Speed Control of Separately Excited Dc Motor Using Fuzzy Logic Controller

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***Abstract*— This paper demonstrates the importance of a fuzzy logic controller over conventional method. The speed control of a separately excited DC motor is performed using fuzzy logic controller (FLC) in MATLAB environment. The controller is designed based on the expert knowledge of the system. For the proposed dc motor case, there are 9 fuzzy rules designed for fuzzy logic controller. The output response of the system is obtained by using two types of controllers, namely, PID and fuzzy logic controller. The performance of the designed fuzzy controller and classic PID Speed controller is compared and investigated. Finally, the result shows that the fuzzy logic approach has minimum overshoot, minimum transient and steady state parameters, which shows more effectiveness and efficiency of FLC than conventional PID controller.**

KEYWORDS: Fuzzy logic controller, PID control, Simulink, DC motor, Fuzzy inference system, Membership function.

I. INTRODUCTION

Accurate control is critical to every process that leads to various types of controllers which are being widely used in process industries. Tuning methods for these controllers are very important for process industries. The aim of this paper is to design a fuzzy logic controller for speed control of a DC motor. Because of their high reliabilities, flexibilities and low costs, DC motors are widely used in industrial applications, robot manipulators and home appliances where speed and position control of motor are required.

All control systems suffer from problems related to undesirable overshoot, longer settling times and vibrations and stability while going from one state to another state. Real world systems are nonlinear, accurate modelling is difficult, costly and even impossible in most cases conventional PID controllers generally do not work well for non-linear systems. Therefore, more advanced control techniques need to be used which will minimize the noise effects. To overcome these difficulties, there are three basic approaches to intelligent control: knowledge based expert systems, fuzzy logic, and neural networks. All three approaches are interesting and very promising areas of research and development [6]. In this paper, we present only the fuzzy logic approach. Fuzzy logic, proposed by Lotfi A. Zadeh in 1973. Zadeh introduced the concept of a linguistic variable. The fuzzy logic, unlike conventional logic system, is able to model inaccurate or imprecise models. The fuzzy logic approach offers a simpler, quicker and more reliable solution that is clear advantages over conventional techniques.

Fuzzy Logic has been successfully applied to a large number of control applications. The most commonly used controller is the PID controller, which requires a mathematical model of the system. A fuzzy logic controller provides an alternative to the PID controller.The control action in fuzzy logic controllers can be expressed with simple "if-then" rules. Fuzzy controllers are more sufficient than classical controllers because they can cover a much wider range of operating conditions than classical controllers and can operate with noise and disturbances of a different nature. [7]

II. SYSTEM MODELING OF SEPARATELY EXCITED DC MOTOR

The term speed control stand for intentional speed variation carried out manually or automatically DC motors are most suitable for wide range speed control and are there for many adjustable speed drives.

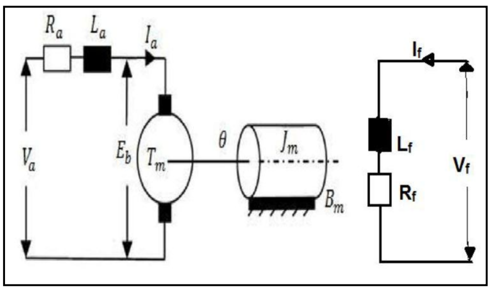

Fig.1 separately excited dc motor model

The armature voltage equation is given by:

$$V_a = E_b + I_a R_a + L_a \left(\frac{dI_a}{dt}\right) \quad (1)$$

Now the torque balance equation will be given by:

$$T_m = J_m \left(\frac{d\omega}{dt}\right) + B_m\, \omega + T_L \quad (2)$$

Friction in rotor of motor is very small (can be neglected), so Bm = 0 Therefore, new torque balance equation will be given by:

$$T_m = J_m \left(\frac{d\omega}{dt}\right) + T_L \quad (3)$$

Taking field flux as Φ and Back EMF Constant as K. Equation for back emf of motor will be:

$$E_b = K\varphi \quad (4)$$

Also,

$$T_m = K\varphi I_a \quad (5)$$

Taking Laplace transform of the motor's armature voltage equation we get

$$I_a(S) = (V_a - E_b)/(R_a + L_a\, S \quad (6)$$

Now, taking equation (4) into consideration, we have:

$$I_a(S) = (V_a - K\varphi\omega)/R_a\left(1 + L_a\frac{S}{R_a}\right) \quad (7)$$

And

$$\omega(S) = (T_m - T_L\,)/J_S = (K\varphi I_a\, - T_L\,)/\, J_m S) \quad (8)$$

Armature Time Constant

$$T_a = \frac{L_a}{R_a} \quad (9)$$

III. BLOCK DIAGRAM

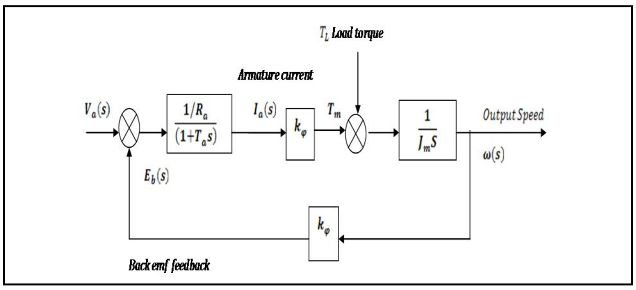

Fig.2 Block diagram of separately excited dc motor

After simplifying the above motor model, the overall transfer function will be

$$\frac{\theta(s)}{V_a(s)} = \frac{k\varphi}{L_a J_m s^2 + R_a J_m s + k^2\varphi^2} \quad (10)$$

For the DC motor with parameters given in Appendix A, the overall transfer function of the system is given as:

$$\frac{\theta(s)}{V_a(s)} = \frac{0.5}{0.002S^2 + 0.050S + 0.625} \quad (11)$$

IV. FUZZY LOGIC CONTROLLER

A. Description

Fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. Fuzzy logic control technology has been widely and successfully utilized in industrial applications. Fuzzy Logic is a multi-valued logic, that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low and emerged as a tool to deal with uncertain, imprecise, or qualitative decision making problems. Fuzzy logic is a way to make machines more intelligent to reason in a fuzzy manner like humans.

A fuzzy logic model is a logical-mathematical procedure based on an "IF-THEN" rule system that mimics the human way if thinking in computational form. Generally, a fuzzy rule system has four modules.

- Fuzzification
- Fuzzy Inference
- Rule base
- Defuzzification

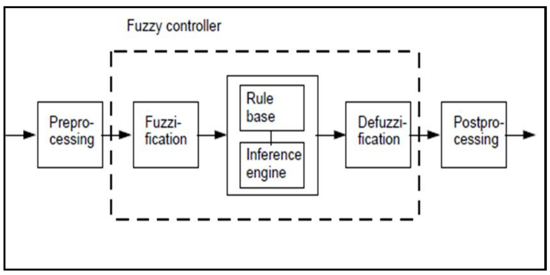

Fig.3 Structure of fuzzy logic controller

Fuzzification

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.

Fuzzy inference

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 corresponding to the rule premise's computed degree of truth (fuzzy logic AND). In PRODUCT inference, the output membership function is scaled by the rule premise's computed degree of truth.

Rule base

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

Defuzzification is a process in which crisp output is obtained by the fuzzy output. In other words, process of converting fuzzy output to crisp number. There is more Defuzzification methods in which two of the more 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 value is chosen as crisp value for the output variable [8].

B. Designing procedure

This paper presents a methodology for rule base fuzzy logic controller applied to a system. Before running the simulation in MATLAB/SIMULINK, the Fuzzy Logic Controller is to be designed. This is done using the FIS editor. FIS file is created using the Fuzzy logic toolbox. The design of a Fuzzy Logic Controller requires the choice of Membership Functions. After the appropriate membership functions are chosen, a rule base is created. The set of linguistic rules is the essential part of a fuzzy controller. The various linguistic variables to design rule base for output of the fuzzy logic controller are enlisted in Table I. The response of the fuzzy logic controller is obtained using in MATLAB/SIMULINK. A two input which is Speed Error (e) & Change in Error (ec) and one – output Change in control, fuzzy controller is created and the membership functions and fuzzy rules are determined. The membership functions (MF) for inputs are shown below in Fig. 4(a), 4(b) and the MF for output is shown in fig. 4(c).

1) Membership functions for inputs and output variables

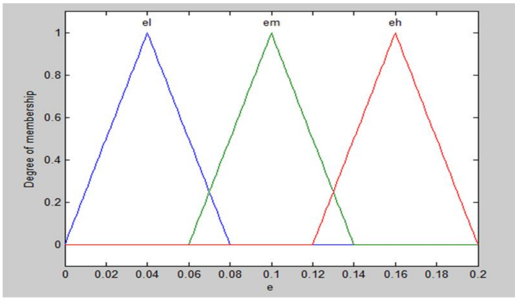

Fig. 4(a) Fuzzy input variables "error".

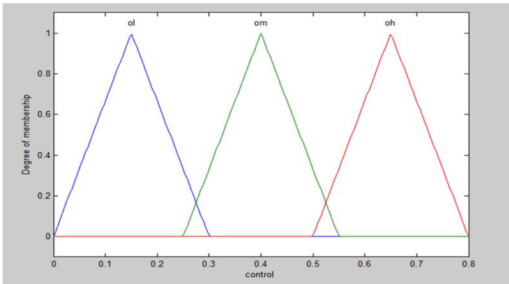

Fig. 4(b) Fuzzy input variables "change in error"

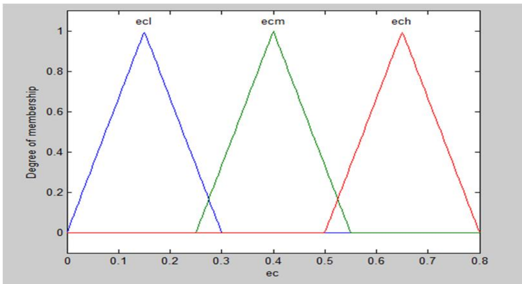

Fig. 4(c) Fuzzy output variable "control".

2). Fuzzy inference rule

TABLE I
RULE TABLE FOR OUTPUT VARIABLE"CONTROL"

e/ec	ecl	ecm	ech
el	ol	om	om
em	ol	om	oh

eh	om	om	oh

3). Construction of rules and rule viewer

In figure 5(A) fuzzy if-then rules are shown and in figure 5(B) Analysis of the two inputs (error and change in error) and output are shown. There are total 9 rules output variable.

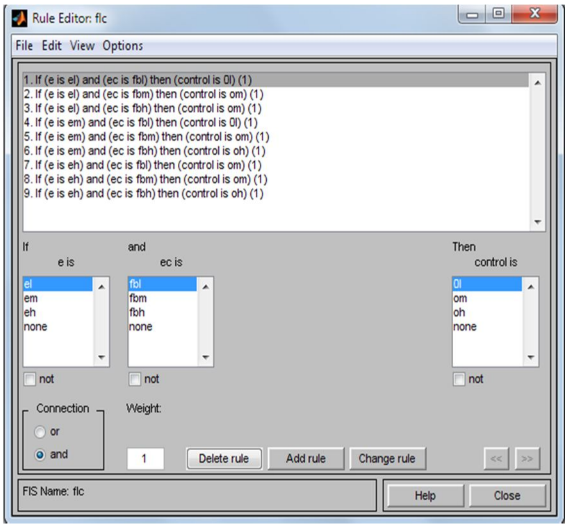

Fig. 5(A) Fuzzy If – then rules

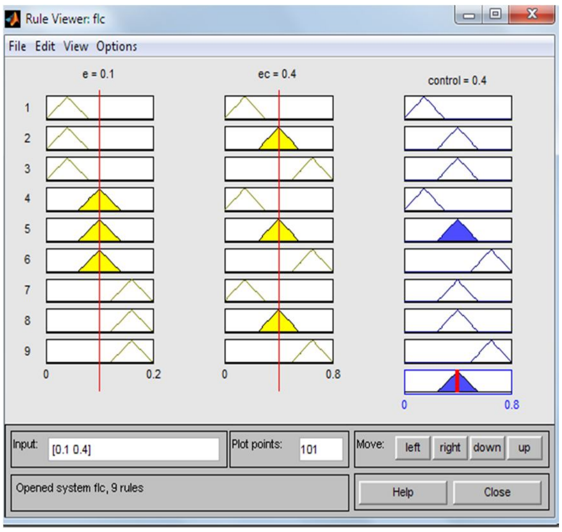

Fig. 5(B) Analysis of both the inputs and outputs

V. SIMULINK IMPLEMENTATION AND RESULTS

The results of the system with using different type of controllers are shown here. The responses of the system with several controllers such as PID, Fuzzy Logic Controller are being applied. In this section transfer function of the separately excited dc motor is used as a system and find out the response of the system applying the step function as an input.

A. PID controller

Figure 6 shows the PID control system designed in MATLAB/Simulink where controller parameters are adjusted using (Z-N) method.

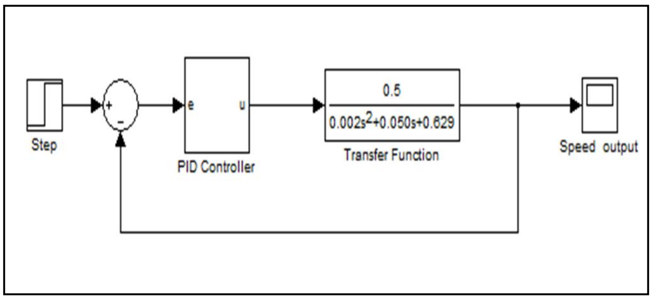

Fig. 6 Matlab/Simulink model of system using PID controller

The simulation output of the PID Controller for 2nd order system is represented in Fig

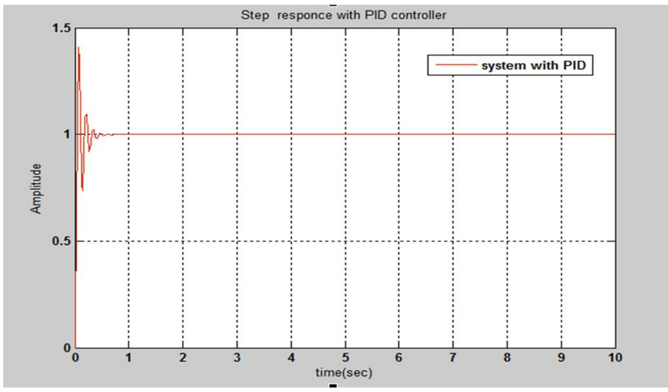

Fig. 7 Step response of the system with PID controller

As can be seen from the figure, the PID controlled response of the system has considerably high overshoot and larger settling time values. Hence, an attempt is made to further improve the response of the system using fuzzy logic controller.

B. Fuzzy logic controller

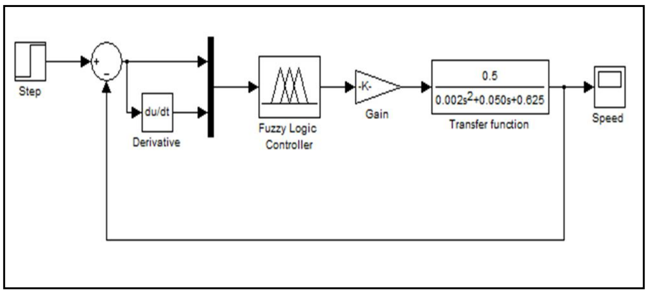

Fig. 8 Matlab/Simulink model of system using fuzzy logic controller

C. Step responses

The simulation output of the Fuzzy Logic Controller for System is represented in Figure. 9.

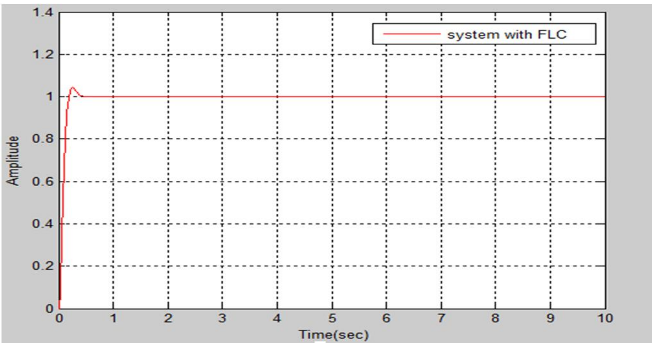

Fig. 9 Step response of system using fuzzy logic controller

From above figure, it can be easily seen that the overshoot has been considerably reduced with fuzzy logic controller as compared to the PID using classic ZN method. Comparative step response for PID regulated system and FLC controlled system is shown in figure 10.

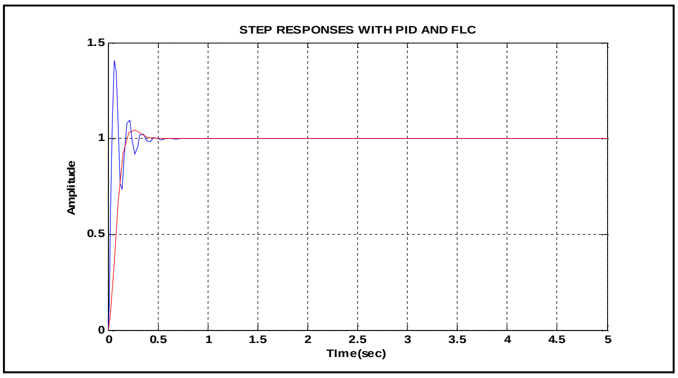

Fig.10 Step responses of system using PID and fuzzy logic controller

Figure 10 shows that the response of the system has greatly improved on application of fuzzy logic controller (FLC). The overshoot of the system using FLC has been reduced, settling time, peak time of the system also shows appreciable reduction as analyzed in Table II.

TABLE II
COMPARISON BETWEEN THE OUTPUT RESPONSES FOR CONTROLLERS

Title	PID controller	Fuzzy logic controller
Rise time (sec)	0.0286	0.1240
Peak time (sec)	1.0763	0.2662
Settling time(sec)	1.3950	0.3405
% Overshoot	39.5190	4.1997

VI. CONCLUSIONS

In this paper the speed of a DC motor is controlled using fuzzy logic and PID controller. The simulation results are obtained using MATLAB/SIMULINK. The fuzzy logic response is compared with that of conventional PID controller. The results show that the overshoot, settling time, peak time and control performance has been improved greatly by using Fuzzy Logic controller. The proposed fuzzy Logic controller has more advantages, such as higher flexibility, control, better dynamic and static performance compared with conventional controller. Hence, Fuzzy logic controller design was proposed and implemented.

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APPENDIX A: SYSTEM MODEL PARAMETERS

Armature resistance (Ra)	0.5Ω
Armature inductance (La)	0.02 H
Armature voltage (Va)	200 V
Mechanical inertia (jm)	0.1 Kg.m2
Friction coefficient (Bm)	0.008 N.m/rad/sec
Back emf constant (k)	1.25 V/rad/sec
Motor torque constant (k)	0.5 N.m/A

NOMENCLATURE

Va is the armature voltage (Volts)
Eb is back emf the motor (Volts)
Ia is the armature current (Ampere)
Ra is the armature resistance (Ohm)
La is the armature inductance (Henry)
Tm is the mechanical torque developed (Nm)
Jm is moment of inertia (Kg/m^2) (rad/sec)
Bm is friction coefficient of the motor (Nms)
ω is angular velocity

MEANING OF THE LINGUISTIC VARIABLES IN THE FUZZY INFERENCE SYSTEM

el	Error low
em	Error medium
el	Error high
ecl	Change in error change low
ecm	Change in error medium
ech	Change in error high
ol	Control output is low
om	Control output is medium
oh	Control output is high