INTELLIGENT LIQUID LEVEL CONTROL OF A COUPLED NONLINEAR THREE TANK SYSTEM SUBJECTED TO VARIABLE FLOW PARAMETERS

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Abstract: In this paper, an intelligent control system technique is proposed to model and control of a nonlinear coupled three tank system. Two pumps fed the tank 1 and tank 2 and a fractional flow of these two pumps fed tank 3. The main aim of this paper is to make a set point tracking experiments of the tanks level using a nonlinear autoregressive moving average L-2 (NARMA L-2) and neural network predictive controllers. The proposed controllers are designed with the same neural network architecture and algorithm. Comparison of the system with the proposed controllers for tracking a step and random level set points for a fixed and variable flow parameter and some good results have been obtained.

Keywords: Neural network, NARMA L-2, NN Predictive Controller

1. INTRODUCTION

Liquid level control is important in most industrial applications, especially in the petrochemical and food processing industries. The level controller's accuracy affects the final product's performance. Level control systems with a recently deceased time are difficult to control in industries. The controller's objective is to keep running smoothly be able to change the set point and implement a new. The control of liquid level is a crucial problem in the process industries such as Petrochemical industries, paper making process or mixing process wherein series of tanks are used as processing unit [1].

Water level control in a tank is one of the major control engineering benchmarks for understanding the performance behavior of a controller [1]. One of the major applications of this system is for nuclear reactors. Controlling a nonlinear three tank system now a day becomes one of the major control engineering issues. In this paper, a three tank interconnected system level control is modelled and designed with a variable flow parameter in order to control the level of the three tanks using nonlinear feedback control theory. The controller performance is tested using tracking a reference level of each tanks individually [2, 3]. The level accuracy is also tested for different flow parameter of the liquid which enters the tanks. A neural network based NARMA L-2 and Predictive controllers have been proposed for this system. In order, to compare the performance of the controllers, they designed with the same number of layers and algorithm [4, 5].

2. EXPERIMENTAL SETUP

2.1. Three coupled tank system description

The three coupled tank system design is shown in Figure 1 below.

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The relationship between the flows to the tanks and the flow from pump A and pump B depends on the flow parameters γ_1 and γ_2 as equation (1):

$$\begin{aligned} q_1 &= \gamma_1 Q_a \\ q_{1D} &= (1-\gamma_1) Q_a \\ q_2 &= \gamma_2 Q_b \\ q_{2D} &= (1-\gamma_2) Q_b \end{aligned} \tag{1}$$

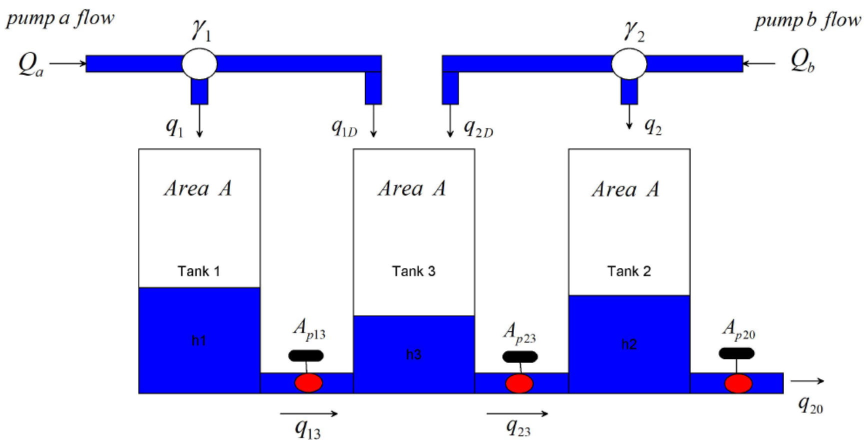

Fig. 1. Three coupled tank system design.

In this paper a controller is designed to control the liquid level to the given set point. The level of each tank is designated as *h*. The flow of the liquid out of the tank through the exit pipe let exits. This flow is representing as *q*. The flow of a liquid to the tank is done by the pump [6].

The flow of the liquid, *Q*, will be adjusted by the proposed controller. The cross sectional area of the three tanks is the same and representing as *A*. The mass balance equation of this system as a function of time is equations (2-4):

$$\begin{aligned} A\frac{dh_1}{dt} &= q_1 - q_{13} \\ &= \gamma_1 Q_a - q_{13} \end{aligned} \tag{2}$$

$$\begin{aligned} A\frac{dh_2}{dt} &= q_2 - q_{23} - q_{20} \\ &= \gamma_2 Q_b - q_{23} - q_{20} \end{aligned} \tag{3}$$

$$\begin{aligned} A\frac{dh_3}{dt} &= q_{1D} + q_{2D} - q_{13} - q_{23} \\ &= (1-\gamma_1) Q_a + (1-\gamma_2) Q_b - q_{23} - q_{20} \end{aligned} \tag{4}$$

The output flow from the tank, *q* through the exit pipe let and the manual valve is given as equation (5):

$$q_{13} = \Psi_1 A_{p13}\sqrt{2g\left|h_1 - h_3\right|}$$
$$q_{23} = \Psi_3 A_{p23}\sqrt{2g\left|h_3 - h_2\right|}$$
$$q_{20} = \Psi_2 A_{p20}\sqrt{2gh_2} \tag{5}$$

where ψ_1, ψ_2 and ψ_3 are a coefficient of friction of the pipe let exit. The term A_{p13}, A_{p23} and A_{p20} represents the cross-sectional area of the pipe let exits. The system parameters of the three tank system are given in Table 1 below.

Table 1. Three tank system parameters.

No	Parameter	Symbol	Value
1	Area of the tanks	A	6 m^2
2	Area of the outflow b/n Tank 1&3	A_{p13}	0.15 m^2
3	Area of the outflow b/n Tank 3&2	A_{p23}	0.12 m^2
4	Area of the outflow Tank 2	A_{p20}	0.09 m^2
5	Coefficient of friction of tank 1	Ψ_1	0.75
6	Coefficient of friction of tank 2	Ψ_2	0.9
7	Coefficient of friction of tank 3	Ψ_3	0.4
8	Gravitational acceleration	g	9.8 m/s^2

The nonlinear three tank system block diagram is shown in Figure 2.

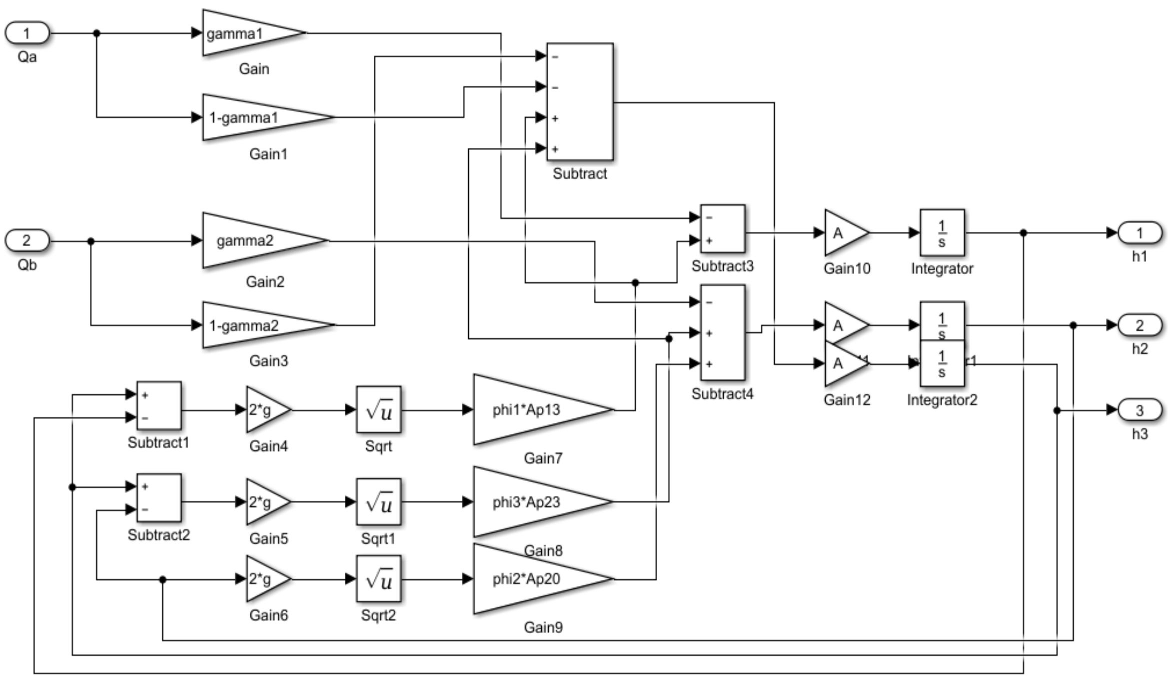

Fig. 2. Three tank system block diagram.

2.2. The proposed controllers design

2.2.1. NARMA L-2 Controller Design

This neuro controller is described by two different names: response linearization control and NARMA L-2 control. The feedback linearization control is when the plant model has a particular form. The NARMA L-2 model control is when the system model is approximated by the same model [7].

The main theory of this type of control is to convert the nonlinear system into linear system by eliminating the nonlinearities. In this paper the companion model of the system is done by identifying the system using a neural network model.

Then the identified neural network model is used to construct the controller. The main advantage of the NARMA L-2 is that you can adjust the control input signal in order to get the output signal follows efficiently the reference input signals (Figure 3).

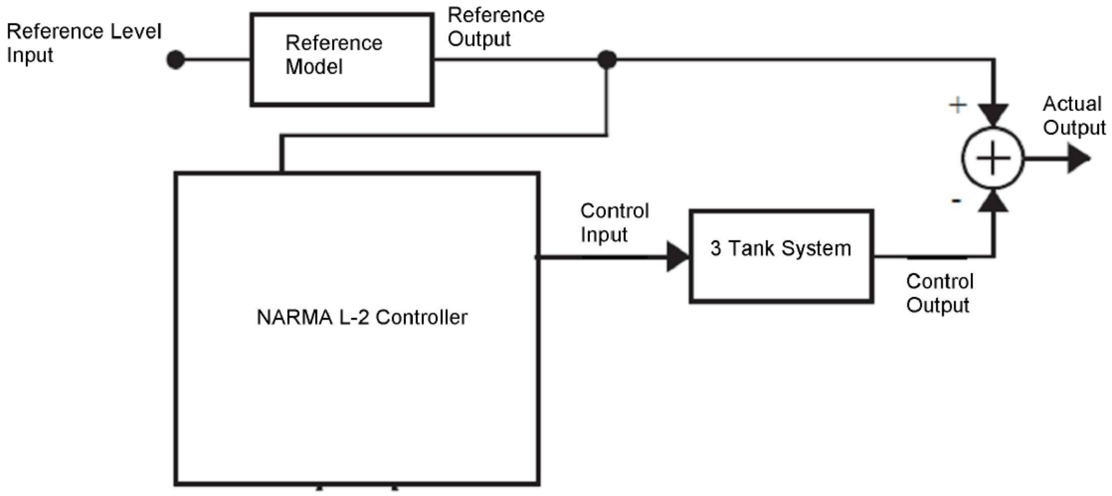

Fig. 3. Three tank system with NARMA L-2 controller.

2.2.1. NN Predictive Controller Design

There are many types of the neural network predictive controller for especially controlled a linear system predictive controllers (Figure 4). In this paper, the neural network predictive controller is used to control a neural network system of a nonlinear model to predict the system performance improvement in futures [8 - 11].

The proposed controller will adjust the control input to improve the system performance for a specific future time horizon. The main advantage of the model predictive control is to evaluate the neural network system model and this model is controlled by the controller to predict future improvement.

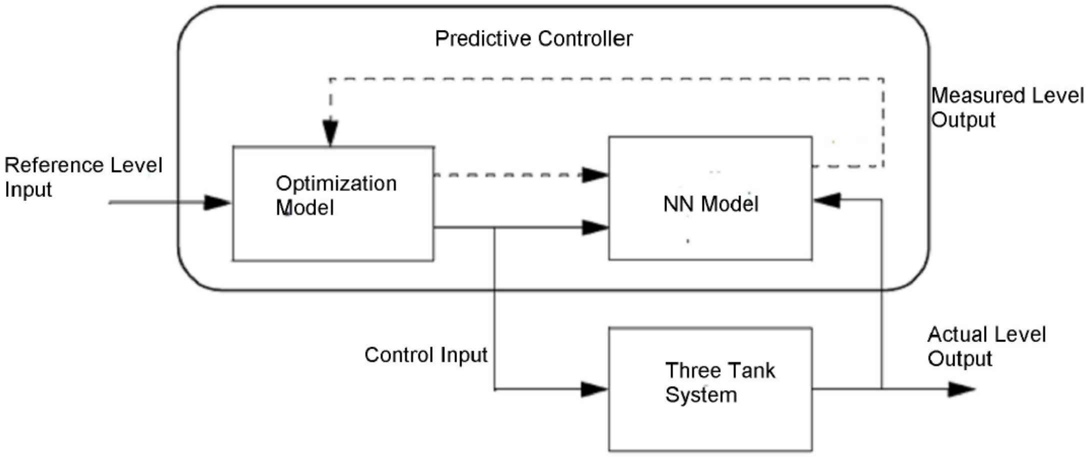

Fig. 4. Three tank system with NN Predictive controller.

Table 2 illustrates the network architecture, training data and training parameters of the proposed controllers.

Table 2. Neural network parameters.

Network Architecture			
Size of hidden layer	7	Delayed plant input	2
Sample interval(sec)	0.1	Delayed plant output	3
Training Data			
Training sample	100	Maximum Plant output	3
Maximum Plant input	2	Minimum Plant output	1
Minimum Plant input	1	Max interval value (sec)	5
Min interval value (sec)			10
Training Parameters			
Training Epochs			100

The neural network algorithm used in this paper is Levenberg-Marquardt implemented in Matlab toolbox as shown in Figure 5.

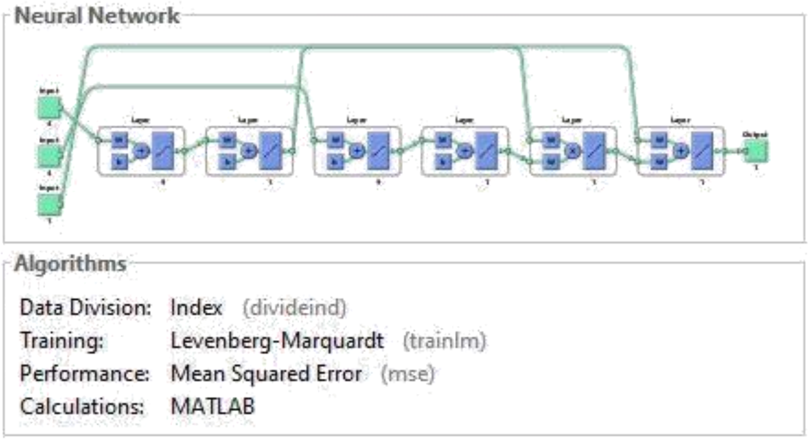

Fig. 5. Neural network algorithm.

3. RESULT AND DISCUSSION

Here in this section the comparison of the three tank system level control using NARMA L-2 and NN predictive controllers have been done using a step and random reference level signals. The performance of the proposed controllers has been evaluated and the best controller is further evaluated for different flow parameters.

3.1. Comparison of the three tank system with NARMA L-2 and predictive controllers for tracking level (h1) using step reference signal

The comparison of the coupled three tank system with NARMA L-2 and NN Predictive controllers is done for assigning a set point level h1 to 2.75 m and tracking this reference step input level to the two input flows Qa and Qb with a flow parameter gamma 1 assigned as 0.9 and gamma 2 assigned as 0.1. This flow meter values makes more flow into the tank 1 and tank 3 more and this makes q13 to flow slowly to check the performance of tank 1 level with the proposed controllers. The simulation result is shown in Figure 6 below.

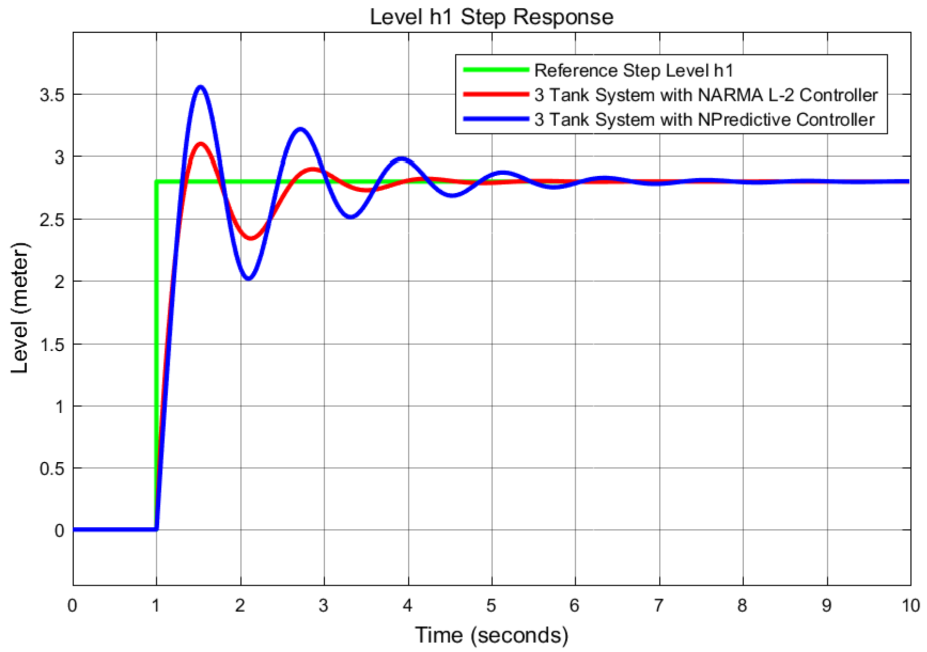

Fig. 6. Step response of tank 1 level h1.

The simulation result shows that the three coupled tank system with NARMA L-2 controller tracks the set point level h1 input with small percentage overshoot and less settling time as compared to the three coupled tank system with NN Predictive controller.

3.2. Comparison of the Three Tank System with NARMA L-2 and Predictive Controllers for Tracking Level (h2) using Step Reference Signal

The comparison of the coupled three tank system with NARMA L-2 and NN Predictive controllers is done for assigning a set point level h2 to 2.75 m and tracking this reference step input level to the two input flows Qa and Qb with a flow parameter gamma 1 assigned as 0.1 and gamma 2 assigned as 0.9. This flow meter values makes more flow into the tank 3 and tank 2 more and this makes q23 and q20 to flow slowly to check the performance of tank 2 level with the proposed controllers. The simulation result is shown in Figure 7.

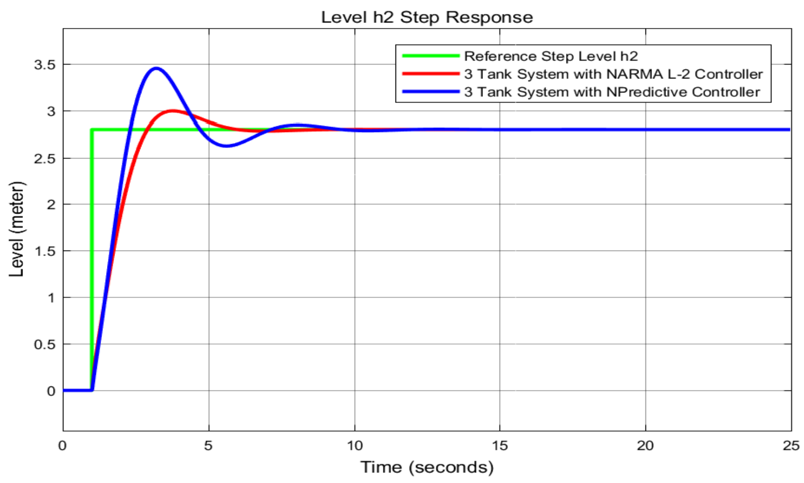

Fig. 7. Step response of tank 2 level h2.

The simulation result shows that the three coupled tank system with NARMA L-2 controller tracks the set point level h2 input with small percentage overshoot and less settling time as compared to the three coupled tank system with NN Predictive controller. The NN Predictive controller mean while improve the rise time.

3.3. Comparison of the three tank system with NARMA L-2 and predictive controllers for tracking level (h3) using step reference signal

The comparison of the coupled three tank system with NARMA L-2 and NN Predictive controllers is done for assigning a set point level h3 to 2.75 m and tracking this reference step input level to the two input flows Qa and Qb with a flow parameter gamma 1 assigned as 0.1 and gamma 2 assigned as 0.1. This flow meter values makes more flow into the tank 3 and this makes q13 and q23 to flow slowly to check the performance of tank 3 level with the proposed controllers. The simulation result is shown in Figure 8.

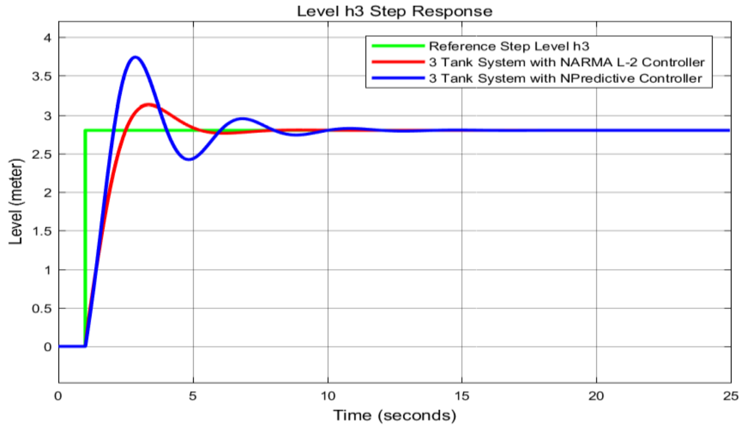

Fig. 8. Step response of tank 3 level h3.

The simulation result shows that the three coupled tank system with NARMA L-2 controller tracks the set point level h2 input with small percentage overshoot and less settling time as compared to the three coupled tank system with NN Predictive controller. The NN Predictive controller mean while improve the rise time.

From the above simulations we conclude that the three coupled tank system with NARMA L-2 controller has better performance to regulate the three tank levels better than the proposed NN Predictive controller and the following comparisons is done for testing the performance of the NARMA L-2 controller with different flow parameter values.

3.4. Comparison of the three tank system with NARMA L-2 and predictive controllers for tracking level (h1) using random reference signal for 0.8, 0.5 and 0.3 flow parameters

The comparison of the coupled three tank system with different flow parameters with NARMA L-2 controller is done for assigning a set point level h1 to a random value and tracking this reference random input level to the two input flows Qa and Qb with a flow parameters gamma 1 and gamma 2 assigned as 0.8, 0.5 and 0.3. This flow meter values makes tank 1 with variable flow values to check the performance of tank 1 level with the proposed controller. The simulation result is shown in Figure 9 below.

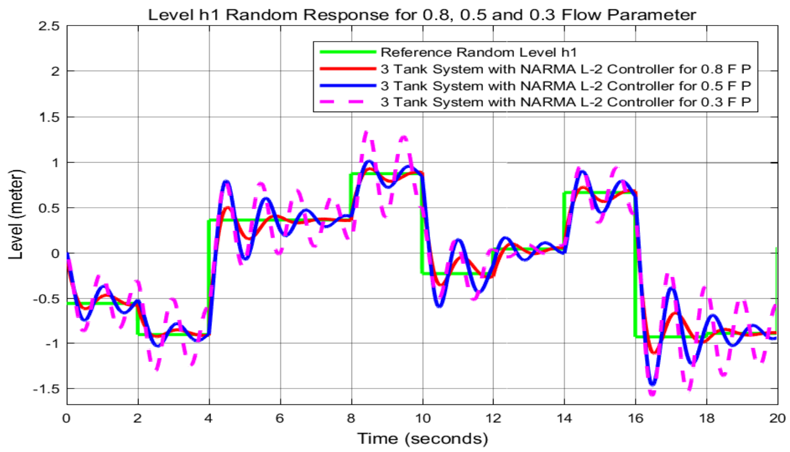

Fig. 9. Random response of tank 1 level h1 with 0.8, 0.5 and 0.3 flow parameters.

The simulation result shows that the level h1 of tank 1 of the three coupled tank system with 0.8 flow parameters value shows a better response with more inlet flow values to tank 1 and tank 2 in improving the overshoot and steady state value.

3.5. Comparison of the three tank system with NARMA L-2 and predictive controllers for tracking level (h2) using random reference signal for 0.8, 0.5 and 0.3 flow parameters

The comparison of the coupled three tank system with different flow parameters with NARMA L-2 controller is done for assigning a set point level h2 to a random value and tracking this reference random input level to the two input flows Qa and Qb with a flow parameters gamma 1 and gamma 2 assigned as 0.8, 0.5 and 0.3. This flow meter values makes tank 2 with variable flow values to check the performance of tank 2 level with the proposed controller. The simulation result is shown in Figure 10.

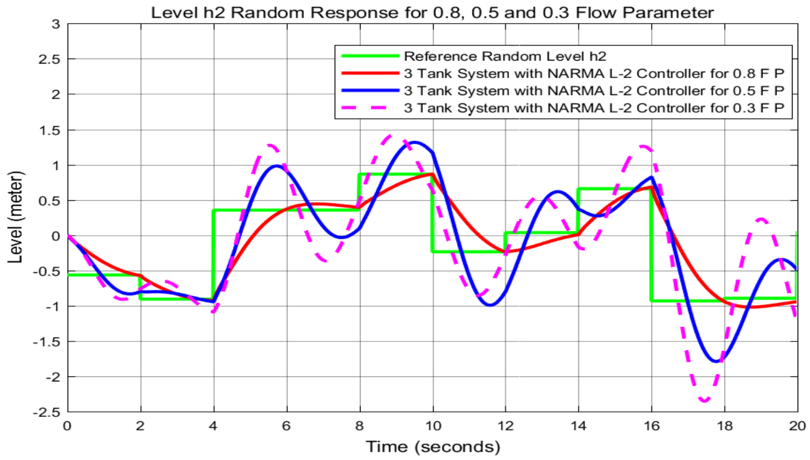

Fig. 10. Random response of tank 2 level h2 with 0.8, 0.5 and 0.3 flow parameters.

The simulation result shows that the level h2 of tank 2 of the three coupled tank system with 0.8 flow parameters value shows a better response with more inlet flow values to tank 1 and tank 2 in improving the system with no overshoot and slow steady state value.

3.6. Comparison of the three tank system with NARMA L-2 and predictive controllers for tracking level (h3) using random reference signal for 0.8, 1 and 1.4 flow parameters

The comparison of the coupled three tank system with different flow parameters with NARMA L-2 controller is done for assigning a set point level h3 to a random value and tracking this reference random input level to the two input flows Qa and Qb with a flow parameters gamma 1 and gamma 2 assigned as 0.8, 0.5 and 0.3. This flow meter values makes tank 3 from less to high flow value to check the performance of tank 3 level with the proposed controller. The simulation result is shown in Figure 11.

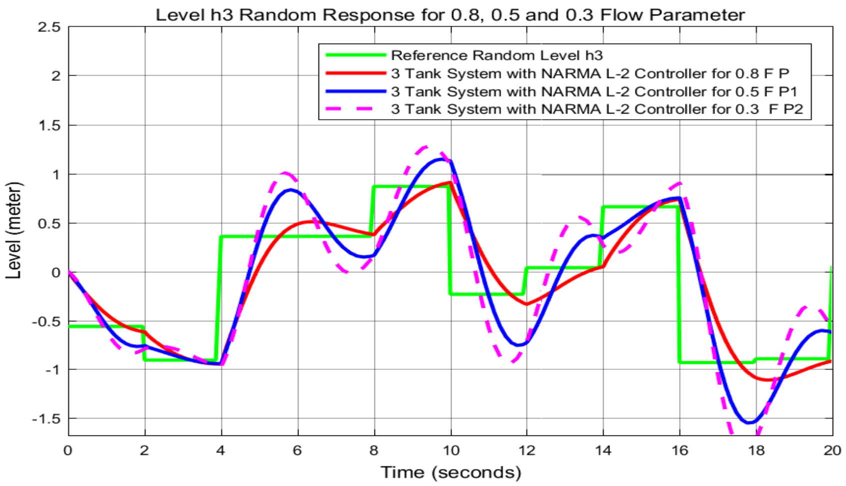

Fig. 11. Random response of tank 3 level h3 with 0.8, 0.5 and 0.3 flow parameters.

The simulation result shows that the level h3 of tank 3 of the three coupled tank system with 0.8 flow parameters value shows a better response with less inlet flow values to tank 3 in improving the system with minimum overshoot and slow steady state value.

4. CONCLUSION

As the technology shows improvement in industry machineries, the conventional controllers shows poor performance for nonlinear systems. This nonlinear systems performance can be improved using intelligent controllers. In this paper, an intelligent control system has been implemented to solve this problem. The design and control of a nonlinear coupled three tank system has been done using NARMA L-2 and NN Predictive controllers. These neural network controllers used Levenberg-Marquardt algorithms with seven hidden layers. Comparison of the system with the proposed controllers for tracking a step set point level with fixed flow parameter shows that the system with NARMA L-2 controller improves the set point tracking mechanism better than the proposed NN Predictive controller. The comparison of the system with NARMA L-2 controller for a variable flow parameter using a random set point level shows that the system with higher flow parameter shows a better performance. Finally the comparison results proved that the proposed NARMA-L2 controller shows performance improvement than the NN Predictive Controller.

REFERENCES

[1] Riccardo, V., Sofia, F., Instability of the tank level control system of water mains in mountainous environments, Journal of hydraulic engineering, vol. 145, no. 7, 2019, p. 130-137.
[2] Saunak, B., Moumita, C., Pradip, K. S., Bias, B., Study of a PID control system for liquid level measurement using non-contact type sensor, International journal of computational intelligence & IoT, vol. 2, no. 3, 2019, p. 197-208.
[3] Fayiz, A., Active disturbance rejection control off a coupled tank system, Journal of engineering, vol. 2018, no. 2, 2018, p. 878-881.
[4] Nayanmani, D., Lini, M., PID Controller for nonlinear interacting two tank liquid level control, International journal of development research, vol. 07, no. 1, 2017, p. 192-200.
[5] Riadh, A.K., Abdul, K.K., Abdul, R.S., Abdul, H.G., Implementing of liquid tank level control using Arduino labview interfacing with ultrasonic sensor, KUFA journal of engineering, vol. 8, no. 2, 2017, p. 29-41.
[6] Borkowski, D., Water level control of a small hydropower plant with a surge tank, Journal of hydraulic research, vol. 55, no. 2, 2017, p. 284-291.
[7] Sy Yi, S., Sie, L. K., Kim, G.T., Optimal control of a coupled tanks system with model reality differences, AIP conference proceedings, vol. 1872, no. 1, 2017, p. 1-6.
[8] Mohd, I., Khan, K.A., Simulation of water level control in a tank using fuzzy logic in Matlab, International journal of engineering and computer science, vol. 6, no. 5, 2017, p. 21303-21306.
[9] Saad, M., Performance analysis of a nonlinear coupled tank system using PI controller, Universal journal of control and automation, vol. 15, no. 2, 2017, p. 55-62.
[10] Nagammai, S., Latha, S., Design of optimal controllers for a three tank process, Journal of Scientific and Innovative Research, vol. 5, no. 2, 2016, p. 65-70.
[11] Lekshmipriya, J, Modelling and level control of a three tank hydraulic system, International journal of advanced research in electrical, electronics and instrumentation engineering, vol. 4, no. 11, 2015, p. 165-170.