

Simplified Fuzzy Logic Controller Design for Higher Order Processes

Ahmed I. Mohamed

Alexandria, Egypt

Abstract: Several industrial processes are getting complicated day by day introducing an unstable higher order models. The proportional integral derivative (PID) controller is the most widely used control strategy in industry due to their robust performance in a wide range of operating conditions & their simple tuning methods. This paper presents design of PID controller using Ziegler-Nichols (ZN) tuning technique for controlling the higher order system. For the same purpose, A Fuzzy logic controller (FLC) using smaller rule set is proposed. Simulation results are demonstrated using MATLAB. Performance analysis shows the effectiveness of the designed Fuzzy logic controller as compared to the ZN tuned PID controller.

Keywords: Process control, PID, Fuzzy logic.

1. Introduction

The need for simple advanced control alternatives especially arises in the control processes area, where most of the real processes are generally complex and difficult to model [1]. The best known controllers used in the industrial processes are the conventional PID controller because of their simple structure and robust performance in wide operating conditions [2-3]. This controller deals with both time response and frequency response improvements if they are properly tuned [4-5]. But as the demands increases to control different complicated systems, performance of conventional PID controllers are tend to degrade. There is drastic change in the performance of controllers with the introduction of FLC [6]. Recently, FLC have been successfully applied to a wide range of industrial processes as well as consumer products, and show certain advantages over the conventional PID controllers [7-9]. 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 [10].

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 (4 rules) as it gives the same performance as by the larger rule set [11-14]. Simulation results for a higher (third) order system have been demonstrated. A performance comparison between Ziegler Nichols tuned PID controller, fine-tuned PID controller and the proposed FLC 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. The simulation results and dynamic performance analysis of this

investigation are presented in section VI. Some general conclusions are summarized in the last section.

2. Generalized Model of PID Controller

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

$$G_c(s) = P + I + D \\ = K_p + K_i / s + K_d s \dots \dots \dots (1)$$

Or,

$$G_c(s) = K_p (1 + 1/ T_i s + T_d s) \dots (2)$$

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 and 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.

3. Design Consideration

A PID controller is being designed for a higher order system. Consider a series of 'n' tanks (or compartments) where the volumetric flow rate 'q' and the respective volumes, 'v' are constant (Fig. 1).

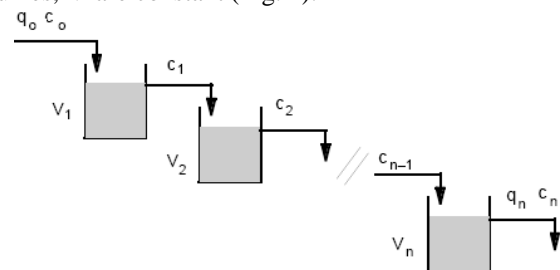


Figure 1: Illustration of tanks-in-series.

If all the tanks have the same space time, $\tau_1 = v_1/q_0 = \tau_2 = \dots \dots \tau$, The Laplace transform of the mass balance in deviation variables or transfer function for the system would be given in the form[15]:

$$G(S) = \frac{1}{(\tau s + 1)^n} \dots\dots (3)$$

For n=3, A PID controller is being designed for a system with transfer function:

$$G(s) = 1 / (s^3 + 3s^2 + 3s + 1) \dots\dots\dots (4)$$

The Simulink model of the PID controller and the plant with unity feedback is shown in Fig. 2. The author have proposed design of i) PID controller using Z-N technique (ii) FLC, so that the closed loop system exhibit small overshoot Mp and settling time Ts with zero steady state error Ess.

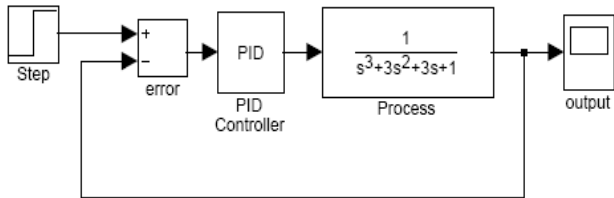


Figure 2: Process with PID controller

4. Design of PID Controller

Frequency response method suggested by Ziegler-Nichols is applied for design of PID controller [4], [12]. 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 $k_p = 8$ is shown in Fig. 3.

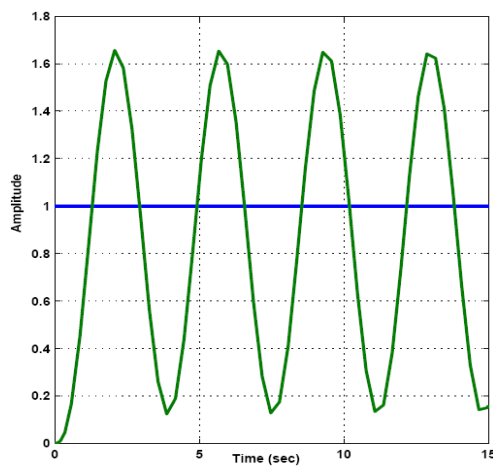


Figure 3 Step response for $k_p = 8$

The previous response clearly shows that sustained oscillation occurs for $k_p = k_u = 8$. The ultimate period T_u obtained from the time response is 3.75. The value of controller parameters are $k_p = 0.6$ $k_u = 4.8$, $T_i = 0.5$ $T_u = 1.875$, $T_d = 0.125T_u = 0.468$. The unit step response of the closed loop system with obtained values of k_p , T_i and T_d is shown in Fig. 4.

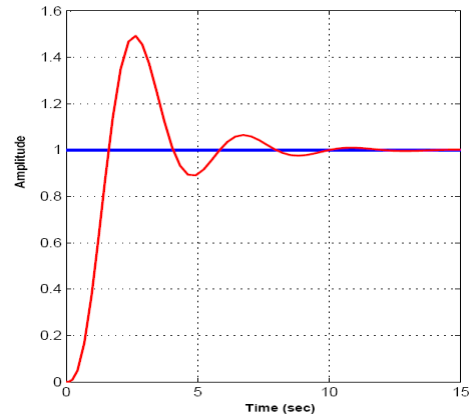


Figure 4: System response with PID controller.

5. Design of FLC

Simulink model of the fuzzy controller and the considered process with unity feedback is shown in Fig. 5.

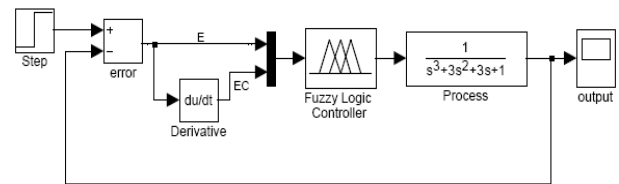


Figure 5: Process with FLC

For a two input fuzzy controller, 3,5,7,9 or 11 membership functions for each input are mostly used [11]. In this paper, only two fuzzy membership functions are used for the two inputs error 'E' and derivative of error 'EC' as shown in Figure. 6. The fuzzy membership functions for the output parameter 'U' are shown in Fig. 7, where N means Negative, Z means Zero and P means Positive.

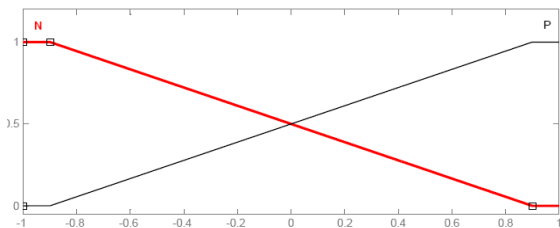


Figure 6: Membership functions for inputs 'E' and 'EC'

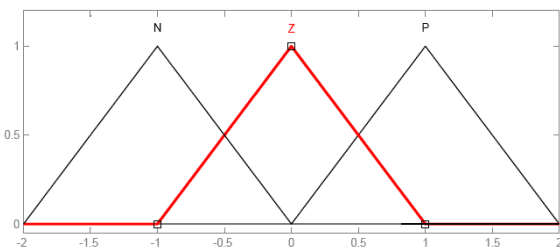


Figure 7: Membership functions for output 'U'

The output response of the system is given in Fig.8. A plot of the time variation of error versus the time variation of its change is shown in Fig. 9.

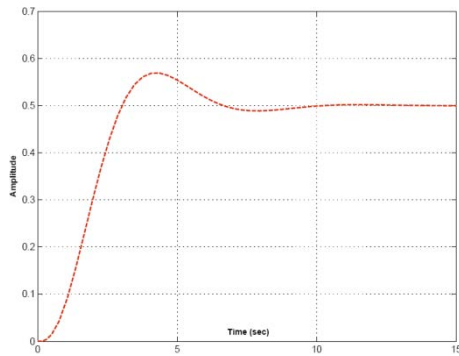


Figure 8: System step output response

As it clear in Fig. 8, the system response can be divided in two phases. Phase I - System output is below a value of 0.5. Phase II - System output is above the same value. Also, Fig. 9 shows that the error value swings around a value of 0.5 in the positive region. Depending upon whether the output is increasing or decreasing, 4 rules were conducted for the fuzzy logic controller (Table 2), where the sign of the output 'u' takes the sign of 'E' [16]. These four linguistic rules are sufficient to cover all possible situations. [2], [12], [13].

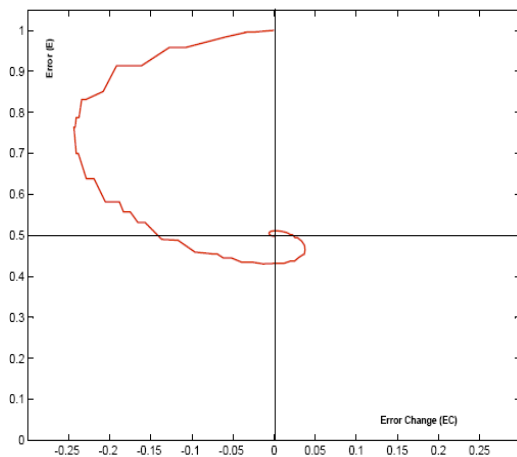


Figure 9: Space representing the time response of E versus EC.

Table 2: Fuzzy Rules for FLC

	E		
EC	U	N	P
	N	P	P
	P	P	P

6. Results and Discussions

Step response of the controlled third order process is shown in Fig. 10. Comparison between the responses of used controllers is shown in Fig. 11.

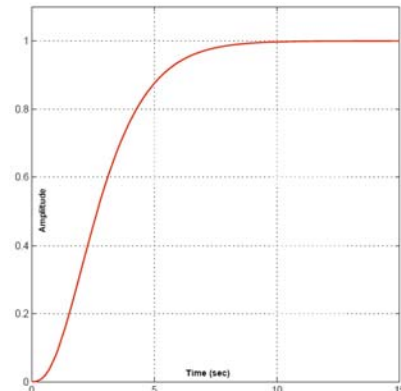


Figure 10: System response with FLC

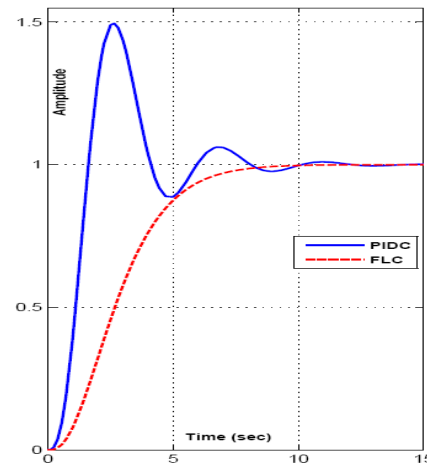


Figure 11: comparing the responses with different controllers

The performance time domain specifications are now calculated by observing Fig. 11. These are compared and tabulated as shown in the Table 2

Controller	Time domain performance parameters		
	M_p (%)	T_s (sec)	E_{ss} (%)
Used			
PID	49.24	8.83	0
FLC	0	7.5	0

Table 1: Comparing Time Response Parameters

7. Conclusions

Hence, in this paper firstly, design of PID controller using ZN technique is used for control higher order process. Later on, FLC with smaller rule set is introduced for the same. The performance of both is evaluated against each other. In summary, we can conclude that ZN technique is one of the tuning procedures for PID controllers for controlling higher order process. But the FLC gives better response. PID controller using ZN method gives high overshoot and high settling time with zero steady state error. FLC gives zero % overshoot, steady state error and lesser settling time.

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Author Profile

Ahmed I. Mohamed obtained his PhD in Electrical Engineering from Alexandria University, Egypt in 2011. Currently, He's an individual researcher; his general research interests span the areas of Renewable Energy Systems, Advanced Process Control, and Water Desalination.