Design and Tuning of PID Controller Parameters Based on Fuzzy Logic

Priyanka Chaurasia[#1], Dr. Sulochana Wadhwani[#2]
[#]Department of Electrical Engineering, MITS, Gwalior-474005
[1]rani199108@gmail.com
[2]dr.s.wadhwani@gmail.com

Abstract— **PID controller is the most popular feedback controller and being widely used in industry due to their well-grounded established theory, simplicity, less maintenance requirements and ease of tuning. The basic structure of the PID controllers makes it easy to regulate the process output However, PID controller tuning is the most challenging task for an efficient and stable control system.**

Keywords— **PID controller, PID Tuning, Ziegler Nichols (ZN), Fuzzy Logic (FL).**

I. INTRODUCTION

With the advancement in technology, control systems have acquired a vital role in the development and modernization of various industrial sectors as well as daily activities of life. Control theory provides design strategies for various controllers that allow a better understanding of the system being controlled in order to obtain the desired response. It has been found that PID is a remarkable control strategy being widely used in process control applications.

Over the past few decades, many techniques have been developed to acquire the optimum control parameters for PID controllers. The Zeigler-Nichols formulation is a classical tuning method which found a wide range of applications in the control design process [4]. A PID controller calculates an "error" value which is the difference between a measured process variable and a desired 'set point'. PID controller is well known as three term control, the proportional (P), integral (I) and derivative (D). The output of the controller is the control signal u(t).Another approach in the design of controller is the Fuzzy Logic. Fuzzy logic basically tries to replicate the human thought process in its control algorithm [9]. Fuzzy logic has been useful in recent years to formalize the ad-hoc approach of PID control. A fuzzy PID controller takes the conventional PID controller as the foundation which uses the fuzzy reasoning and variable universe of discourse to regulate the PID parameters. The characteristics of a fuzzy system such as robustness and adaptability can be successfully incorporated into the controlling method for better tuning of PID parameters [8].

This paper describes the application of conventional Zeigler-Nichols approach. The paper involves simulation results based on MATLAB obtained for a step input to a third-order plant.

II. PID CONTROLLER

The PID controller, represented by Fig.1, is well known and widely used to improve the dynamic response as well as to reduce or eliminate the steady state error. The Derivative controller adds a finite zero to the open loop plant Transfer function and improves the transient response. The Integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady state error due to a step function to zero. PID controller consists of three types of control Proportional, Integral and Derivative control [6].

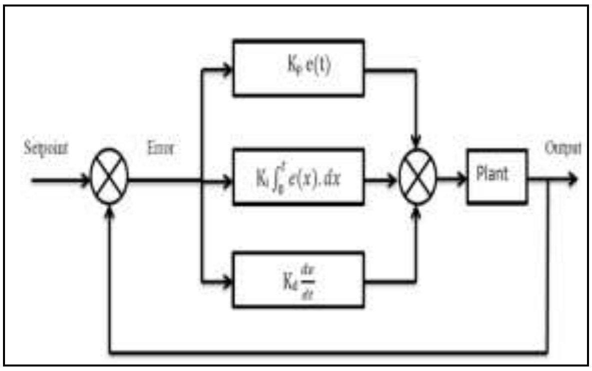

Fig.1 Block diagram of conventional PID controller.

The PID controller output relating the error can be described by,

$$u(t) = K_p e(t) + K_i \int_0^t e(t)\,dt + K_d \frac{de(t)}{dt} \quad (1)$$

Where e(t) is the error, u(t) the controller output, and Kp, Ki and Kd are the Proportional, Integral and Derivative gains.

In the frequency domain, the relation between the PID controller input E (error signal) and output U (input to the plant) can be expressed by the following transfer function:

$$G_C(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d\, s \quad (2)$$

The closed loop transfer function is given by,

$$G_{CL}(s) = \frac{Y(s)}{R(s)} = \frac{G_c(s)G(s)}{1+G_c(s)G(s)} \quad (3)$$

The tuning of a PID controller consists of selecting gains *Kp*, *Ki* and *Kd* so that performance specifications are satisfied.
The system under consideration is

$$G(s) = \frac{1}{s^3+9s^2+23s+15} \quad (4)$$

The open-loop step response of the above system given by (4) is shown in Fig. 2

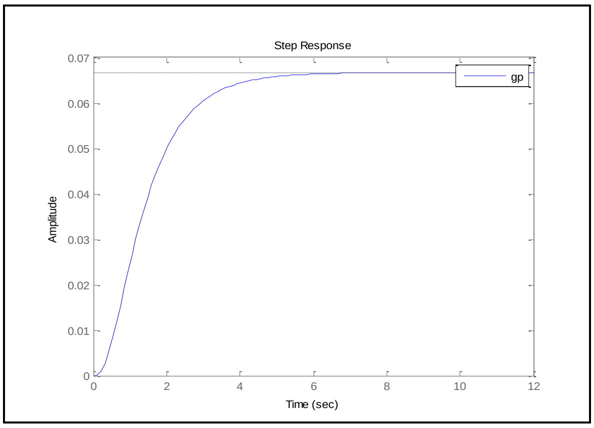

Fig. 2 Open-loop step response of the system.

As can be seen from Fig. 2, the system dynamics, steady state error, settling time, rise time are rendering the system towards undesirable performance and so the system needs to be controlled using suitably tuned controllers.

III. TUNING OF PID CONTROLLER USING CONVENTIONAL APPROACH

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Conventional Approach - Ziegler Nichols Method

Ziegler-Nichols (ZN) method for tuning of PID controllers, though a classic method has been widely used for the design of various controllers. Ziegler and Nichols presented two methods, a step response method and a frequency response method. In this paper we have employed the frequency response method for tuning of the PID controller.

B. Implementation of ZN based PID controller

In this method, the integral time Ti will be set to infinity and the derivative time Td to zero. This is used to get the initial PID setting of the system. Thus the proportional control is selected alone. Increasing the value of the proportional gain until the point of instability is reached (sustained oscillations), gives the critical value of gain, Kc. Thereafter measurement of the period of oscillation of the response is used to obtain the critical time constant, Tc.

Once the values for Kc and Tc are obtained, the PID parameters can be calculated, according to the design specifications, as given in Table 1. Further the values of the PID gain coefficients *Kp, Ki* and *Kd* for the system described by equation (3), obtained after simulation in MATLAB are given in Table 2.

TABLE 1
Ziegler-Nichols PID tuning parameters

CONTROLLER	Kp	Ti	Td
P	0.5Kc	Inf	0
PI	0.45Kc	0.833Tc	0
PID	0.6Kc	0.5Tc	0.125Tc

TABLE 2
Ziegler-Nichols PID tuning values

Gain Coefficients	Kp	Ki	Kd
Values	115.2	175.87	18.77

From the above formulation the step response of the overall system with conventionally tuned PID controller is shown in Fig.3.

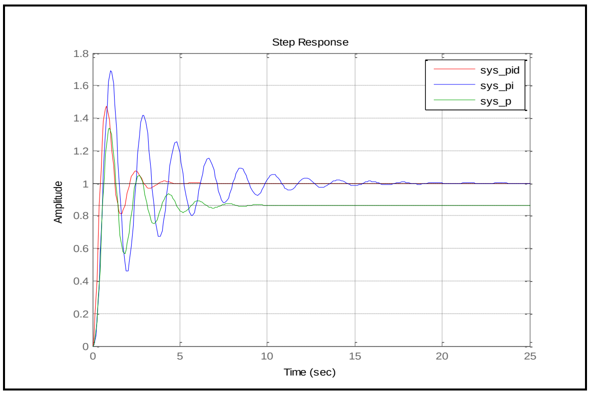

Fig. 3 Step responses of the system with P, PI and PID controllers.

By employing Ziegler-Nichols's method for PID tuning the gains are obtained using ZN tuning parameters given in Table 1. The step response and the value of *Kp* that results in marginal stability are used as starting points for obtaining gain values that guarantee a satisfactory behaviour. Finer adjustments to the gains may also be carried out [3].

IV. TUNING OF PID CONTROLLER USING FUZZY LOGIC APPROACH

A. Overview of Fuzzy Logic

The fuzzy Logic (FL) system was designed by the standard procedure of fuzzy controller design. Fuzzy logic consists of three parts-fuzzification, inference and defuzzification. Fuzzification is an inference that produces a fuzzy subset from the measurement, that is, it is mapping from the set of measurement. Fuzzy inference systems (FIS) are rule-based systems that produces a new fuzzy subset from the result of the fuzzification. The results of the inference are a fuzzy subset associated with the output. The defuzzification is an inference that produces a crisp output from the result of inference.

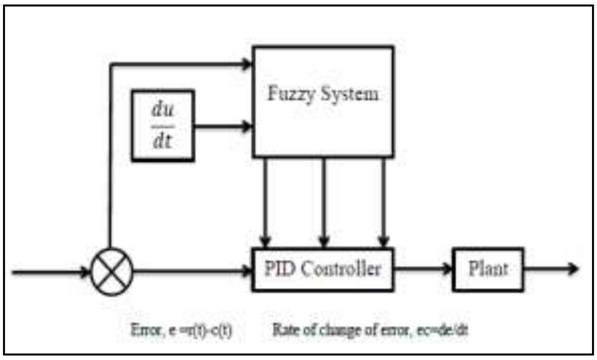

Fig.4 Fuzzy PID controller.

The fuzzy PID controller, which takes error "e" and change-in-error "ec" as the input to the controller. Fig.4 depicts the block diagram of a fuzzy PID controller. As it can be seen from the block diagram, the fuzzification takes two inputs (e and ec) and gives three outputs (*Kp, Ki, Kd*). The tuning of the PID controller is done by selecting the language variables of "e", "ec", *Kp*, *Ki*, and *Kd* and choosing seven fuzzy values (NB, NM, NS, ZO, PS, PM, PB) for each of the parameters. Here (NB, NM, NS, ZO, PS, PM, PB) is the set of linguistic values which respectively represent "negative big", "negative medium", "negative small", "zero", "positive small", "positive medium" and "positive big" [8]. Table 3 shows the fuzzy rule table for parameter ΔK_P. Similarly, rule table for ΔK_I and ΔK_D can be generated.

Table 3 Fuzzy Rule table for ΔK_P

e\ec	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

B. Implementation of FL based PID controller

This paper presents a methodology for rule base fuzzy logic controller applied to a system. The set of linguistic rules is the essential part of a fuzzy controller. The response of the fuzzy PID controller is obtained using MATLAB. A two input and three-output fuzzy controller is created and the membership functions and fuzzy rules are determined. The membership functions (MF) for inputs are shown below in Fig. 5.

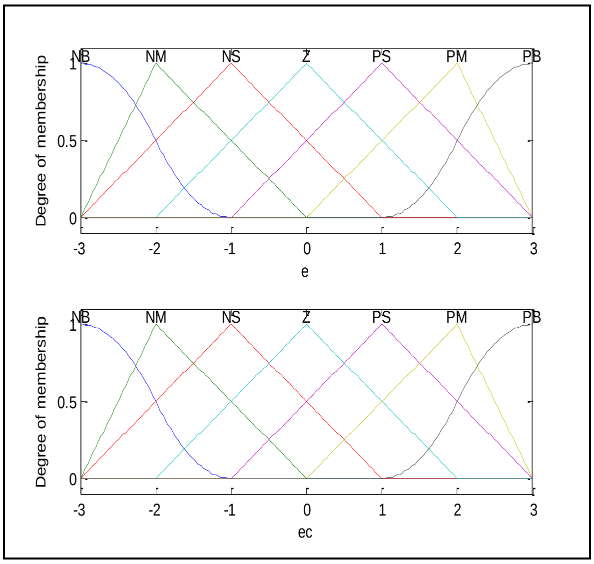

Fig. 5 Illustration of MF for inputs, error and change in error.

Regarding the fuzzy logic controller, there are two inputs to fuzzy inference: error e and change in error ec as shown in Fig. 5. Further there are three outputs for each PID controller parameters ΔK_d, ΔK_i and ΔK_P. Mamdani model is applied as structure of fuzzy inference with some modification to obtain the best value for Kp, Ki and Kd. The membership functions (MF) for outputs are shown below in Fig. 6.

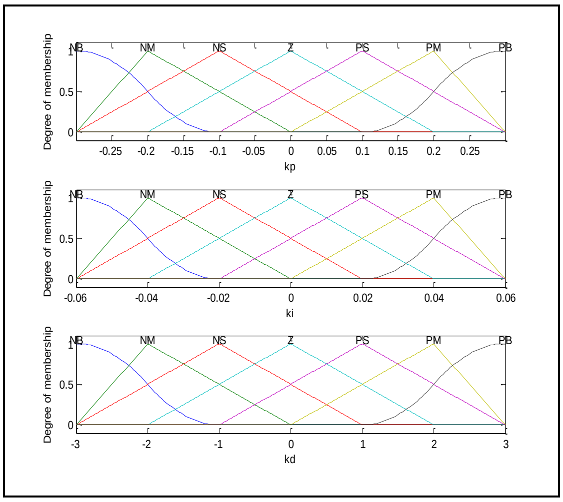

Fig. 6 Illustration of MF for PID parameters tuned by fuzzy logic.

V. RESULTS AND DISCUSSION

In this simulation is consider the zero-pole transfer function with transport delay by using Matlab.

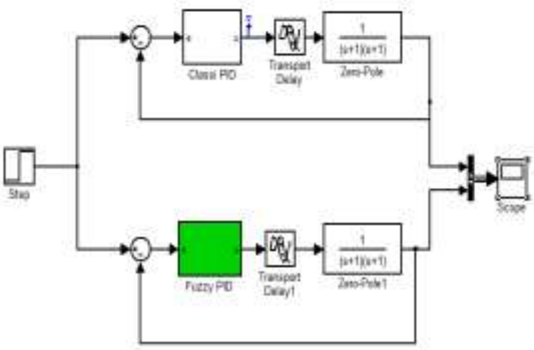

Fig7: Simulation of transfere funcation.

In this result the overshoot has been considerably reduced with fuzzy tuned PID as compared to the classical PID controller.

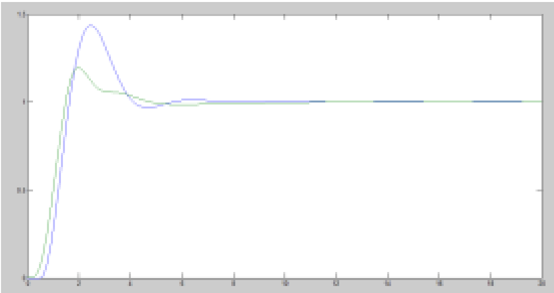

Fig8: waveform of classiPID and fuzzyPID.

Table3: Parameter of transfer function

PARAMETERS	PID CONTROLLER	FUZZY PID CONTROLLER
Rise Time	0.7493	0.8526
Settling Time	5.1599	7.1878
Peak Time	2.4600	2.3200
Overshoot	43.4682	20.1335

VI. CONCLUSIONS

In this system to lesser overshoot and smaller rise time by using fuzzy logic. It is impossible using conventional methodologies. In this simulation to small reducing overshoot as compare to classical PID contrller. The fuzzyPID controller is given minimum overshoot and small rise time. The scheme has been tested on various process, and satisfactory results are obtained in simulation.

In this paper, comparison between different methodologies regarding the tunning of PID controllers using fuzzy inference.

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