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Performance Evaluation of Fuzzy PID Controller for Position Control System via Reduced Order Model

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***Abstract*—The aim of the paper is to design Fuzzy PID controller to the reduced second order system for obtaining fast raise time, quick settling time and minimal overshoot. This paper compares the performances of various tuning method for PID controller. Initially the PID controller is design by the conventional Ziegler and Nichols method and then the Fuzzy PID controller. The design of Fuzzy PID controller via reduced order model retains the original characteristics of the system. It was found that the proposed Fuzzy PID method is better than the Ziegler and Nichol's method. An algebraic approach for model order reduction could be applied to the any higher order system for reducing the computational complexity of mathematical models in numeric simulations.**

***Index Terms*— PID, Fuzzy-PID, GA-PID, Model Order Reduction.**

I. Introduction

The DC motor has excellent speed control characteristics compared to induction motor. This leads to considerable research in the position control of DC motor. PID controller has been used in the industries and has been incorporated for control of speed and position in many motor drives. The section II formulates the system model of a DC motor and its reduced model. The focus of section III is on conventional PID Controller, it's tuning by Ziegler Nichols Method and how it can be applied to DC motors. A brief review of Fuzzy Based PID Controller is brought up in section IV. Also discusses the structure of the Fuzzy based PID controller and its implementation in the system. In section V, simulation results of the system with PID, Fuzzy PID controllers are obtained and compared. For the control of induction motor [8] Adaptive Neural Fuzzy Controller (ANFIS) is utilized.

II. Description Of Model Order Reduction

The model order reduction of a position control for DC motor model, introduction on model order reduction is detailed in [9, 10]. The model order reduction of linear and nonlinear system is detailed in [11]. Genetic Algorithm based PID controller design using reduced model order is given in [4]. A generic transfer function model of the shunted DC motor is given by

$$\theta(s) / V_a(s) = K_b / [J\, L_a\, s^3 + (R_a\, J + B\, L_a)\, s^2 + (K_b^2 + R_a\, B)\, s] \quad (1)$$

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Where, R_a=Armature resistance in ohm,

L_a=Armature inductance in henry,

$V_a(s)$=Armature voltage in volts in S-domain ,

K_b=back emf constant in volt/(rad/sec),

$\theta(s)$=angular displacement of shaft in radians in S-domain,

J = moment of inertia of motor and load in Kg-m^2/rad,

B =frictional constant of motor and load in N-m/(rad/sec)

The DC motor under study has the following parameters
Parameters: R_a = 2.45 ohm, L_a = 0.035 H, K_b = 1.2 volt/ (rad/sec), J=0.022Kg-m^2/rad, B=0.5*10^-3 N-m/ (rad/sec).
The overall transfer function of the system on substitution of the above parameters is given [1] below,

$$\frac{\theta(s)}{V_a(s)} = \frac{1.2}{0.00077\ s^3 + 0.0539\ s^2 + 1.441\ s} \qquad (2)$$

In this paper, a new algebraic scheme is proposed for obtaining reduced order models of a given stable higher order linear time invariant continuous systems (LTICS), represented in the form of transfer functions. In this scheme, the original higher order model is equated with that of the reduced order model transfer function considered. To minimize the computations in model reduction, an expansion scheme is presented. The equations obtained are solved to obtain the unknown parameters of the reduced order model.
The algorithm for a model order reduction is given below

Step 1: Obtain the transfer function of the given higher order system.

Step 2: Reduce to the second order transfer function of the form, $\dfrac{a_1 s + a_0}{b_2 s^2 + b_1 s + b_0}$

Step 3: Simplify and find the relation between the constants

Step 4: Evaluate the general expansion point $'a_0'$

Step 5: The other unknown coefficients (a_1, b_0, b_1 and b_2) are determined by using the relations obtained from step 3.

Step 6: Obtain the required reduced order model.

The above third order system is reduced to second order using mathematical procedure.
The equivalent second order system is

$$\frac{\theta(s)}{V_a(s)} = \frac{-0.01429\ s + 1}{0.02776\ s^2 + 1.2008\ s} \qquad (3)$$

The unit step response of both the above models is shown in Fig. 1. The comparison of response shows both are almost equivalent.

III. PID CONTROLLER

PID Controller is used for the position control of DC motor in the industries. The initial values of Proportional gain (K_p), Integral gain (K_i) and Derivative gain(K_d) are chosen as 10, 1 and 0.001 respectively. The PID controller is tuned using Ziegler Nichols method. The block diagram of closed loop system with PID Controller is shown in below Fig. 2.
The response of the DC motor for unit step input with PID controller is shown in Fig. 3. The delay time is the time required for the response to reach 50% of its final value. The rise time is the time taken for the response from 10% to 90 % of the final steady state value. The settling time is the time required to reach and stay within 5% of the final value. For the DC motor control system with PID Controller the delay time, rise time and settling time are 0.102sec, 0.1734sec and 0.2569sec respectively. There is no over shoot in the response.

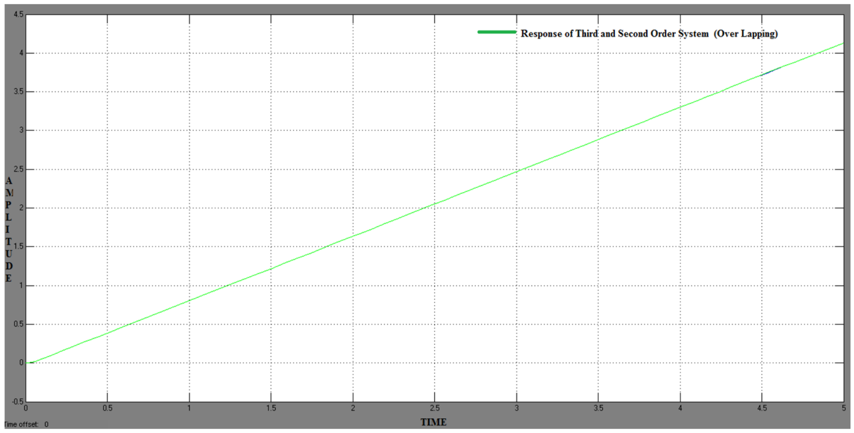

Figure 1. Step Response of 3rd Order and Reduced Order System

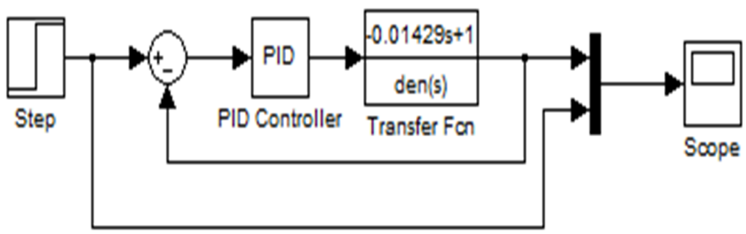

Figure 2. Simulink Block with PID Controller

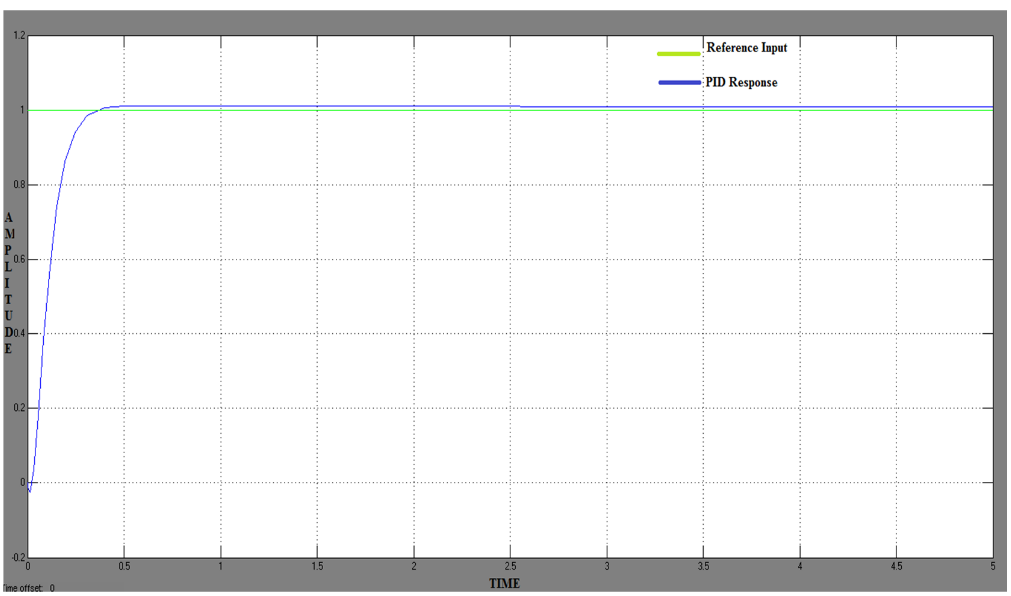

Figure 3. Response with PID Controller

IV. FUZZY PID CONTROLLER

The Fuzzy PID Controller takes error and rate of change of error as its input variable and provides the controller output. The Kp, Ki, Kd values are chosen using fuzzy logic. These three values are then given to the PID controller present at next stage. In the fuzzy control the membership functions are applied to the input variables.ie, Fuzzufication is done during preliminary stage. It uses rule base to obtain the fuzzy output. The defuzzification is done to convert them to crisp values. The Fuzzy logic with engineering applications [2] and Neuro-fuzzy soft computing techniques [3] are studied for the implementation of the simulation work. The Fig 4. Shows the simulink block for the system with Fuzzy PID Controller.

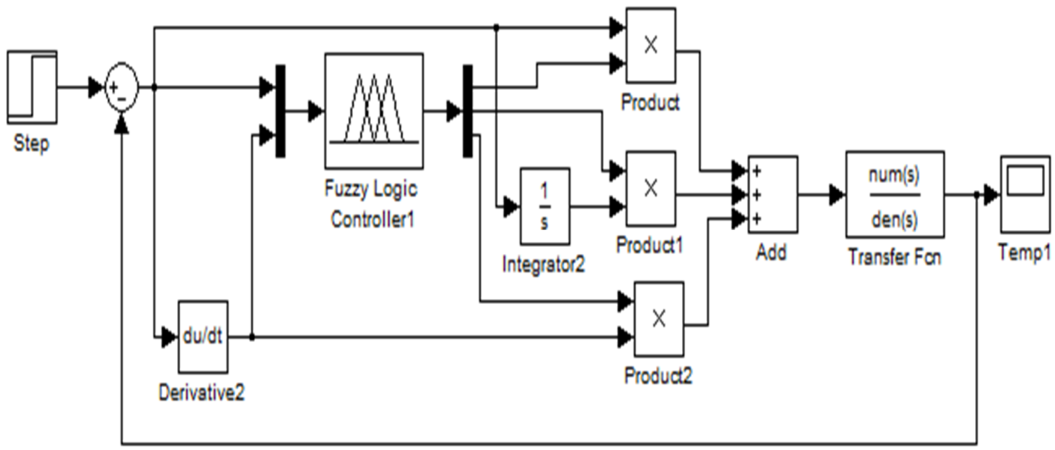

Figure 4. Simulink Block with Fuzzy PID Controller

The procedure for implementation of fuzzy logic shown [6] has been adopted for the motor control. The Fuzzy Inference System (FIS) for Fuzzy PID controller is shown in Fig. 5. The performance of PID and Fuzzy PID has been shown for reduced higher order system [7].

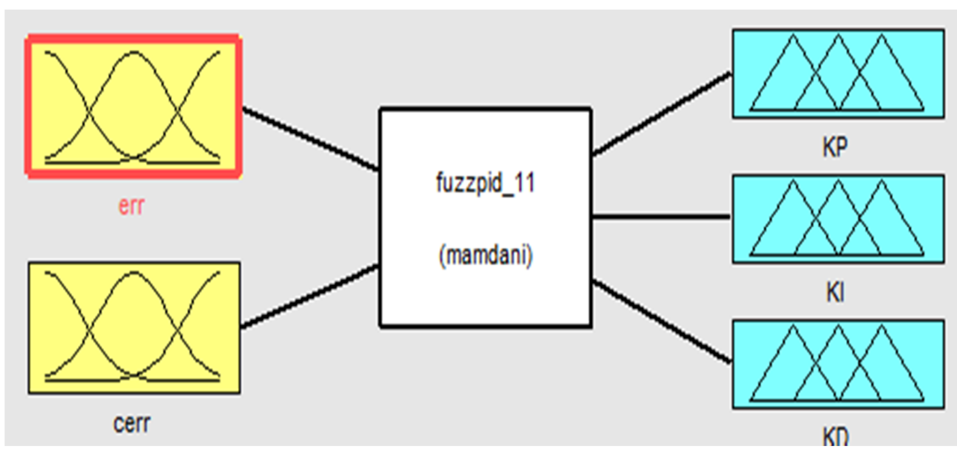

Figure 5. Fuzzy Inference System

The Error and change in error are chosen in the range between -100 to 100 and -1 to +1 respectively. The K_p, K_i, K_d values are choose in the range between 0.1 to 35, 0.1 to 1.0 and 0.075 to 0.275 respectively. Five Triangular membership functions labeled Negative Big, Negative Medium, Zero, Positive Medium and Positive Big are chosen for each of the inputs and outputs respectively. Five rules are applied for the Fuzzy Inference System. The fuzzy PID controller also shows better response than conventional PID Controller. The fuzzy controller has quick rise and delay time, better settling time, no steady state error and negligible overshoot. The K_p, K_i, K_d parameter range are specified in the fuzzy PID controller. The response of the system with fuzzy PID controller is shown in Fig. 6. The fuzzy controller has been used for speed control [5]. For the DC motor control system with Fuzzy PID Controller the delay time, rise time and settling time are 0.071sec, 0.0987sec and 0.1567sec respectively. There is no over shoot in the response.

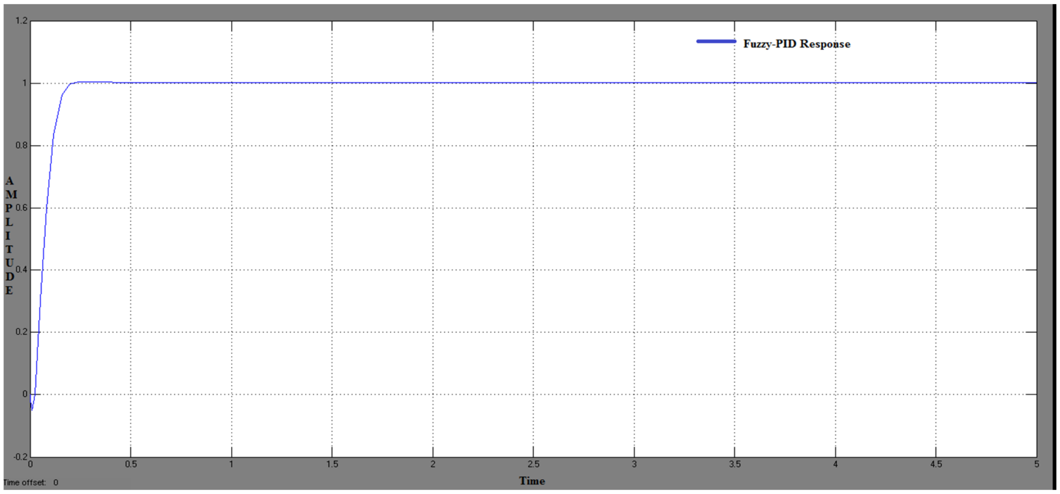

Figure 6. Response with Fuzzy PID Controller

V. RESULT AND DISCUSSION

The comparative responses of DC motor with conventional PID controller and Fuzzy PID Controller for position control is shown in Figure 7.

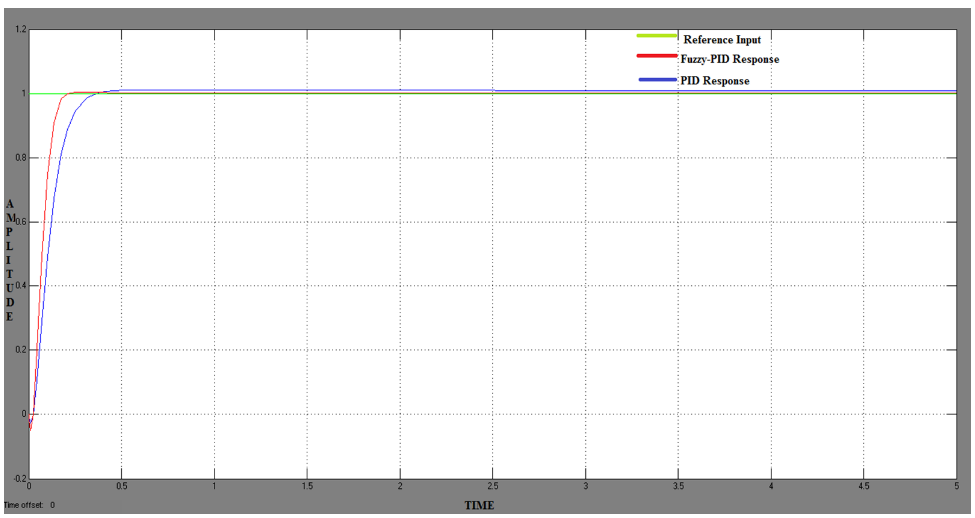

Figure 7. Comparative Response of Conventional PID and Fuzzy PID Controller

The Table 1 shows the comparative performance parameters of Conventional, GA Based and Fuzzy based PID controllers.

TABLE I. PERFORMANCE COMPARISON OF CONTROLLERS

Types of Controller	Delay Time (t_d) in Sec.	Rise Time (t_r) in Sec.	Settling Time (t_s) in Sec.	Peak Overshoot (Mp) %
GA Based PID Controller	-	0.1	0.1	1
Conventional PID (Reduced Order Model)	0.102	0.1734	0.2569	Nil
The Proposed Fuzzy PID (Reduced Order Model)	0.071	0.0987	0.1567	Nil

VI. CONCLUSION

The existing GA based PID controller designed [1] for the DC motor position control system (Third order model) has 0.1 sec rise time and settling time respectively with 1% overshoot in the response. The proposed Fuzzy PID controller for the same reduced order model has less delay time, quick rise time and nominal settling time compared to conventional PID controller and GA based PID controller. There is no overshoot in both the PID and Fuzzy PID responses. The result shows the reduced order model response for the system with Fuzzy PID Controller is almost equivalent to GA based controller response. The proposed Fuzzy PID for reduced order model retains the characteristics of higher order system.

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