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An Intelligent Controller Design Approach for MIMO Coupled Tank System

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ABSTRACT

Nowadays, versatilities of controllers have been developed to control the Coupled Tank System (CTS) such as proportional, integral, derivative (PID), fuzzy, fuzzy PID and neuro network. This paper focused on the control of the pump flow rate, in and out of the tank against the cross-sectional area of the CTS's tank. The main objective of this paper is to design a CTS by using MATLAB since the Fuzzy Logic Controller (FLC) is widely utilized in the control of engineering applications in the industrial. Therefore, the FLC will be utilized to control and improve the performance of the CTS. The conventional PID controller will be applied, which reacts as a benchmark in the performance of the FLC. Parameters such as steady state error, settling time, and maximum overshoot will be part of the simulation results. As a result of the dynamic response executed in the closed-loop environment, it can be concluded that the FLC is capable of performing better than the conventional PID controller.

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1. INTRODUCTION

Modern utilization of coupled tanks system (CTS) is broadly utilized as a part of the chemical process. There are a few procedures of CTS, for example, single input single output (SISO) or multiple input multiple output (MIMO) that has been utilized generally as a part of the industrial area. Moreover, the control procedure for MIMO is more convoluted than SISO in light of the fact that there is a communication between other control circles of MIMO procedures. Furthermore, the control structure implemented in the SISO system cannot be used in the control of the MIMO adequately. Generally, control design for MIMO which uses modern method controller to centralized the controller to satisfy response specification.

Recently, CTS is generally utilized as a part of shopper fluid continuing and synthetic handling industry. With a specific end goal to control the stature of the fluid a cutting edge Fuzzy Logic Controller (FLC) had been executed. The FLC has an assortment control that was capable of handle the CTS system with SISO or MIMO structures. The primary preferences of these fuzzy logic based control plans lie in the way that the created controller is capable to progressively manage the complex system and execute the process without exact information of the model structure [1].

In this paper, the simulation and the design of FLC are conducted in MATLAB/Simulink environment. Then, the performance of the designed fuzzy logic controller will be compared with the established conventional PID controller.

2. FUZZY LOGIC CONTROLLER CONCEPT

Fuzzy logic is a standout amongst the best uses of fuzzy set in which the factors are semantic as opposed to numeric [2]. The outline of an intelligent control system has turned into a range of serious research intrigue. Industrial process control system has many components, for example, non-straight, inertial slack, time deferral and time changing so on [3, 4]. Because of this, exact scientific demonstrating is impractical. Conventional PID calculation does not hold well for such system which has unsettling influences. Fuzzy has more preferences when compared with PID [5]. It has a quick reaction, little overshoot and great against impedance capacity.

2.1. Fuzzy Logic Design

Fuzzy Logic (FL) is a way to deal with control building issues, which mirrors how a man would decide, just much speedier [6]. FL consolidates a basic manage based "IF X AND Y THEN Z" way to deal with a taking care of control issue instead of endeavouring to demonstrate a system scientifically [7]. Each Fuzzy system is made out of four key pieces [8]:

i. Knowledge base: Rules and parameters for membership functions.
ii. Decision making unit: Inference operations on the rules.
iii. Fuzzification interface: Transformation of the crisp inputs into degrees of the match with linguistic variables.
iv. De-fuzzification interface: Transformation of the Fuzzy result of the inference into a crisp output.

3. MATHEMATICAL MODELLING OF CTS

It is essential to comprehend the arithmetic displaying of the conduct of Coupled Tank System (CTS). In this structure, the nonlinear element model is watched and the linearization procedure is done from the nonlinear model. In light of Figure 1, H1 and H2 are the liquid levels in Tank 1 and Tank 2.

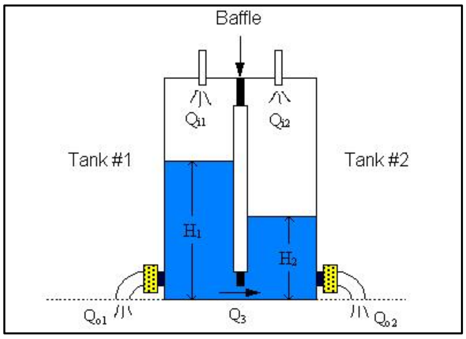

Figure 1. Schematic representation of the considered coupled tank

The liquid level is measured regarding the relating outlet. Considering a basic mass adjustment, the rate of progress of liquid volume in every tank breaks even with the net stream of liquid into the tank. In this way, the condition for Tank 1 and Tank 2 as shown in equations (1,2) [9][10]:

$$A_1 \frac{dh_1}{dt} = Qi_1 - Qo_1 - Q_3 \tag{1}$$

$$A_2 \frac{dh_2}{dt} = Qi_2 - Qo_2 - Q_3 \tag{2}$$

Where:
H_1, H_2 =Height of fluid in tank 1 and 2,
A_1, A_2 =Cross-sectional area of tank 1 and 2,
Q_3 =The rate flow of fluid between tanks,
Q_{i1}, Q_{i2} =Pump flow rate into tank 1 and 2,
Q_{o1}, Q_{o2} =Flow rate of fluid out of tank 1 and 2.

Every outlet depletes can be displayed as a basic hole. The Bernoulli's condition for consistent, non-gooey, incompressible demonstrates that the outlet stream in every tank is corresponding to the square foundation of the head of water in the tank. Similarly, the stream between the tanks is relative to the square base of the head differential. Thus equations (3), (4):

$$A_1 \frac{dh_1}{dt} = Q_1 - \frac{\alpha_1}{2\sqrt{H_1}} h_1 - \frac{\alpha_3}{2\sqrt{H_1 - H_2}} (H_1 - H_2) \tag{3}$$

$$A_2 \frac{dh_2}{dt} = Q_2 - \frac{\alpha_2}{2\sqrt{H_2}} h_2 - \frac{\alpha_3}{2\sqrt{H_1 - H_2}} (H_1 - H_2) \tag{4}$$

From the equations (3) and (4), to be equations (5), (6)

$$A_1 \dot{h}_1 = Q_1 - \frac{\alpha_1}{2\sqrt{H_1}} h_1 - \frac{\alpha_3}{2\sqrt{H_1 - H_2}} \left(H_1 - H_2\right) \tag{5}$$

$$A_2 \dot{h}_2 = Q_2 - \frac{\alpha_1}{2\sqrt{H_1}} h_2 - \frac{\alpha_3}{2\sqrt{H_1 - H_2}} \left(H_1 - H_2\right) \tag{6}$$

The manipulated variable is the perturbation to tank 1 inflow. Assuming that mutually all variables are at their steady state value. Thus equations (7) and (8)

$$A_1 \dot{h}_1 = Q_1 - \frac{\alpha_1}{2\sqrt{H_1}} h_1 - \frac{\alpha_3}{2\sqrt{H_1 - H_2}} \tag{7}$$

$$A_2 \dot{h}_2 = Q_2 - \frac{\alpha_1}{2\sqrt{H_1}} h_2 - \frac{\alpha_3}{2\sqrt{H_1 - H_2}} \tag{8}$$

The h_2 is the process variable and q_1 is the manipulated variable. The case will be considered when q_2 is zero. Equations (7) and (8) will be expressed in a form that relates between the manipulated variable, q_1 and the process variable, h_2. Therefore equations (9)-(16):

$$T_1 \dot{h}_1 + h_1 = K_1 q_1 + K_{12} h_2 \tag{9}$$

$$T_2 \dot{h}_2 + h_2 = K_2 q_2 + K_{21} h_1 \tag{10}$$

Where,

$$T_1 = \frac{A_1}{\left[\frac{\alpha_1}{2\sqrt{H_1}}\right] + \left[\frac{\alpha_3}{2\sqrt{H_1 - H_2}}\right]} \tag{11}$$

$$T_2 = \frac{A_2}{\left[\frac{\alpha_2}{2\sqrt{H_2}}\right] + \left[\frac{\alpha_3}{2\sqrt{H_1 - H_2}}\right]} \tag{12}$$

$$K_1 = \frac{1}{\left[\frac{\alpha_1}{2\sqrt{H_1}}\right] + \left[\frac{\alpha_3}{2\sqrt{H_1 - H_2}}\right]} \tag{13}$$

$$K_2 = \frac{1}{\left[\frac{\alpha_2}{2\sqrt{H_2}}\right] + \left[\frac{\alpha_3}{2\sqrt{H_1 - H_2}}\right]} \tag{14}$$

$$K_{12} = \frac{\left[\frac{\alpha_3}{2\sqrt{H_1 - H_2}}\right]}{\left[\frac{\alpha_1}{2\sqrt{H_1}}\right] + \left[\frac{\alpha_3}{2\sqrt{H_1 - H_2}}\right]} \tag{15}$$

$$K_{21} = \frac{\left[\frac{\alpha_3}{2\sqrt{H_1 - H_2}}\right]}{\left[\frac{\alpha_2}{2\sqrt{H_2}}\right] + \left[\frac{\alpha_3}{2\sqrt{H_1 - H_2}}\right]} \tag{16}$$

The provided parameters are shown in Table 1 below from model CTS-001 manual.

Table 1. Parameters of CTS

Parameters	Value	Unit
H_1	17.00	cm
H_2	15.00	cm
α_1	10.78	$cm^{3/2}$/sec
α_2	11.03	$cm^{3/2}$/sec
α_3	11.03	$cm^{3/2}$/sec
A_1	32.00	cm^2
A_2	32.00	cm^2

Then, all the parameters in Table 1 have been inserted into the equations (11), (12), (13), (14), (15) and (16) as shown in Table 2:

Table 2. Value for the Equations (11), (12), (13), (14), (15) and (16)

Equation	T_1	T_2	K_1	K_2	K_{12}	K_{21}
Value	6.15	6.01	0.19	0.188	0.75	0.73

All calculations from Table 2 must be insert together at equations (9) and (10) for two tanks where are equations (17) and (18):

$$6.15\dot{h}_1 + h_1 = 0.19q_1 + 0.75h_2 \tag{17}$$

$$6.01\dot{h}_2 + h_2 = 0.18q_2 + 0.73h_1 \tag{18}$$

From the equations (17) and (18), we wanted $\dot{h}_1$ and $\dot{h}_2$ only for both tanks. Thus, the actual transfer function of the plant with the completed value is:

$$\dot{h}_1 = \frac{1}{6.15}\left(0.19q_1 + 0.75h_2 - h_1\right) \tag{19}$$

$$\dot{h}_2 = \frac{1}{6.01}\left(0.18q_2 + 0.73h_1 - h_2\right) \tag{20}$$

4. CONTROLLER DESIGN

As discussed in the modelling section, the actual transfer function obtained will be inserted into the MATLAB/Simulink. Figure 2 depicts the block diagram of the CTS's actual plant in the MIMO structure.

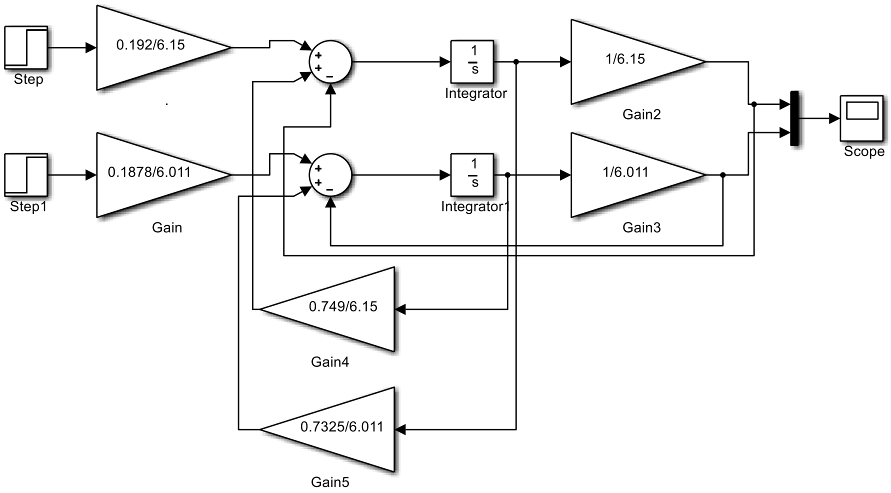

Figure 2. Actual plant of CTS with MIMO structure

The CTS plant that has been developed will be then controlled by using the proposed controllers in order to improve the performance of the CTS.

4.1. PID Controller

The plant will be first connected to the PID controller as initial process or the performance in the early state. It is well-known that the performance of the PID controller is very much affected by the tuning method. Therefore, the PID controller implemented to the CTS plant will be tuned by using numerous tuning method as follow:

i. Trial and Error.
ii. Auto tuning.
iii. Ziegler-Nichols (Z-N) tuning.

Table 3 demonstrates the parameters of the PID controller (K_p, K_i and, K_d). As indicated in Table 3, the tuning strategy for PID controller has demonstrated the ability of the system by utilizing either estimation approach or encounters approach.

Table 3. Parameters of the PID controller

Methods	Tank-1-			Tank-2-		
	K_p	K_i	K_d	K_p	K_i	K_d
Trial and Error	15.00	01.00	08.00	15.00	01.00	08.00
Auto-Tuning	66.23	06.51	-127.71	59.54	09.43	-135.25
Ziegler-Nichols	11.73	10.74	02.68	31.34	03.76	00.94

4.2. Fuzzy Logic Controller

By utilizing same plant of the CTS MIMO that connected with PID controller. The plant will be connected with fuzzy logic controller with 2 different type rules that use in this simulation. This fuzzy logic controller will test by using: i) Fuzzy logic controller – 3 rules. ii) Fuzzy logic controller – 5 rules.

From this two set of simulations, two input which are level of water and rate of water flow into the tank and output variable of the controller. The output is the valve that controls the rate of water flow into tanks [11].

4.2.1. Fuzzy Logic Rule Base

The output of the controller is a valve which varies corresponding changes in input. For Fuzzy Logic 3 rules, three states were considered for both inputs while performing the rule base namely high, okay, and low for water level input. Second input namely negative, zero and positive. The output namely close, average, and none [12]. The rules of fuzzy 3 rules as follows: i) If the level is high then the valve is closed. ii) If the level is ok and the rate is zero, then the valve is average. iii) 3. If the level is low then the valve is open.

While fuzzy logic 5 rules for water level input namely very low, low, okay, high, and very high. Second input namely very negative, negative, zero, positive, and very positive. The output name as fast close, close, normal, open, and fast open. The rules of fuzzy controller 5 rules as follows: i) If the level is high then the valve is fast close. ii) If the level is ok and the rate is positive then the valve is fast close. iii) If the level is ok then the valve is closed. iv) If the level is low then the valve is normal. v) If the level is very low then the valve is fast open.

5. RESULTS AND DISCUSSION

Table 4 demonstrates the rundown of the transient response particular of the PID controller by the traditional tuning technique regarding the parameters in Table 3, where T_r represent the rise time, T_s is the settling time, and *OS*% is the overshoot of the system in percentage.

Table 4. Transient Response of the PID Controller

Methods	Tank-1-			Tank-2-		
	T_r (sec)	T_s (sec)	*OS*%	T_r (sec)	T_s (sec)	*OS*%
Trial and Error	93.00	204.00	00.00	93.10	204.00	00.00
Auto-Tuning	04.70	38.60	0.198	04.95	25.60	08.27
Ziegler-Nichols	06.14	46.30	26.30	24.20	43.90	00.00

From the conventional tuning technique, the performance of the controller will be discussed based on the graph according to the parameter of the PID controllers which is one of the transient response particulars which are settling time demonstrates that auto tuning strategy had the quickest time for the system to achieve the steady condition in the system. From the tuning technique for Z-N, the reaction of the framework is the second speediest after the auto tune, contrasted with the other tuning strategy. Plus, auto tune technique demonstrates that it has the quickest time in the ascent time in the framework tooked after by Z-N, and Trial and Error strategy. Be that as it may, auto tune technique has the speediest time reaction for the framework, however, the rate of the overshoot is higher in tank 2 contrasted with the strategies of the other.

Then, FLC has been applied in order to enhance the capability of the CTS. Table 5 demonstrates the transient response analysis particularly for the fuzzy logic controller with both rules base as discussed in the previous section.

Table 5. Transient Response of the Fuzzy Logic Controller

Methods	Tank-1-			Tank-2-		
	T_r (sec)	T_s (sec)	*OS*%	T_r (sec)	T_s (sec)	*OS*%
3 Rules	49.30	88.60	0.00	49.10	88.40	0.00
5 Rules	25.20	46.10	0.00	25.00	45.90	0.00

From the Table 5, the performance of the controller will be discussed based on the graph according to robustness and time to settle down. Fuzzy logic 5 rules and 3 rules demonstrate a good stability which had zero overshoot for both tanks. In this case, both controllers are robust however fuzzy logic 5 rules had the quickest time for the system to achieve the steady condition in the system while fuzzy logic 3 rules take more than 30 seconds to achieve the steady condition. This case shows that fuzzy logic 5 rules more robust and faster and it will compare with PID controller at the discussion.

In order to evaluate the performance and capabilities of the proposed controller implemented in the CTS with MIMO structure, the best tuning technique and control rule, which is Ziegler-Nichols for the PID controller and fuzzy logic controller with 5 rules have been selected. Figures 3, 4, 5, and 6 demonstrate the graphical results for both controllers.

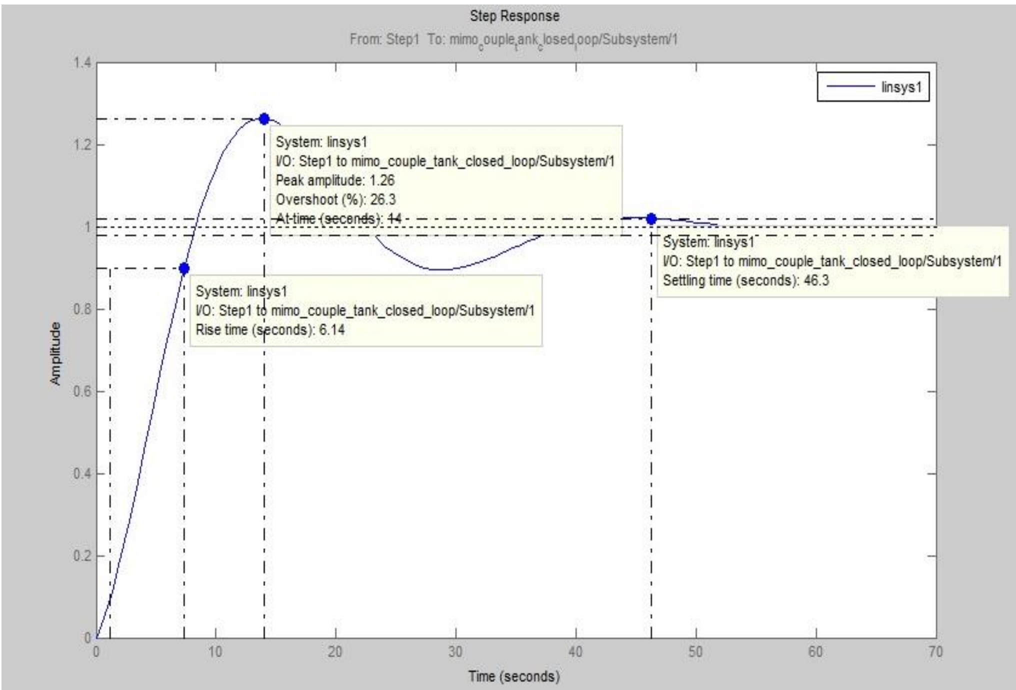

Figure 3. Z-N result of PID controller for tank 1

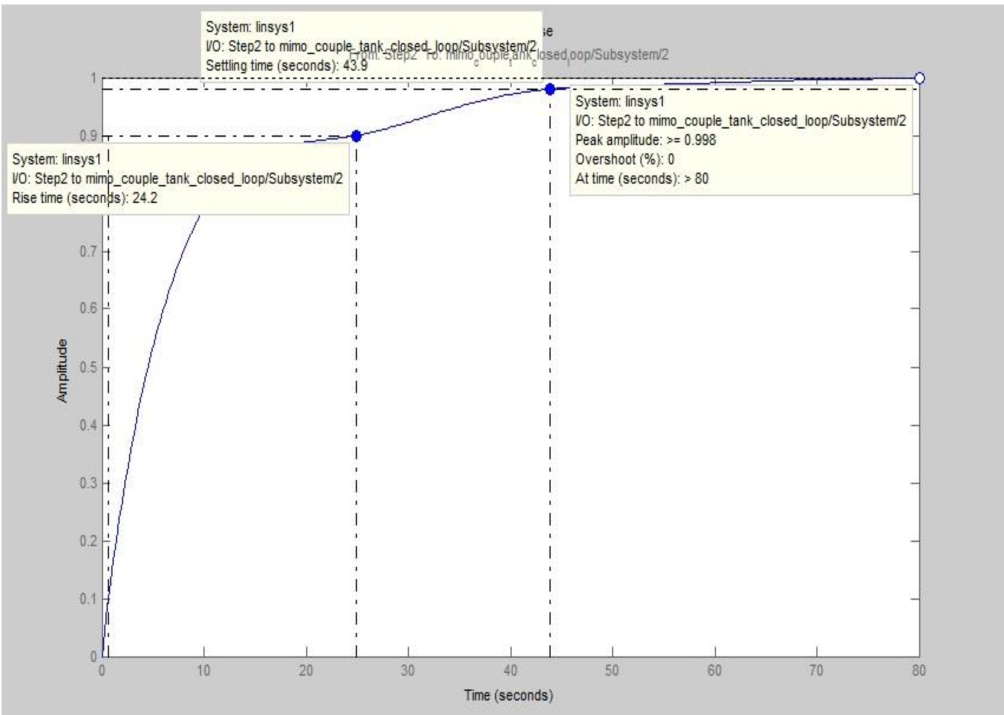

Figure 4. Z-N result of PID controller for tank 2

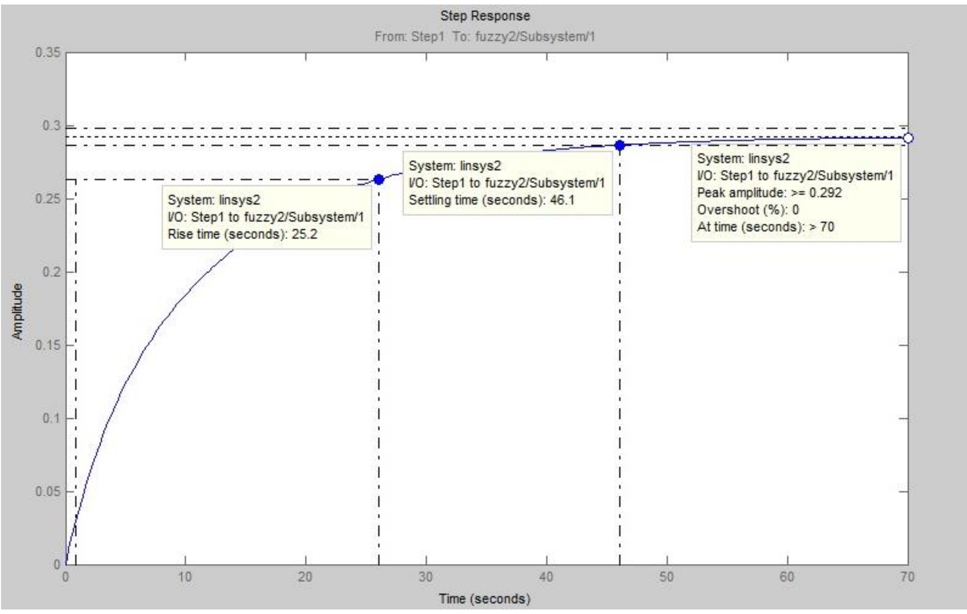

Figure 5. Fuzzy logic controller with 5 rules for tank 1

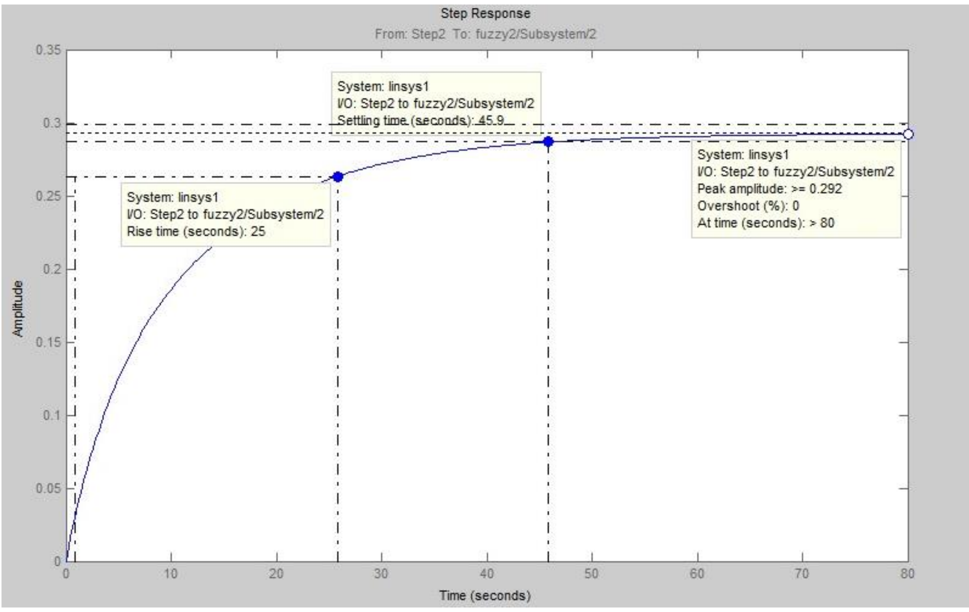

Figure 6. Fuzzy logic controller with 5 rules for tank 2

Table 6 depicts the comparison analysis in term of the transient response of both controllers implemented in the tank 1 and 2 of CTS plant.

Table 6. The comparison for both PID and fuzzy logic controllers with the best performances

Methods	Tank-1-			Tank-2-		
	T_r (sec)	T_s (sec)	*OS%*	T_r (sec)	T_s (sec)	*OS%*
Ziegler-Nichols	06.14	46.30	26.30	24.20	43.90	0.00
5 Rules	25.20	46.10	00.00	25.00	45.90	0.00

Referring to the Table 5, it can be inferred that by utilizing the Z-N routine tuning strategy for PID controller have their own particular favourable circumstances and inconveniences. For the Z-N tuning technique, it is the well-known strategy in the business. This strategy required brief time to finish and simple to use than alternate techniques. Despite the fact that it is a famous technique yet through this strategy, it delivered a forceful pickup and overshoot in the system. The procedure response bend is gotten first from the open-loop system before substituting the esteem in the standard suggested condition. The Z-N strategy is the parameters of T_i and T_d can be acquired in open-loop and closed-loop system for Z-N technique. Thus, for the Auto-Tuning technique despite the fact that it is the least difficult strategy yet the esteem got from this strategy does not allude on the individual parameter. The esteem which is gotten from this technique is the blend of the parameters in PID controller.

After both controller being compare based on observation fuzzy logic controller for 5 rule base produce a great result even though PID controller for Z-N tuning method great in settling and rise time. Fuzzy logic controller for 5 rules base creates a great stability in order to achieve desired output other than PID controller that have poor in stability which is almost 30%. Last but not least, to create a great performance by using FLC, it sets aside long opportunity to accomplish a decent execution unless having enough involvement to tune it. At that point, it can spare time.

6. CONCLUSION

For PID controller the parameter can be tuned by the customary strategy. For example, Trial and error, Z-N, and auto-tuning and same go to the FLC which has a lot of different type of rules. The execution of the both system which is PID and FLC for CTS may accomplish the great execution however very troublesome for finding the parameters. It required a great deal of exertion and encounters to get a decent pick up of the both controllers. In this manner, improvement approach will be executed to locate the ideal parameters of the controller. By utilizing this approach, a better gain and performance is normal. Therefore, in future, the FLC will be integrated with different set of rules in order to achieve the great performance based on settling time, rise time, and overshoot.

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