Design of a Fluid Level Controller for a Coupled Tank System

Marvi Jamali, Dr Arbab Nighat, Dr Farida Memon, Fida Hussain Jamali

Abstract—This research presents an ANFIS (Adaptive Neuro-Fuzzy Inference System) controller which combines the capabilities of a fuzzy logic controller with a neural network to control the fluid level and flow rate in interacting and non-interacting coupled tank system, respectively, using MATLAB/Simulink. To achieve this, the Simulink models of two various configured coupled tank system, such as interacting and non-interacting coupled tank system, are developed and simulation results are presented. The proposed ANFIS controller's performance for the level and flow rate has been analyzed using the control parameters rise time, settling time, peak time, and overshoot. The results shows that the ANFIS (Adaptive Neuro-Fuzzy Inference System) controller provides satisfactory performance in terms of minimal rise time, settling time, peak time, and less steady state error as compared to other controllers.

Index Terms—ANFIS, Coupled tank system, Dynamics, Fluid level, Process industries

1 INTRODUCTION

NOWADAYS, the several parameters in the process industries are controlled, for example temperature, level, etc. [1]. One of the most fundamental aspect of the industrial process control is fluid level control specifically in chemical process industries, such as food processing industries, water treatment plant, textile industries, pharmaceutical industries, boilers, nuclear power plants, sugar mills and paper industries [2]. Emergency shutdowns of the power plants is due to the inadequate control of the water level of the steam generator, which has a significant impact on the plant effectiveness, utilization of time, system maintenance and material quality [3]. Therefore, it is primary requirement of process industries to have an exact and consistent control of the level and flow rate of fluid in a coupled tank system.

The fluid level in a coupled tank system must be controlled by the appropriate controller. PID controller is the most often used controller in the process industry for its simplicity and efficiency. The traditional approaches for tuning of PID controller have some drawbacks. They provide inadequate results for tuning about one operating point. Furthermore, PID controllers includes overshoots and settling time, which are not desirable features. PID fails to respond quickly because of the non-linearity of the system [4],[5]. Nonlinear processes are difficult to regulate with a linear PID controller. Therefore, Fuzzy logic controller is being examined to control non-linear processes [6]. In process industries, such as chemical process control, fuzzy logic control is commonly utilized. The fuzzy logic controller, unlike the PID controller, has advantages in terms of system response to handle a level control problem [7]. In Fuzzy control, rules are gained from a human expertise. This technique, however, has significant drawbacks because human knowledge frequently leads to incorrect rules [8]. Many control models have been developed and applied for efficient fluid level control, but due to its linear structure, another methodology that can be used in both linear and non-linear models is required [9]. To control any non-linear process plant, ANFIS controller is a best choice because Neuro-Fuzzy controller regulates the rules automatically, decreases processing time, adapts quicker, and produces least errors than the different controllers [10].

This research presents an ANFIS (Adaptive neuro-fuzzy inference system) controller for a coupled tank system. An ANFIS controller is designed using MATLAB/Simulink to optimize the fluid level and flow rate parameters of an interacting and non-interacting coupled tank system.

2 LITERATURE REVIEW

Fluid level control have been extensively studied in the literature. Many researchers have examined different methodologies of controller design for efficient fluid level control. A brief review of literature is given below:

Nayanmani Deka [11] have developed a PID and fuzzy Logic controller for the tank system liquid level control using LabView and provides comparative analysis between PID and fuzzy logic controller. As a result of comparison, fuzzy logic controller is observed as 1.8 times more rapidly than the PID controller. Davis, et al. [12] have designed a Simulink model of fuzzy controller to control the water tank level in MATLAB/Simulink and compared the results of designed controller with the effects of a PID controller. Fuzzy controller considerably reduced the overshoot and steady state error than the PID controller. Nayanmani Deka, Dr. Lini Mathew

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[13] have proposed a PID controller for controlling the two-tank liquid level using LabView. The proposed system is stabilized near to the set point without being manually adjusted. Mursyitah, et al. [14] have presented a PID controller with Fuzzy Logic for tuning the PID controller parameters Kp, Ki, and Kd to control the fluid level in a coupled tank system. Mianmian Dong and Baoyi Guo [15] have analyzed the algorithm of water-tank level control to eliminate the control error of water level and designed two-dimensional fuzzy logic controller to get the better control performance. Ihedioha Ahmed C. and Eneh Ifeanyichukwu I. [16] have implemented a fuzzy based controller for controlling and monitoring the water level. The proposed fuzzy logic controller has advantages of the quick system response and provides promising results for level control to various industrial level controlling apparatus than the PID controller. Deign Gloria Jose, Shalu George K [17] have developed a PID controller using empirical Zeigler-Nichols Tuning method in MATLAB for the liquid level system. Khalid et al. [18] have proposed a nonlinear artificial neural network controller to control the flow rate and level of fluid in a four coupled tank system.

From the literature review it is found that, most of the research work is done using PID and Fuzzy logic controller to control the water tank level system. This research is focused on the design of ANFIS (Adaptive Neuro-Fuzzy Inference System) controller to control the fluid level and flow rate parameters of coupled tank system using MATLAB/Simulink software.

3 DYNAMICS OF A COUPLED TANK SYSTEM

Coupled tank system are arranged in two various configurations: Interacting and non-interacting coupled tank system.

3.1 Interacting coupled tank system

In interacting coupled tank system, dynamics of the first tank affects the dynamics of the second tank because the flow rate varies with the difference between the fluid levels. Interacting coupled tank system is shown in Fig. 1.

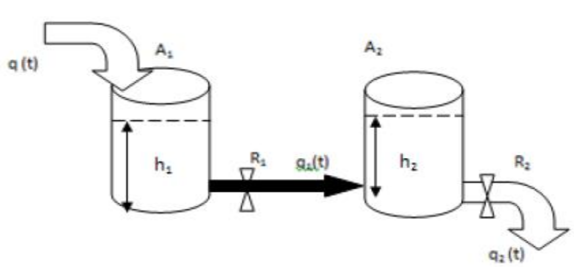

Fig. 1. Interacting coupled tank system [2]

Interacting coupled tank system is designed using specifications shown in Table 1 by using MATLAB/Simulink software.

TABLE 1
PARAMETERS OF INTERACTING COUPLED TANK SYSTEM

S.No.	Parameter (s)	Symbol	Value (s)
1	Cross-sectional area of tank-1 and tank-2	A	66.4424 cm^2
2	Change in level of tank 1	dH_1	52.5105 cm
3	Change in level of tank 2	dH_2	33.0066 cm
4	Change in flow rate	dQ	33.34 $\frac{cm^3}{sec}$
5	Resistance of outlet valve of tank 1	R_1	1.575
6	Resistance of outlet valve of tank 2	R_2	0.99
7	Time constant of tank 1	T_1	104.6468 $second$
8	Time constant of tank 2	T_2	65.77798 $second$

3.1.1 Mathematical Modeling of an Interacting coupled tank system

Applying mass balance equation for each tank

Tank 1:

$$q - q_1 = A_1 \frac{dh_1}{dt} \quad (1)$$

$$q_1 = \left(\frac{h_1 - h_2}{R_1}\right) \quad (2)$$

Using eq (2) in eq (1)

$$A_1 \frac{dh_1}{dt} = q - \frac{(h_1 - h_2)}{R_1} \quad (3)$$

Tank 2:

$$q_1 - q_2 = A_2 \frac{dh_2}{dt} \quad (4)$$

$$q_2 = \frac{h_2}{R_2} \quad (5)$$

Using eq (2) and eq (5) in eq (4)

$$A_2 \frac{dh_2}{dt} = \frac{(h_1 - h_2)}{R_1} - \frac{h_2}{R_2} \quad (6)$$

The overall transfer function for the level of an interacting system is [2]

$$\frac{H_2(s)}{Q(s)} = \frac{R_2}{\tau_1 \tau_2 s^2 + (\tau_1 + \tau_2 + A_1 R_2)s + 1} \quad (7)$$

Using the values illustrated in Table 1 then the transfer function for the level becomes:

$$\frac{H_2(s)}{Q(s)} = \frac{0.99}{6883.455117s^2 + 236.202756s + 1}$$

From eq (5)

$$H_2 = Q_2 R_2 \quad (8)$$

Using eq (8) in eq (7) then the transfer function for the flow rate of an interacting system is

$$\frac{Q_2(s)}{Q(s)} = \frac{1}{\tau_1 \tau_2 s^2 + (\tau_1 + \tau_2 + A_1 R_2)s + 1} \quad (9)$$

Using the values illustrated in Table 1 then the transfer function for the flow rate becomes:

$$\frac{Q_2(s)}{Q(s)} = \frac{1}{6883.455117s^2 + 236.202756s + 1}$$

3.2 Non-interacting coupled tank system

In non-interacting coupled tank system, dynamics of the first tank does not affects the dynamics of the second tank. Non-interacting coupled tank system is shown in Fig. 2.

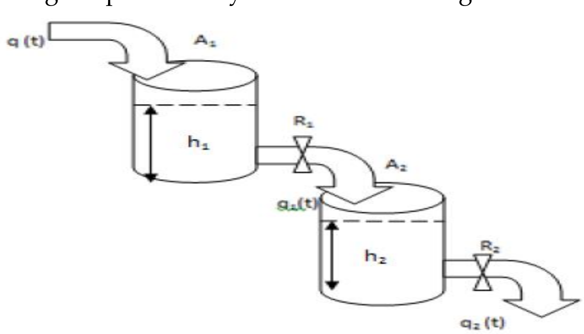

Fig. 2. Non-interacting coupled tank system [2]

Non-interacting coupled tank system is designed using specifications illustrated in Table 2 by using MATLAB/Simulink software.

TABLE 2
PARAMETERS OF NON-INTERACTING COUPLED TANK SYSTEM

S.No.	Parameter (s)	Symbol	Value (s)
1	Cross sectional area of tank-1 and tank-2	A	66.4424 cm^2
2	Change in level of tank 1	dH_1	$35.007\ cm$
3	Change in level of tank 2	dH_2	$50.76015\ cm$
4	Change in flow rate	dQ	33.34 $\frac{cm^3}{sec}$
5	Resistance of outlet valve of tank 1	R_1	1.05
6	Resistance of outlet valve of tank 2	R_2	1.5225
7	Time constant of tank 1	τ_1	$69.76452\ second$
8	Time constant of tank 2	τ_2	$101.1586\ second$

3.2.1 Mathematical Modeling of non-interacting coupled tank system

Applying mass balance equation for each tank

Tank 1:

$$q - q_1 = A_1 \frac{dh_1}{dt} \quad (10)$$

$$q_1 = \frac{h_1}{R_1} \quad (11)$$

Using eq (11) in eq (10)

$$A_1 \frac{dh_1}{dt} = q - \frac{h_1}{R_1} \quad (12)$$

Tank 2:

$$q_1 - q_2 = A_2 \frac{dh_2}{dt} \quad (13)$$

$$q_2 = \frac{h_2}{R_2} \quad (14)$$

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Using eq (11) and eq (14) in eq (13)

$$A_2 \frac{dh_2}{dt} = \frac{h_1}{R_1} - \frac{h_2}{R_2} \qquad (15)$$

The transfer function for the level of non-interacting tank system is [2]

$$\frac{H_2(s)}{Q(s)} = \frac{R_2}{(\tau_1 s+1)(\tau_2 s+1)} \qquad (16)$$

Using the values illustrated in Table 2 the transfer function for the level of non-interacting tank system is

$$\frac{H_2(s)}{Q(s)} = \frac{1.5225}{7057.281173s^2 + 170.92312s + 1}$$

From eq (14)

$$q_2 = \frac{h_2}{R_2}$$

Taking Laplace transform of eq (14)

$$Q_2(s)R_2 = H_{2(s)} \qquad (17)$$

Using eq (17) in eq (16) then the transfer function for the flow rate of non-interacting tank system is

$$\frac{Q_2(s)}{Q(s)} = \frac{1}{(\tau_1 s+1)(\tau_2 s+1)} \qquad (18)$$

Using the values illustrated in Table 2 the transfer function for the flow rate of non-interacting tank system is

$$\frac{Q_2(s)}{Q(s)} = \frac{1}{7057.281173s^2 + 170.92312s + 1}$$

4 DESIGN OF AN ANFIS (ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM) CONTROLLER

For designing an ANFIS controller for controlling the level and flow rate of an interacting and non-interacting tank system, the fuzzy logic controller is designed in MATLAB/Simulink to acquire the data set for the training of an ANFIS controller.

4.1 Design of a Fuzzy Logic Controller

In fuzzy logic controller (FLC), there are two inputs error and derivative of error and one output.

Seven gaussian type membership functions are chosen for each input and output. The membership functions and their symbols can be shown in Table 3.

TABLE 3

MEMBERSHIP FUNCTIONS AND THEIR REPRESENTATIONS

Membership function	**Symbol**
Large negative	NL
Medium negative	NM
Small negative	NS
Zero	Z
Small positive	PS
Medium positive	PM
Large positive	PL

All membership functions are selected of a gaussian type, and all are the same. The width of the fuzzy sets is selected by using hit and trial method.

The width of fuzzy set for the level and flow rate of an interacting tank system is selected as:

- e = [-8 8]
- ce = [-8 8]
- output = [-19 19]

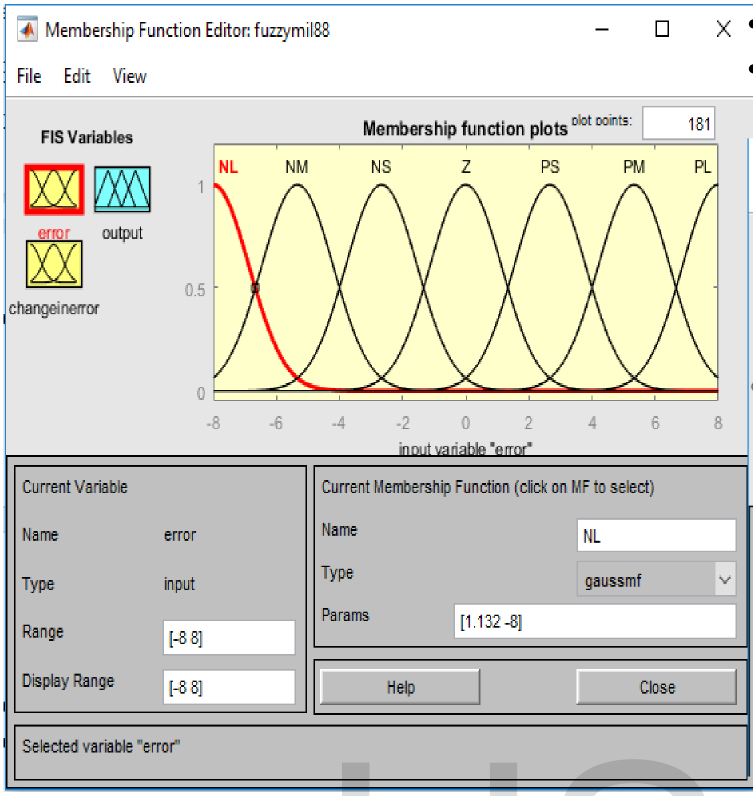

Fig. 3. Gaussian membership functions for the error

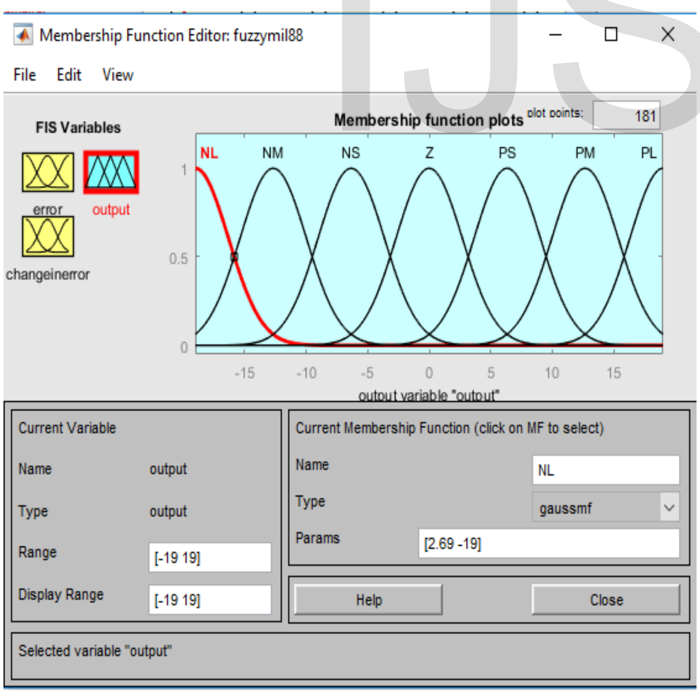

Fig. 4. Gaussian Membership functions for the output

The width of fuzzy set for the level and flow rate of non-interacting tank system is selected as:

- e = [-1 1]
- ce = [-1 1]
- output = [-1 1]

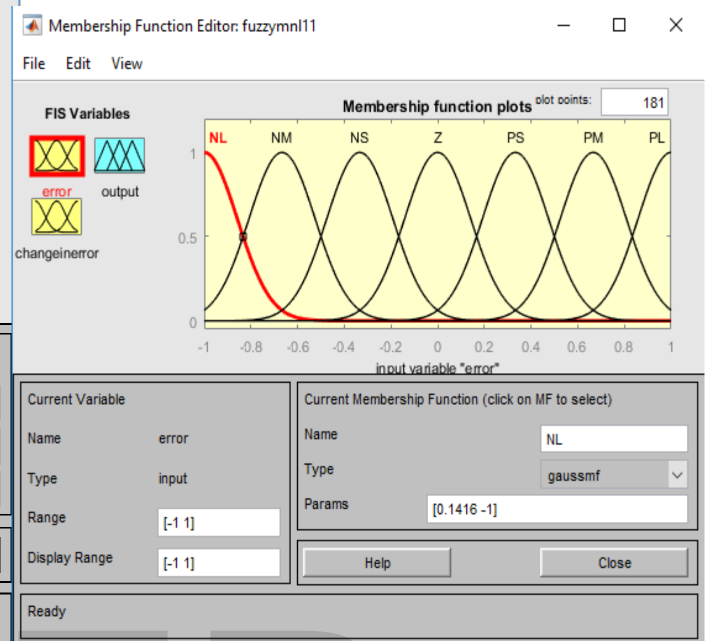

Fig. 5. Gaussian membership functions for the error

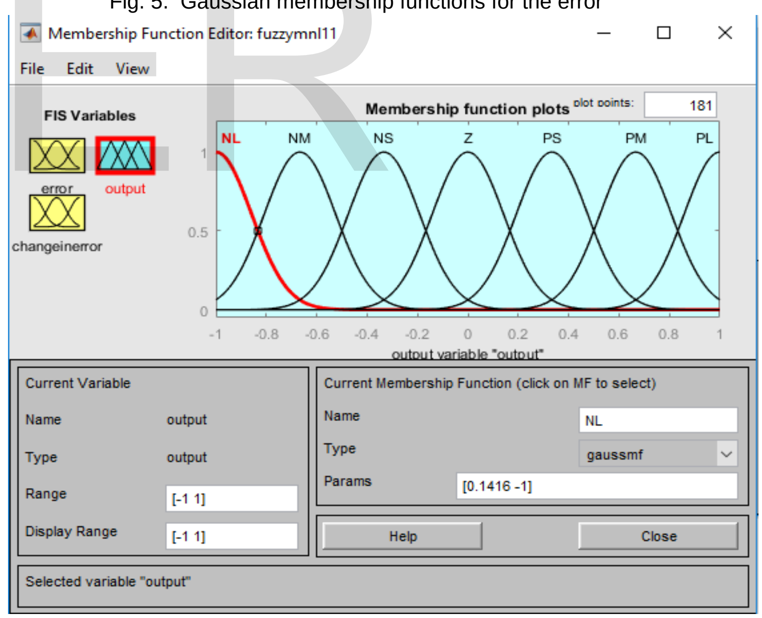

Fig. 6. Gaussian Membership functions for the output

A set of 49 rules is built by using seven gaussian type membership function for the inputs error and change in error. The fuzzy rule base is shown in Table 4.

TABLE 4
RULE BASE

	Error						
Change	NL	NM	NS	Z	PS	PM	PL

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	NL	NL	NL	NL	NL	NM	NS	Z
	NM	NL	NL	NL	NM	NS	Z	PS
	NS	NL	NL	NM	NS	Z	PS	PM
	Z	NL	NM	NS	Z	PS	PM	PL
	PS	NM	NS	Z	PS	PM	PL	PL
	PM	NS	Z	PS	PM	PL	PL	PL
	PL	Z	PS	PM	PL	PL	PL	PL

4.2 ANFIS (Adaptive neuro-fuzzy inference system) controller

ANFIS controller is designed in MATLAB/Simulink for controlling the fluid level and flow rate of an interacting and non-interacting coupled tank system.

The two inputs error and derivative of error are utilized to generate the rules in the ANFIS. The Fuzzy Inference System (FIS) generate using MATLAB ANFIS toolbox is trained using the input/output data set from the coupled tank system with the MF's parameters for the inputs error and derivative of error are adjusted by employing hybrid learning method. As a result, a fuzzy approach can learn from the data it is modeling. For training the epochs is set to 100. The number of MF's for the error and derivative of error are 3 and 3, respectively. There are nine rules in total. The Gaussian type membership function is used for the inputs.

The Simulink model of an interacting and non-interacting coupled tank system for the fluid level and flow rate control using ANFIS controller are shown in fig. 7, 8, 9 and 10 respectively.

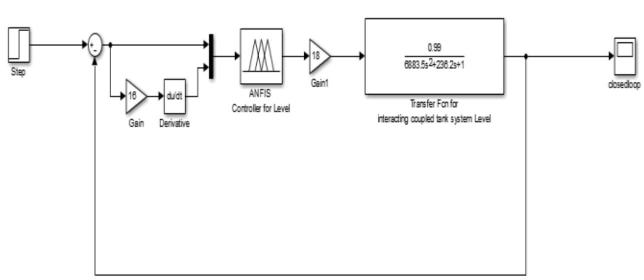

Fig. 7. Simulink model for the fluid level control of an interacting coupled tank system

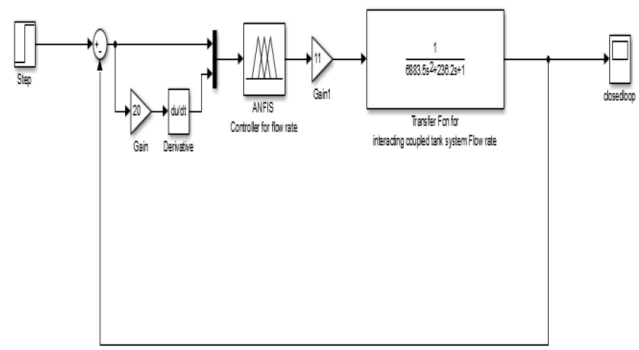

Fig. 8. Simulink model for the fluid flow rate control of an interacting coupled tank system

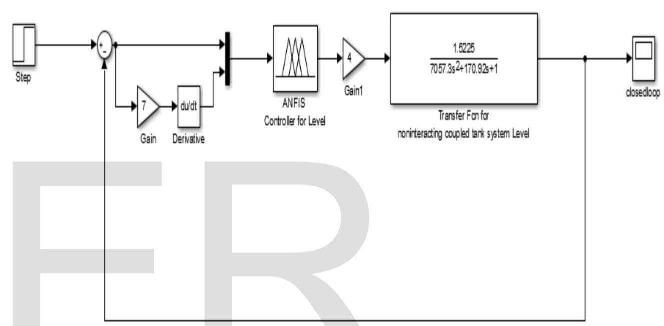

Fig. 9. Simulink model for the fluid level control of non-interacting coupled tank system

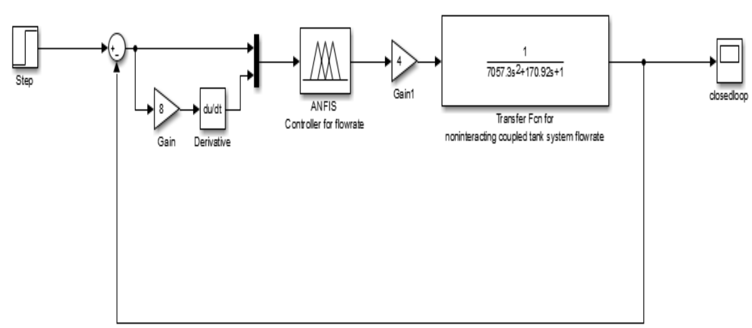

Fig. 10. Simulink model for the fluid flow rate control of non-interacting coupled tank system

5 RESULTS AND DISCUSSION

An extensive simulation analysis is done on the coupled tank system which usually includes the simulation of control of both interacting and non-interacting tank system using the ANFIS controller in MATLAB/Simulink.

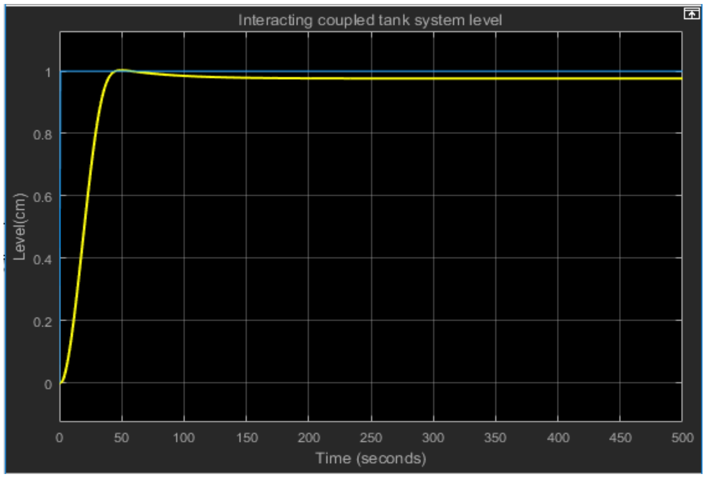

Fig. 11. Fluid level control of an interacting coupled tank system with ANFIS controller

Fig.11 shows the step response of fluid level control of an interacting coupled tank system using ANFIS controller. The step characteristics can be observed as: rise time= 24.3sec, settling time=67.2sec, peak time= 49sec, overshoot= 2.5%.

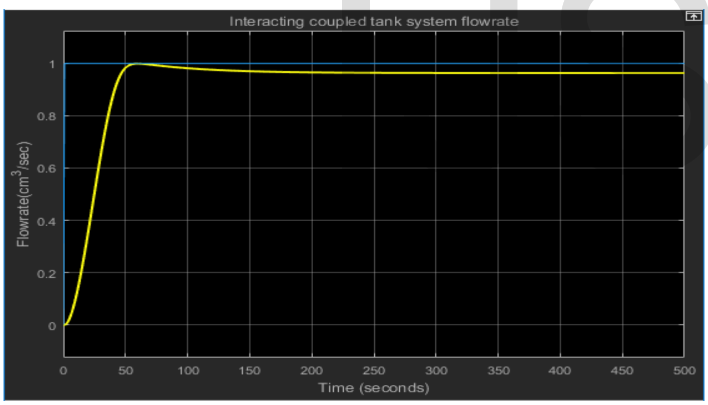

Fig. 12. Fluid flow rate control of an interacting coupled tank system with ANFIS controller

Fig.12 shows the step response of fluid flow rate control of an interacting coupled tank system using ANFIS controller. The step characteristics can be observed as: rise time= 29.5sec, settling time=98sec, peak time= 60sec, overshoot= 3.6%.

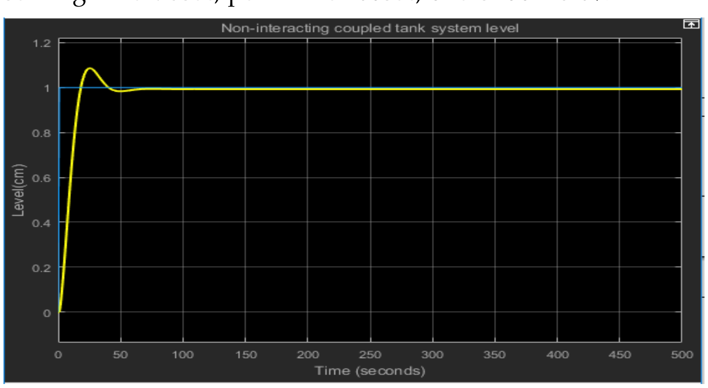

Fig. 13. Fluid level control of non-interacting coupled tank system with ANFIS controller

Fig.13 shows the step response of fluid level control of non-interacting coupled tank system using ANFIS controller. The step characteristics can be observed as: rise time= 12sec, settling time=38.8sec, peak time= 25sec, overshoot= 9.3%.

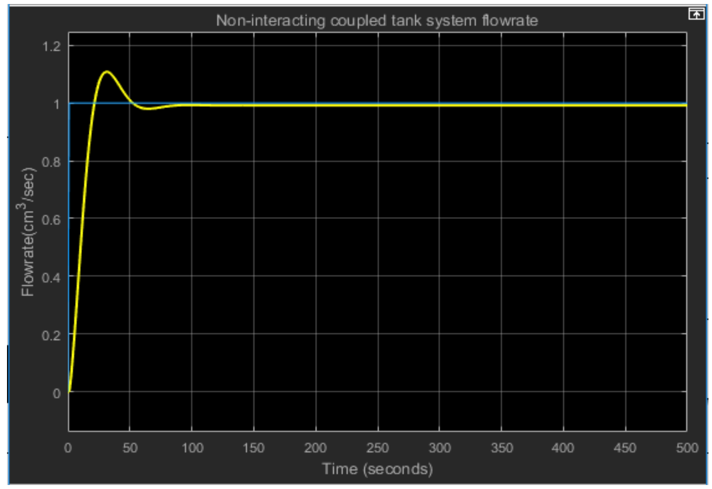

Fig. 14. Fluid flow rate control of non-interacting coupled tank system with ANFIS controller

Fig.14 shows the step response of fluid flow rate control of non-interacting coupled tank system using ANFIS controller. The step characteristics can be observed as: rise time= 14.4sec, settling time=50sec, peak time= 31sec, overshoot= 11.7%.

5.1 Controller Validation

To validate the results of the proposed ANFIS controller for the level of an interacting and non-interacting tank system four control parameters of the step response are taken into consideration namely rise time, settling time, peak time, and overshoot. Comparison of the results of proposed ANFIS controller with the existing ANFIS controller [2] are shown in Table 5 and Table 6 respectively.

TABLE 5
STEP CHARACTERISTICS FOR THE LEVEL OF AN INTERACTING COUPLED TANK SYSTEM

INTERACTING COUPLED TANK SYSTEM				
Controller	Rise Time (sec)	Settling Time(sec)	Peak Time(sec)	Overshoot (%)
Existing ANFIS Controller [2]	35.3	75	52.8	0
Proposed ANFIS Controller	24.3	67.2	49	2.5

TABLE 6
STEP CHARACTERISTICS FOR THE LEVEL OF THE NON-INTERACTING COUPLED TANK SYSTEM

NON-INTERACTING COUPLED TANK SYSTEM				
Controller	Rise Time (sec)	Settling Time(sec)	Peak Time (sec)	Overshoot (%)
Existing ANFIS Controller [2]	33.6	46.8	56	0.002
Proposed ANFIS Controller	12	38.8	25	9.3

6 CONCLUSION

In this research, a challenge of controlling the fluid level and flow rate of an interacting and non-interacting coupled tank system has been analyzed. The control of fluid level and flow rate in a coupled tank system is achieved by using ANFIS (Adaptive neuro-fuzzy inference system) controller. The simulation has been carried out on MATLAB/Simulink software. The simulation results show that the ANFIS controller is capable to reduce the rise time, settling time, peak time and settle down the response rapidly. From the performance of the ANFIS controller it is observed that non-interacting coupled tank system is faster than the interacting coupled tank system**.**

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