# Design and Performance of PID and Fuzzy Logic Controller with Smaller Rule Set for Higher Order System

S.R.Vaishnav, Z.J.Khan

*Abstract*—**The proportional integral derivative (PID) controller is the most widely used control strategy in industry. The popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity. This paper presents design of PID controller using Ziegler-Nichols (ZN) technique for higher order system. A Fuzzy logic controller using simple approach & smaller rule set is proposed. Simulation results are demonstrated. Performance analysis shows the effectiveness of the proposed Fuzzy logic controller as compared to the ZN tuned PID controller & fine tuned PID controller.**

*Index Terms*—**PID controller, Ziegler-Nichols tuning, Fuzzy logic controller, simulation.**

## I. INTRODUCTION

The proportional – integral – derivative (PID) controller operates the majority of the control system in the world. It has been reported that more than 95% of the controllers in the industrial process control applications are of PID type as no other controller match the simplicity, clear functionality, applicability and ease of use offered by the PID controller [3], [5]. The PID controller is used for a wide range of problems like motor drives, automotive, flight control, instrumentation etc. PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly. Various tuning methods are explained in [4], [6]. Among the tuning methods, the Ziegler-Nichols (ZN) technique has been very influential. Ziegler-Nichols presented two tuning methods, a step response method and a frequency response method [4], [6]. The frequency response method is more reliable than the step response method [4]. In this paper, we will investigate frequency response method for higher order system. A survey of various sophisticated PID software packages & hardware models is found in [5].

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The field of Fuzzy control has been making rapid progress in recent years. Fuzzy logic control has been widely exploited for nonlinear, high order & time delay system [2].

This paper has two main contributions. Firstly, a PID controller has been designed for higher order system using Ziegler-Nichols frequency response method and its performance has been observed. The Ziegler Nichols tuned controller parameters are fine tuned to get satisfactory closed loop performance. Secondly, for the same system a fuzzy logic controller has been proposed with simple approach and smaller number of rules (four rules) as it gives the same performance as by the larger rule set [1], [3], [7], [8], [9], [10]. Simulation results for a higher order system have been demonstrated. A performance comparison between Ziegler Nichols tuned PID controller, fine-tuned PID controller and the proposed fuzzy logic controller is presented. The paper has been organized as follows, Section-II explains generalized model of PID controller. Section-III describes the design consideration for a higher order system. Section IV presents design of PID controller using Z-N technique. Section V presents design of fuzzy logic controller using simple approach and smaller rule base. Section VI finally conclusion close the paper.

## II. GENERALISED MODEL OF PID CONTROLLER

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

$$G_c(s) = P + I + D$$
$$= K_p + K_i/s + K_d s \ldots\ldots\ldots\ldots\quad (1)$$
$$\text{Or}\quad G_c(s) = K_p\,(1 + 1/T_i s + T_d s) \ldots\quad (2)$$

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 referred to as derivative action time. Such a controller has three different adjustments ($K_p$, $T_i$, & $T_d$), which interact with each other. For this reason, it is very difficult and time consuming to tune these three parameters in order to get best performance according to the design specification of the system.

## III. Design Consideration

A PID controller is being designed for a higher order system with transfer function

$$G(s) = 10 / [s (s^2 + 6s + 8)]$$

Fig.1 shows the simulink model of the PID controller and the plant with unity feedback. The authors have proposed design of i) PID controller using Z-N technique (ii) fuzzy controller so that the closed loop system exhibit small overshoot $M_p$ and settling time $t_s$ with zero steady state error $e_{ss}$.

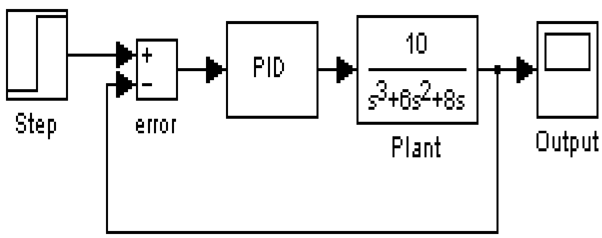


Fig.1. Plant with controller

## IV. DESIGN OF PID CONTROLLER

Frequency response method suggested by Ziegler-Nichols is applied for design of PID controller [4], [6], [8].

By setting $T_i = \infty$ & $T_d = 0$ and using the 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 the corresponding period of oscillation.

The unit step responses for different values of gain $k_p$ were observed. The step response for the $k_p = 4.8$ is shown in Fig. 2.

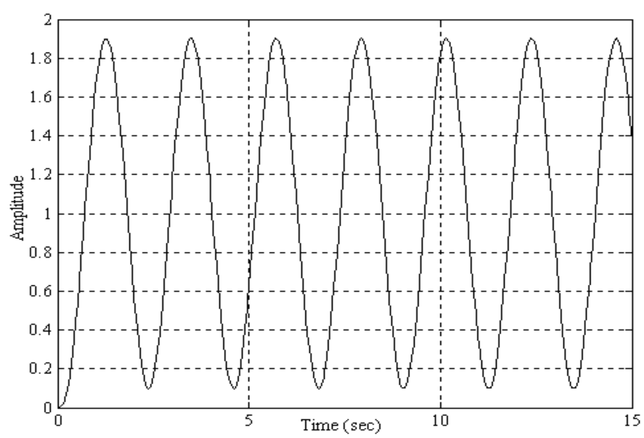


Fig. 2. Step response for $k_p = 4.8$

The above response clearly shows that sustained oscillation occurs for $k_p = k_u = 4.8$. The ultimate period $T_u$ obtained from the time response is 2.22. The value of controller parameters are $k_p = 0.6\ k_u = 2.88$, $T_i = 0.5\ T_u = 1.11$, $T_d = 0.125T_u = 0.277$.

As the mathematical model of the plant is known, $k_u$ and $w_u$ ($w_u$ is the frequency of sustained oscillation and $T_u = 2\pi / w_u$) can be found by Root locus method also.

*Root locus method*

Using proportion control action only, root locus for the open loop system G(s) is shown in Fig. 3. The root locus branches intersects the imaginary axis at $k_p = 4.8$ and $w = w_u = 2.82$.Therefore $K_u = k_p = 4.8$ & $T_u = 2\ \pi /2.82 = 2.22$ which is same as obtained using Ziegler Nichols frequency response method.

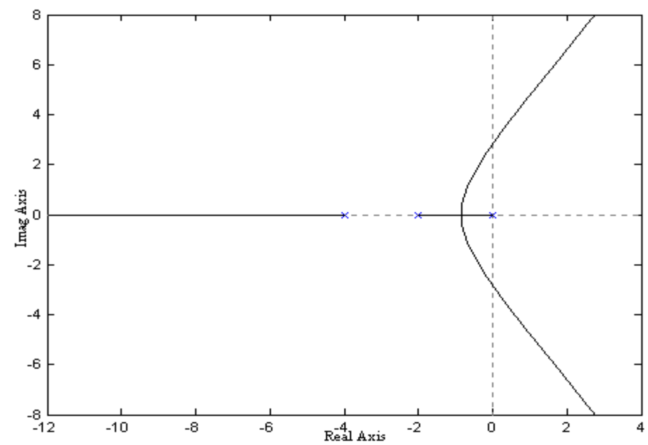


Fig. 3. Root locus for the open loop system G(s)

The unit step response of the closed loop system with $k_p = 2.88$, $T_i = 1.11$ and $T_d = 0.277$ is shown in Fig. 4. $M_p = 71.9$ %, $t_s = 6.33$ sec and $e_{ss} = 0$. Both $M_p$ and $t_s$ are too large.

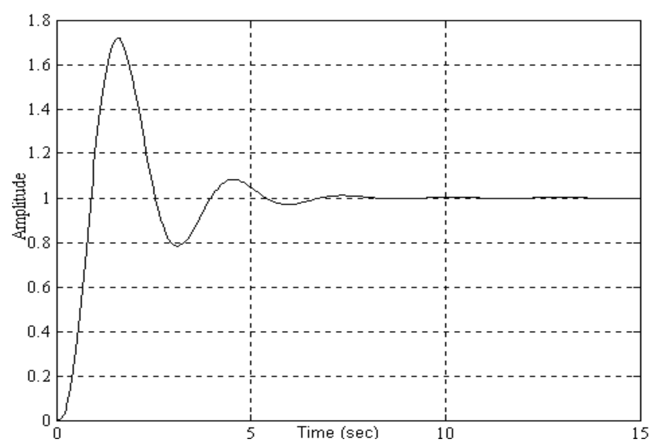


Fig. 4. Unit step response for $K_p = 2.88, T_i = 1.11, T_d = 0.277$

With the initial values of $k_p$, $T_i$ and $T_d$ obtained from Z-N formula, unit step response for different combination of $k_p$, $T_i$ and $T_d$ were observed.

The unit step response for $k_p = 4.4$, $T_i = 2.09$ and $T_d = 0.5$ is shown in Fig. 5, which gives $M_p = 19.8\%$, $t_s = 5.81$ sec. & $e_{ss} = 0$. Both $M_p$ and $t_s$ are small as compared to the initial values obtained from Ziegler Nichols method.

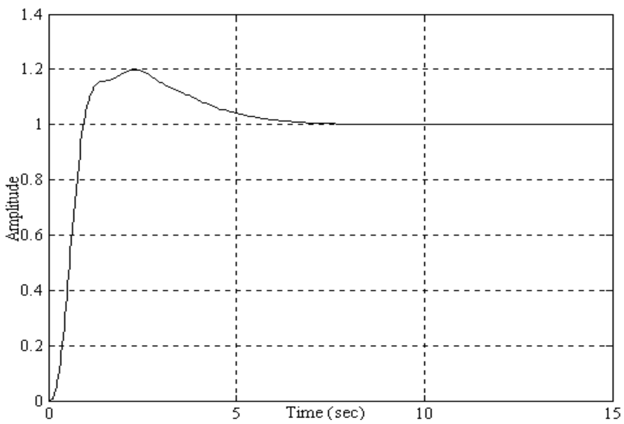


Fig. 5. Unit step response for $K_p = 4.4, Ti = 2.09, T_d = 0.5$

## V. DESIGN OF FUZZY LOGIC CONTROLLER (FLC)

Simulink model of the fuzzy controller and the plant with unity feedback is shown in Fig.6.

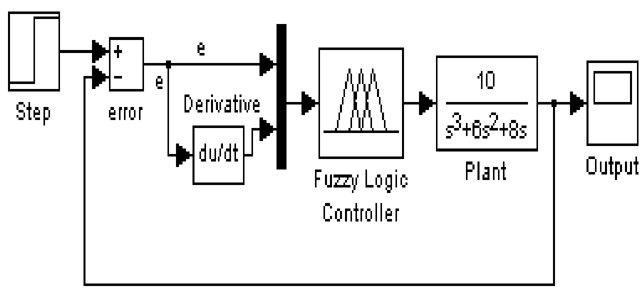


Fig. 6. System with Fuzzy Logic controller

For a two input fuzzy controller, 3,5,7,9 or 11 membership functions for each input are mostly used [7]. In this paper, only two fuzzy membership functions are used for the two inputs error e and derivative of error ė as shown in Fig.7. The fuzzy membership functions for the output parameter are shown in Fig.8, here N means Negative, Z means Zero and P means Positive.

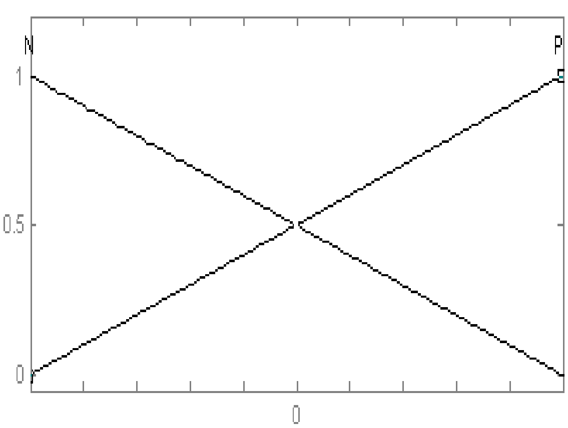


Fig.7. Membership functions for inputs e & ė

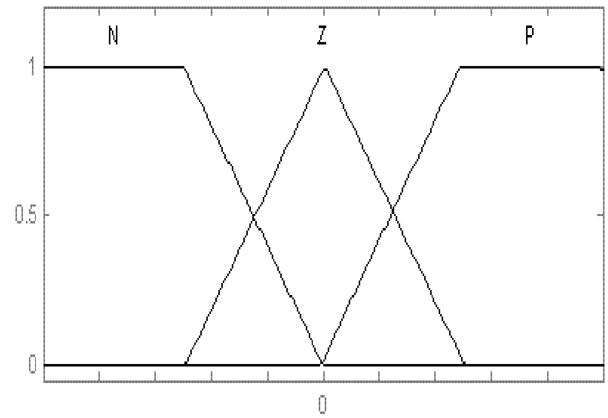


Fig. 8. Membership functions for output

The fuzzy linguistic rules are defined from the output response of the system (Fig.9).

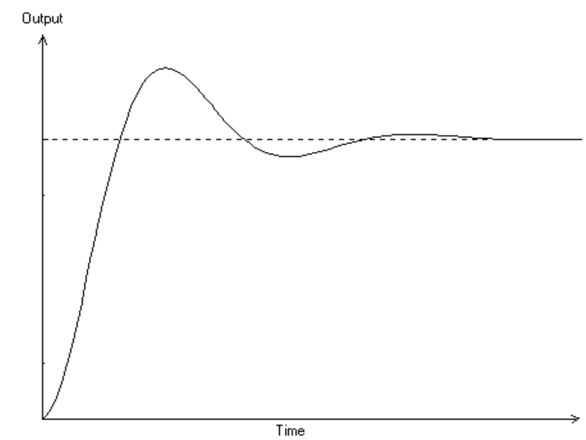


Fig. 9. System step response

The system response can be divided in two phases. Phase A - System output is below the set point. Phase B - System output is above the set point. Depending upon whether the output is increasing or decreasing, 4 rules were derived for the fuzzy logic controller (Table I). These four rules are sufficient to cover all possible situations [1], [3], [8], [9], [10].

TABLE I. FUZZY RULES

| u | | ė | |
|---|---|---|---|
| | | N | P |
| e | N | N | Z |
| | P | Z | P |

Step response of the controlled third order process is shown in Fig. 10. There is no overshoot, settling time is 4.75 sec and no steady state error.

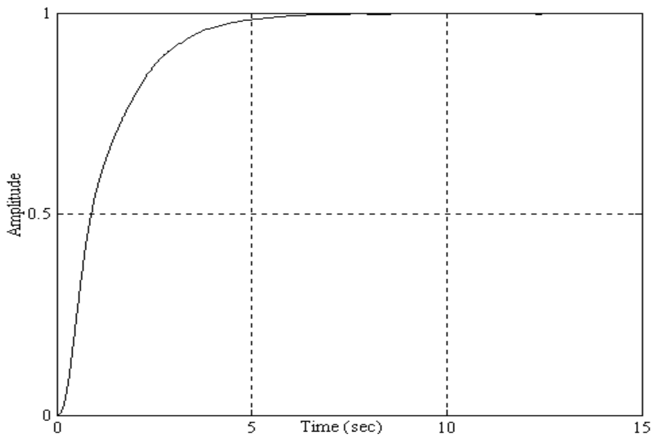


Fig. 10. Step response with FLC

The time response parameters percent overshoot ($M_p$), settling time ($t_s$) and steady state error ($e_{ss}$) for Ziegler Nichols tuned PID controller (ZNPIDC), fine-tuned PID controller (FTPIDC) and fuzzy logic controller (FLC) for the higher order system are presented in table II.

TABLE II. TIME RESPONSE PARAMETERS

| | $M_P$ (%) | $t_s$(sec) | $e_{ss}$ |
|---|---|---|---|
| ZNPIDC | 71.9 | 6.33 | 0 |
| FTPIDC | 19.8 | 5.81 | 0 |
| FLC | 0 | 4.75 | 0 |

## VI. CONCLUSION

The paper presented an overview of PID controller, design of PID controller using Z-N technique and design of fuzzy logic controller for higher order system. Simulation results using MATLAB / SIMULINK are discussed for Ziegler Nichols tuned PID controller, fine tuned PID controller and the Fuzzy logic controller.

Ziegler Nichols technique gives high overshoot and settling time with zero steady state error. Initial controller parameters obtained using Z-N formula need to be adjusted repeatedly through computer simulation to get satisfactory performance. Fine tuned PID controller gives zero steady state error and smaller overshoot and settling time than Ziegler Nichols tuned PID controller.

The Fuzzy Logic controller gives no overshoot, zero steady state error and smaller settling time than obtained using Ziegler Nichols tuned PID controller and fine tuned PID controller. The simulation results confirms that the proposed Fuzzy logic controller with simple design approach and smaller rule base can provide better performance comparing with the Ziegler Nichols tuned PID controller and fine tuned PID controller.

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