SIMULATION PERFORMANCE OF PID AND FUZZY LOGIC CONTROLLER FOR HIGHER ORDER SYSTEMS

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ABSTRACT:

The proportional-integral derivative controller (PID Controller) is a control loop feedback mechanism (Controller) widely used in automatic process control applications in industry today to regulate flow, temperature, pressure, level, and many other industrial process variables. The high demand of PID controller is due to its fine control capabilities in a wide range of operating conditions. This paper presents design of PID controller using Ziegler–Nichols (ZN) technique for higher order systems. A fuzzy logic controller using simple approach and smaller rule set is also proposed. The aim of designed fuzzy controller is to present better control compared with the existing PID controller. The simulation is done using **Matlab/Simulink** by comparing the performance of two controllers for higher order systems. It is finally observed that fuzzy logic controller has better control on timing parameters such as settling time, rise time, maximum overshoot as compared to the existing PID tuning techniques.

KEYWORDS: PID controller, higher order plant, Z-N tuning, Fine-tuning, Fuzzy logic controller, Simulation

I. INTRODUCTION

It is eminent that more than 95% of the control loops are PID controller type in process control [5]. The PID controllers are used in wide range of problems like DC motor, Automotive, Air flight control, etc [7]. A PID controller calculates an error value on the basis of difference between measured process variable and desired set point. The controller attempts to minimize the error by adjusting the tuning parameters [4]. These tuning parameters can be interpreted in term of time proportional (P) which depends on the present error, integral (I) which depends on growth of past value and derivative (D) which predicts the future error. The quality of control in a system depends on settling time, rise time and overshoot values. The main problem is to optimally reduce such timing parameters, avoiding undesirable overshoot, longer settling times and vibrations. To solve this problem, many authors have been proposed different approaches. A first approach is the Proportional Integral Derivative (PID) controller's application. They are extensively used in industrial process control application. Vaishnav and Khan, 2007 designed a Ziegler Nichols PID controller higher order systems [7]. A tuning method which uses PID controller has been developed by Shamusuzzoha and Skogestad, 2010 [9]. Such method requires one closed-loop step set point response experiment similar to the classical Ziegler-Nichols experiment. However, in complex systems characterized by nonlinearity, large delay and time variance, the PID's are of no effect. The design of a PID controller is generally based on the assumption of exact knowledge about the system. Because the knowledge is not available for the majority of systems, many advanced control methods have been introduced. Some of these methods make use of the fuzzy logic which simplifies the control designing for complex models. Fuzzy logic control has been widely implemented for nonlinear, higher order and time delay systems [2]. A fuzzy logic controller has been proposed with simple approach and smaller set of rules This paper has been organized as following; Section I depicts the introduction of the paper. Section II describes the problem formulation. Section III explains the generalized tuning parameters of PID controller. Section IV describes the design consideration for higher order systems. Section V reveals the design of PID controller using Z-N tuning and fine tuning techniques. Section VI describes the design of fuzzy logic controller and a summary table of various results obtained through various techniques. Section VII gives general conclusions.

II. Problem Formulation

The aim of this paper work is to tune a PID controller using various intelligent methods for higher order systems. The input output transfer function of the higher order system is given by [7]

$$G(s) = \frac{10}{s^3+6s^2+8s} \qquad (1)$$

The transfer function is a third order system with right half plane (RHP) zero. The control objective to keep the various performance specifications such as
rise time t_r, settling time t_s, maximum percentage overshoot $M_p(\%)$, maximum percentage undershoot $M_u(\%)$ and steady state error within desirable limits. But several industrial processes have the "dead-time effect " produced due to measurement time delay or due to the approximation of higher order dynamics of the process by a simple transfer function model. This time delay degrades the stability of the whole system. In order to solve this problem, a control method which uses the fuzzy logic controller using simple approach & smaller rule set is proposed.

III. GENERALISED TUNING PARAMETERS OF PID CONTROLLER

The PID controllers have vast range of applications in industrial control because of their simple control structure. The PID controllers require less plant information than a complete mathematical model. In this way, the controller parameters can be adjusted with a minimum effort. One survey of Desborough and Miller (2002) indicates that more than 97% of regulatory controllers utilize the PID algorithms [5].

There are many versions of a PID controller [22].In this study, we consider a controller described by Equation (1)

$$u(t) = [e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d \frac{de(t)}{dt}] \qquad (2)$$

where, u(t) is the input unit step signal sent to the plant model, e(t) = r(t) -y(t). e(t) is the error, r(t) is the reference input signal and y(t) is the output signal respectively. The parameters K_p, T_i and T_d are the tuning parameters [18].

A PID controller is described by the following transfer function in the continuous s-domain [17]

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s \qquad (3)$$

Another way to write above equation (3) is articulated through equation (4) [7]

$$G_c(s) = K_P [1 + \frac{1}{T_I s} + T_d s] \qquad (4)$$

Where K_p is the proportional gain, K_i is the integration coefficient and K_d is the derivative coefficient. T_i is known as integral action time and T_d is known as derivative action time.[17] These types of controllers have three different adjustments (K_p, T_i, and T_d), which interacts with each other. It is always very difficult and time consuming to tune these three parameters in order to get best performance according to the design specification of the system.

IV. DESIGN CONSIDERATION FOR HIGHER ORDER SYSTEM

A PID controller is being designed for a higher order system for transfer function as given below [15]

$$G(s) = \frac{10}{s^3 + 6s^2 + 8s} \qquad (5)$$

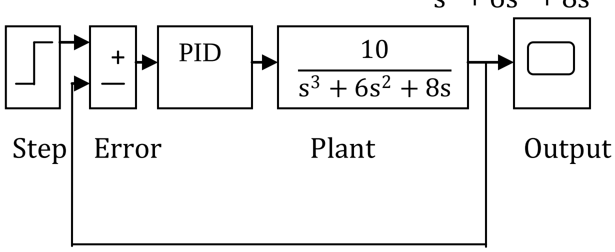

Fig.1. Plant with PID controller [7]

The simulink model of the PID controller and the plant with unity feedback is shown in Fig.1. The authors have proposed design of (**i**) PID controller using Z-N technique (**ii**) fuzzy logic controller through which the closed loop system exhibits small overshoot (M_p) and settling time (t_s) with zero steady state error (e_{ss}).

V. DESIGN OF PID CONTROLLER

Tuning of conventional controller has been done by the Ziegler-Nichols method which is mostly used in industrial PID tuning. Routh's stability criterion method is used to determine the initial value of K_p, K_i and K_d.

CONTROLLER	K_p	K_i	K_d
PID	$0.60K_u$	$2*K_u/T_u$	$K_u*T_u/8$

Table.1: Ziegler-Nichols tuning method [15]

The frequency response method as suggested by Ziegler-Nichols is applied for design of PID controller [13].

By setting $T_i = \infty$ and $T_d = 0$ and using proportional control action (K_p) only, the value of gain is increased from 0 to a critical value K_u at which the output first exhibits oscillations. T_u is known as period of oscillation [7]. The unit step response for different values of gain K_p were observed. The step response for K_p = 2.22 is shown in Fig.2.

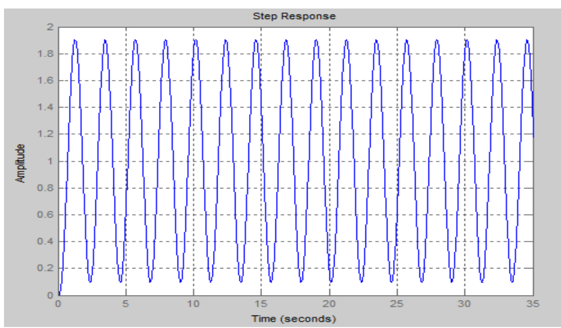

Fig.2. Step response for K_p = 4.8

The above response clearly shows the sustained oscillation occurs at K_p= K_u= 4.8. The period of oscillation T_u obtained from the time response is 2.22.

The value of Ziegler-Nichlos tuning parameters are K_p = $0.6*K_u$ =2.88, T_i= $0.5*T_u$=1.11, $K_i=K_p/T_i$=2.594, $T_d=0.125*T_u$,=0.2775, $K_d=K_p*T_d$=0.7994. The unit step response of closed loop system with K_p=2.88, K_i=2.594, K_d=0.7994 shows that in Fig.3**.** It is also noted that overshoot M_p=59.5%, Rise time t_r=0.472 sec and Settling time t_s =6.46sec. Both M_p and t_s are too large.

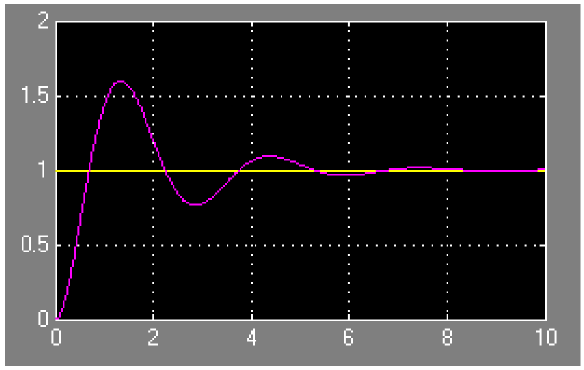

Fig.3. Step response for K_p=2.88, K_i=2.594, K_d=0.7994

The unit step response of closed loop system with Fine-Tuned PID controller parameters are K_p=4.4, K_i=2.11, K_d=2.2 is shown below in Fig.4. Here it is observed that overshoot is M_p=28.9%, rise time t_r=0.315sec and settling time t_s =3.46sec. Both Mp and ts are smaller as compared to the initial values obtained from Ziegler Nichols method.

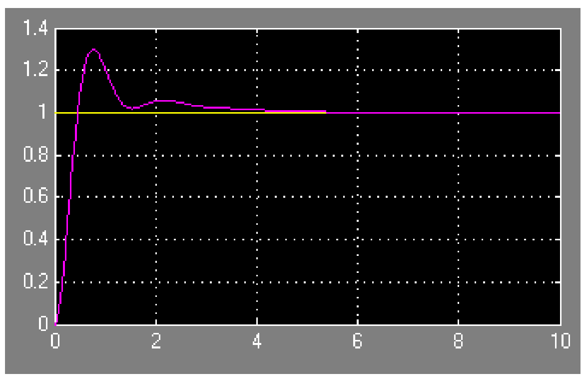

Fig.4. Step response for K_p=4.2, K_i=2.11,K_d=2.2

VI. DESIGN OF FUZZY LOGIC CONTROLLER (FLC)

The simulink model of the fuzzy logic controller and the plant with unity feedback is shown in Fig.5.

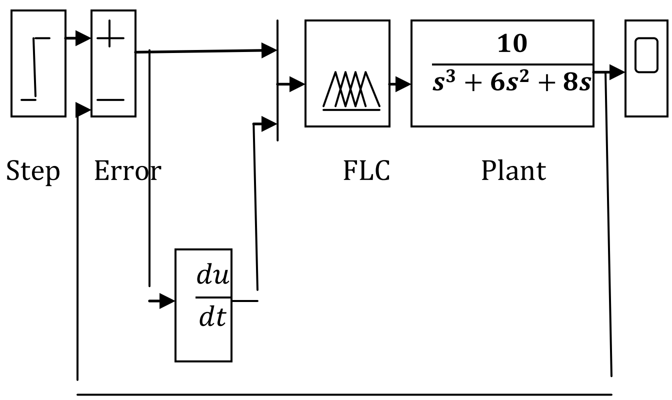

Fig.5. System with Fuzzy logic controller

The fuzzy logic controller has two inputs which are error(e) and the rate of change in error(de) [10]. Error is the difference between the reference value and the output of the controller. The rate of change in error (de) is the difference between the error at time t and (t-1) [19].

These inputs have seven membership functions with linguistic variable name as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero Error (ZE), Positive Small (PS), Positive Medium (PM), Positive Big (PB) [21]. The fuzzy logic controller output has the same membership functions as fuzzy logic controller inputs. Fig.6 and Fig.7 shows the inputs membership functions and Fig.8 shows output membership functions.

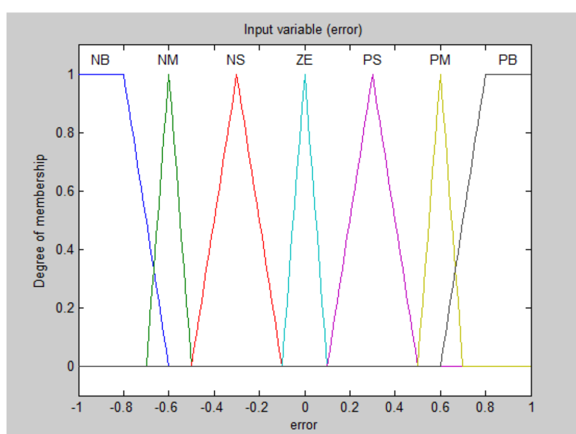

Fig.6. Membership function of input Error

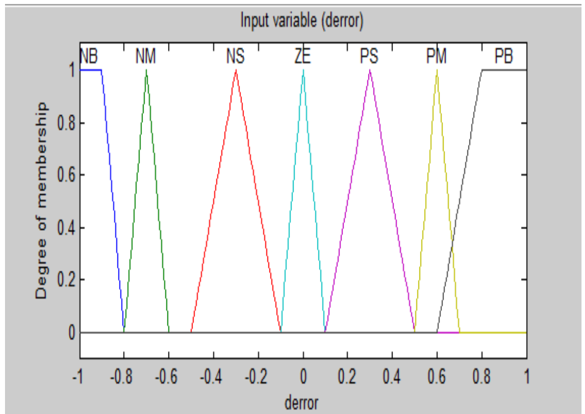

Fig.7. Membership function of input change in Error (de)

It has been observed while designing linguistic rules that 49 rules are sufficient to get the best possible results. There is no positive effect on output response of the system beyond 49 rules as they cover all possible situations as shown in Table.2 given below.[21]

e/de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

Table.2. Fuzzy rules

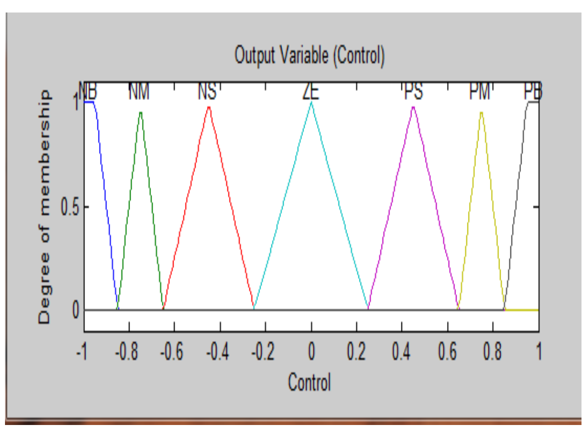

Fig.8. Membership function of output

The fuzzy inference is designed using fuzzy toolbox available in MATLAB. Fig.9. shows the layout of the fuzzy inference in the fuzzy logic controller.

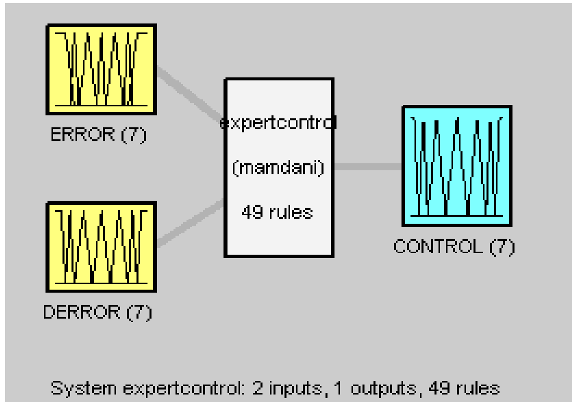

Fig.9. Mamdani Type fuzzy inference in the proposed fuzzy logic controller**.**

Surface viewer generates a 3-D control surface with two input variables and the output from fuzzy inference system as shown below in fig.10.

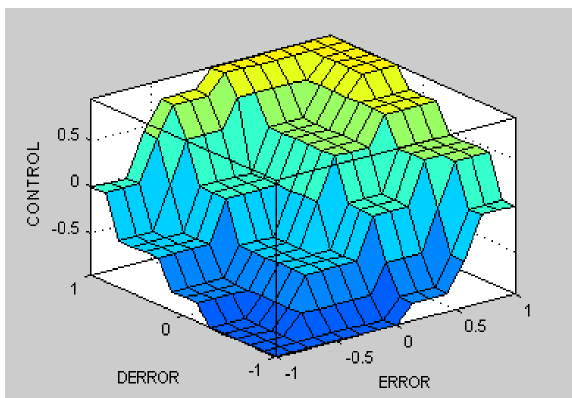

Fig.10. Control surface between inputs and output variable using fuzzy toolbox.

The step response for fuzzy logic controller in higher order plant system is shown in Fig.11. There is no overshoot M_p=0%, rise time t_r = 2.43sec and settling time t_s=3.0522sec. The fuzzy logic controller with optimized membership function has better settling time and overshoot.

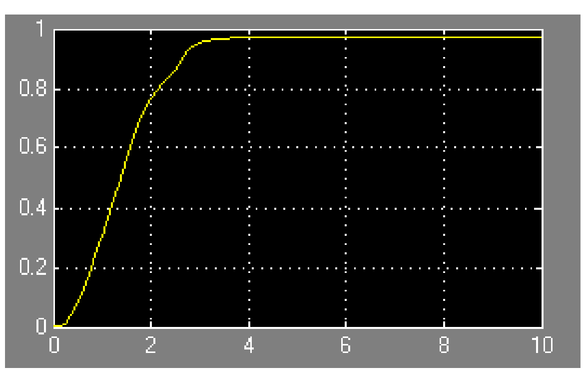

Fig.11. Step response for Fuzzy logic controller (FLC)

The summary of time response parameters like overshoot (M_p),settling time (t_s) and rise time (t_r) through various techniques Ziegler –Nichols tuned PID controller, Fine-tuned PID controller and Fuzzy logic controller for the higher order plant system is given in Table.3.

Controller/ Parameters	ZNPIDC	FTPIDC	FLC
Overshoot M_p(%)	59.5	28.9	0
Rise time t_r (sec)	0.472	0.315	2.46
Settling time t_s (sec)	6.46	3.46	3.0522

Table.3. Time response parameters performance comparison of different controller

VII. CONCLUSION

Different approaches have been presented for control of higher order systems. The first approach employs a PID controller based on Zeigler-Nichols tuning technique to control higher order systems. The design of PID controller gives result in term of rise time, setting time and overshoot. In fact, the simulations shows a value of t_r = 0.47sec, t_s = 6.46sec and M_p(%) = 59.5. The second approach employs a PID controller based on Fine-tuned technique to control higher order systems. The design of PID controller gives good results in term of rise time, settling time and overshoot as compared to Ziegler-Nichols techniques. In fact, simulations shows a value of t_r = 0.315sec, t_s = 3.46sec and M_p(%) = 28.9. In order to improve the overshot and settling time , a fuzzy logic controller have been designed with simple approach as small set of rules. Fuzzy logic controller gives no overshoot and very good value of settling time t_s = 3.0522sec. Hence, we can say that fuzzy logic controller with simple design approach gives much better performance than Ziegler-Nichols tuned and Fined–Tuned PID controllers.

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