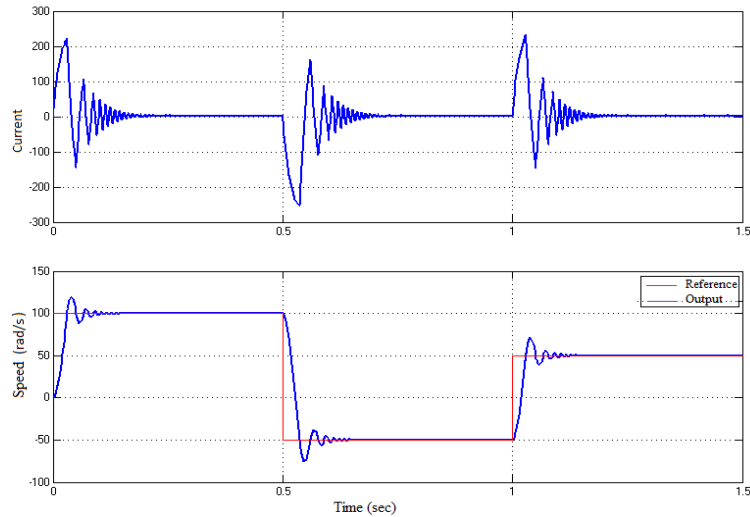


Fig. 8.Simulation result for Fuzzy logic controller

C. Comparison of PI and Fuzzy Logic Controller

To decide which controller is better, the result of both controllers are combined in a graph and compared. The combined result is shown in Fig. 9.

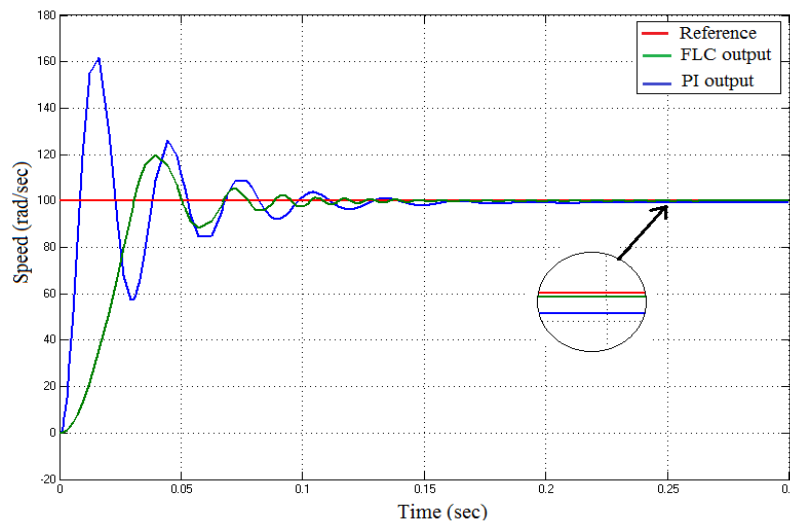


Fig. 9.Combine result of PI & Fuzzy logic controller

Fig.9 show result for only 0.3 sec. here the red line show the reference , blue signal show the PI controller output and the green signal show the fuzzy logic controller output. From figure it is cleared that PI controller make a quick attempt to gain the reference value but it have more pulse ripples and it became stable latter than the fuzzy logic controller. The fuzzy logic controller take more time than PI controller to reach the reference value but it have less ripples and became stable in less time. And if we zoom it we can observed that fuzzy logic controller have more accuracy than PI controller. So at result Fuzzy logic controller give better results.

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V. CONCLUSION

Speed response characteristics of dc motor were obtained by Simulink. The result for PI controller have a settling time and have ripples. These defects are overcome by Fuzzy logic controller which have less settling time comparing to PI and also have less ripples. At starting time the FLC have good response than PI and for variation in load torque the PI controller have good performance but have problem of high starting overshoot and high settling time. As a result it is concluded that FLC has clearly better performance for providing rise time, overshoot and steady state error compare to PI controller. FLC also has more sensitivity to disturbance in load with respect to PI controller.

VI. APPENDIX

Table 2. Specifications of DC Motor & PI Controller

Parameter	Value
Armature Resistance, R_a	6.5 Ω
Armature Inductance, L_a	0.11H
Field Resistance, R_f	101 Ω
Field Inductance, L_f	0.1H
Field voltage, V_f	100v
Armature voltage, V_a	200v
Torque constant, K_t	1.5Nm/A
Armature back emf constant, K_e	1.1v/rad/s
moment of inertia, J	0.001 kg.m ²
viscous friction constant, B	0.11 N.m.s
Proportional Constant, K_p	0.015
Integral constant, K_i	1

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