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Modeling and Simulation of PID and Fuzzy based Controller of a Nonlinear Liquid Level Process using LABVIEW

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Abstract: The system under investigation is a coupled-tank system of a common process in industrial control. The basic control principle of the coupled-tank system is to maintain a constant level of the liquid in the tank when there is an inflow and outflow of liquid in the tank and outflow of liquid out of the tank respectively. The control of liquid level in tanks and flow between tanks is a problem in the process technologies. The process technologies require liquids to be pumped, stored in tanks, and then pumped to another tank systematically. In this work an efficient elementary idea about the controller system and liquid level control for the tank system has been presented. The liquid level control system controls the level of the liquid whatever the disturbances, such as level change, increase/decrease of out flow and interaction between the tanks. The result shown in the project work is encouraging & promising. The main objective of this project is to determine the mathematical model of a coupled-tank system using mass balance technique. It follows by designing the controllers consisting of PID and Fuzzy logic controllers for the system. At the final stage of this project, the usage of the controller in industrial applications is compared and analyzed. The reasons behind the selection of Lab VIEW software among other is because of its strong graphical interface, user friendly tools and highly understandable approach.

Keywords: PID, Simulation, Lab VIEW, Fuzzy.

I. INTRODUCTION

Control of liquid level in many industrial processes, specifically in petrochemical plants, is an important part of the industrial applications. In this thesis work a coupled tank system has been developed. The proposed controller algorithm has been applied on the coupled tank model. In this model of coupled tank system the liquid has to be pumped from first tank to the second tank and the liquid level of second tank has to be maintained at preset value. In spite of the two disturbance signals which are the drain and the interaction between the tanks, the liquid level of the second tank is controlled and maintained at preset value. To maintain the interaction between the tanks the liquid level of the first tank has to be always kept higher than the second tank and this difference in level is maintained throughout the process.

The investigator has gone through the various research papers and drawn several interferences of interest of the present work for developing the controllers. Two controllers have been used to control the liquid level of two tank level process. The PID and Fuzzy logic controller are used separately and simulated by using NI LabVIEW software.

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II. GENERAL FORMULATION OF THE SYSTEM MODEL

Mathematical modeling of Couple Tank system

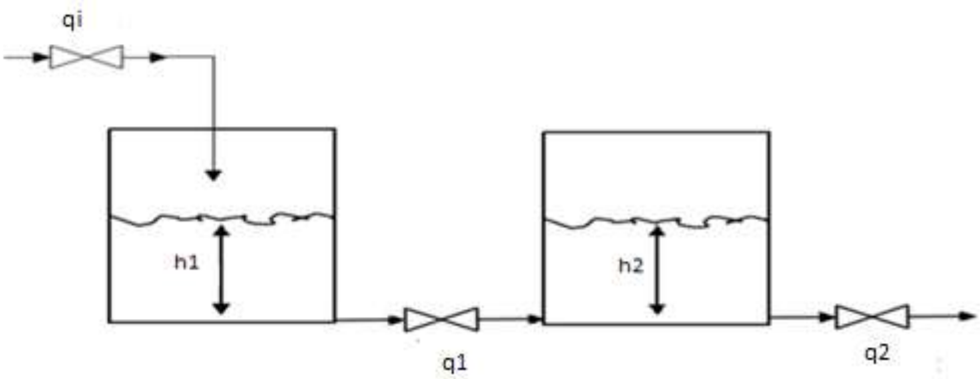

Fig.1 Couple tank system

In the Fig. 1 both tanks are identical in cross section and is represented as A(cm^2). The inlet flow q_i is given to the tank 1 and the outlet flow q_2 is taken from tank 2. A manual valve is available between tank1 and tank2 which can be used to change the interaction between the tanks. The change in water level h_1(cm) in tank1 affects the water level h_2(cm) in tank 2. The water level variation in tank1 and tank2 depends on the inlet and outlet flows. The liquid level in second tank ie, h_2 (cm)is maintained at some desired value by using flow rate of the liquid into first tank q_i(cm^3/ sec) as the manipulated variable. The control of liquid level in tanks presents a challenging problem due to its non-linear behaviour which is due to the interacting characteristics. In interacting process, dynamics of tank1 affects the dynamics of tank2 and vice versa because flow rate depends on the difference between the liquid levels.

Mass balance equation of the level process is as follows:

Rate of change of total mass of fluid inside the tank	=	Mass flow rate of fluid into the tank	-	Mass flow rate of fluid out of the tank

According to the above mass balance equation, and in steady-state mass balance equation around the first tank can be written as

$$\rho A_1 \frac{dh1(t)}{dt} = \rho qi(t) - \rho q1(t)$$

$$A_1 \frac{dhi(t)}{dt} = qi(t) - q1(t) \qquad \text{..........................} (1)$$

Similarly, in steady-state mass balance around the second tank can be written as

$$\rho A_2 \frac{dh2(t)}{dt} = \rho q1(t) - \rho q2(t)$$

$$A_2 \frac{dh2(t)}{dt} = q1(t) - q2(t) \qquad \text{..........................} (2)$$

The liquid flow through a valve is given by the valve equation

$q = k\sqrt{2gh}$, where k is the valve constant ($cm^{2.5}$/sec)

Now for the flow q_1 is given by

$$q_1\,(t) = k_1\sqrt{2g(h1(t) - h2(t)} \qquad \text{.........................} (3)$$

Eq.3 shows that the flow between the tanks depends on the levels in both the tanks, each affecting the other. Hence the system is called an interacting system.

Similarly, the flow through the valve from the 2nd tank

$q_2(t) = k_2 \sqrt{2gh_2(t)}$ ……………………..(4)

Substituting equation in equation 1 & 2, we get

$A_1 \frac{dh1(t)}{dt} = qi(t) - k_1\sqrt{2g(h_1(t) - h_2(t))}$ .... (5)

$A_2 \frac{dh2(t)}{dt} = k_1 \sqrt{2g(h_1(t) - h_2(t))} - k_2\sqrt{2gh_2(t)}$ ....(6)

The above two equations are nonlinear due to the square root terms in the relation and therefore the outputs varies nonlinearly with the inputs.

The above equations (5) and (6) can be used for controller simulation in LabVIEW. The term interacting is often referred to as loading the second tank in the figure is said to as load to the first tank.

III. CONTROLLER DESIGN

The above equations describe the water height as a function of time, due to the difference between flows rates into and out of the tank. It is nonlinear due to its dependence on the square-root of height of the liquid level. The following table 1 shows different values that are taken for the controller design [12].

Table 1 Controller parameter values

Parameters	Values
A_1	10 cm^2
A_2	10 cm^2
K_1	0.15 $cm^{2.5}$/sec
K_2	0.125 $cm^{2.5}$/sec
g	980 cm/sec^2

PID control for the Tank system

In Fig.2, the PID based controller of a nonlinear liquid level process is shown which is developed by the investigator. In the figure two tank system is shown. Process monitor for different parameters for the two tanks are also shown. The system works in both automatic and manual mode. In automatic mode system the set point of tank 2 is set as per requirement. Then it controls the flow rates to maintain the set point irrespective of any load variation. The front panel of PID controller is shown in Fig.2.

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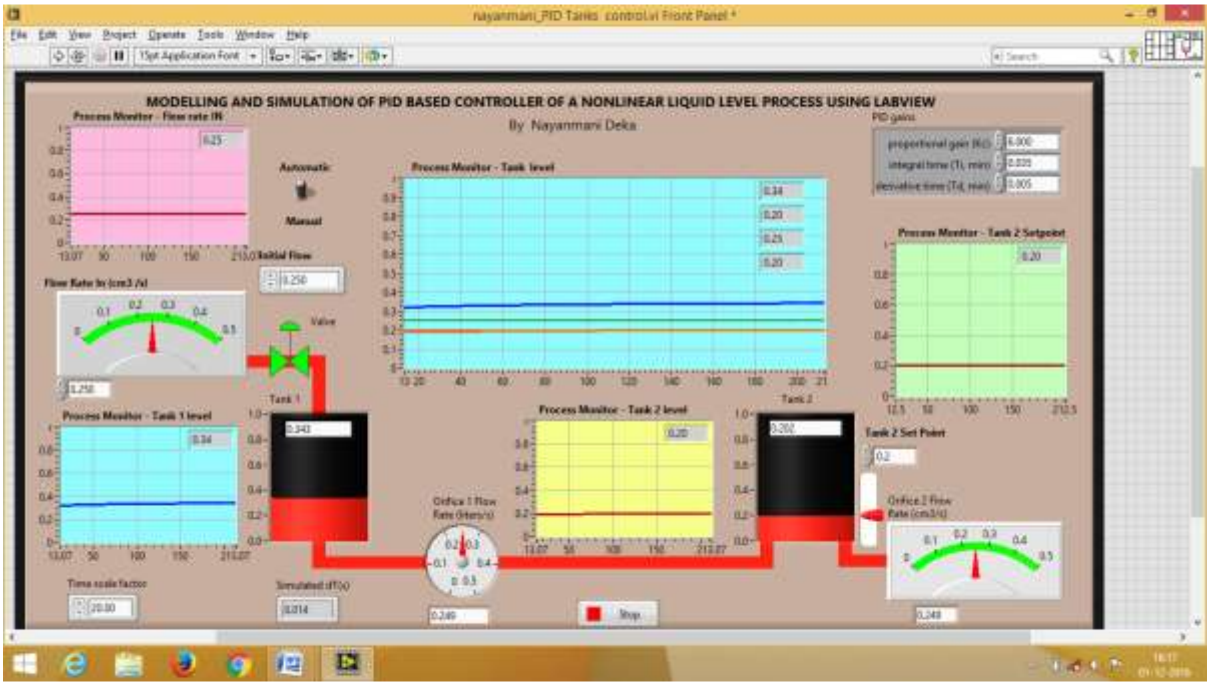

Fig. 2 Working model of PID controller

Fig.3 shows the output response of the tank2 for level set point 0.4. The level has reached to 0.39 , and it has fixed at that level. So there is steady state error of 0.01 unit

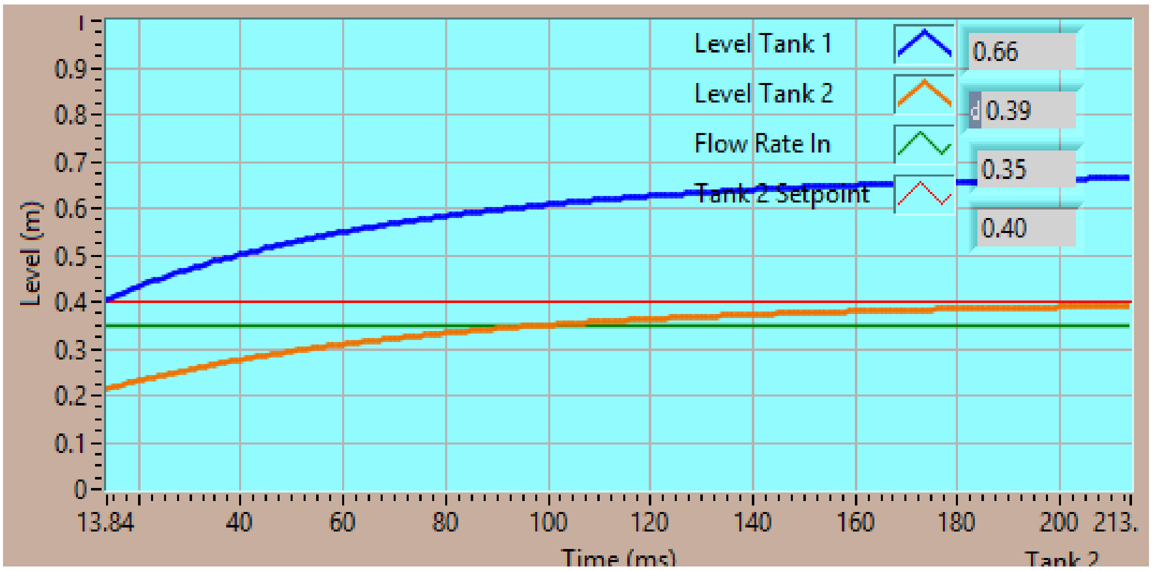

Fig.3 Response of the PID controller with set point 0.4 unit

FUZZY LOGIC CONTROL OF THE TANK SYSTEM

The fuzzy rules are written in the tabular form in the following Table 2

Table2. Fuzzy rules of the Tank system

Tank2 error / dH/dT Tank2	Lg neg	Sm neg	None	Sm pos	Lg pos
Fast neg	No change	Sm pos	Med pos	Lg pos	Lg pos
Slow neg	Sm pos	No change	Sm pos	med pos	Lg pos
Zero	Lg neg	Sm neg	No change	Sm pos	Lg pos
Slow pos	Lg neg	Med neg	Sm neg	No change	Sm pos
Fast pos	Lg neg	Lg neg	Med neg	Sm neg	No change

Membership functions

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The membership functions that are used by the fuzzy controller are trapezeoids and triangles. The inputs are ‘dH/dT tank2’ and ‘Tank2 error’ which ranges from -0.01 to 0.01 and -0.5 to 0.5 respectively. The output is ‘Flow change’ ranges from -0.5 to 0.5. The fuzzy subsets of input dH/dT tank2 are Fast neg, Slow neg, Zero, Slow pos and Fast neg. Where the meaning of neg is negative and pos is positive. Similarly fuzzy subsets of input ‘Tank2 error’ are Lg neg, Sm neg, None, Sm pos and Lg neg. Here the meaning of Lg is large and Sm is small. The fuzzy subsets of output ‘Flow change’ are Lg neg, Med neg, Sm neg, No change, Sm pos, Med pos and Lg pos. Meaning of Lg, Med and Sm are Large, Medium and Small respectively.

Table 3 shows the crisp range table for input dH/dt Tank2 which ranges from -0.01 to 0.01.

Table 3. Crisp Range Table for input ‘dH/dt Tank2’

Fuzzy variable	MF used	Crisp input range
Fast neg	Trapezoid	-0.01 to -0.00266
Slow neg	Trapezoid	-0.00666 to 0
Zero	Trapezoid	0 to 0.00266
Slow pos	Trapezoid	0 to 0,00666
Fast neg	Trapezoid	0,00266 to 0.01

Table 4 shows the crisp range table for input Tank2 error which ranges from -0.5 to 0.5.

Table 4. Crisp Range Table for input ‘Tank 2 error’

Fuzzy variable	MF used	Crisp input range
Lg neg	Trapezoid	-0.5 to -0.1
Sm neg	Trapezoid	-0.3 to 0
None	Trapezoid	-0.1 to 0.1
Sm pos	Trapezoid	0 to 0.3
Lg pos	Trapezoid	0.1 to 0.5

Table 5 shows the crisp range table for the output Tank2 error which ranges from -0.5 to 0.5.

Table 5. Crisp Range Table for output ‘Flow change’

Fuzzy variable	MF used	Crisp output range
Lg neg	Triangle	-0.05 to -0.03
Med neg	Trapezoid	-0.05 to -0.01
Sm neg	Trapezoid	-0.03 to 0
No change	Trapezoid	-0.01 to 0.01
Sm pos	Trapezoid	0 to 0.03
Med pos	Trapezoid	0.01 to 0.05
Lg pos	Triangle	0.03 to 0.05

In fig. 4, the test system tool of the LabVIEW is used to check the proper functioning of the fuzzy system developed. That shows the Input output relationship field for dual input of the fuzzy system using Surface view of the Rule base for the couple tank system.

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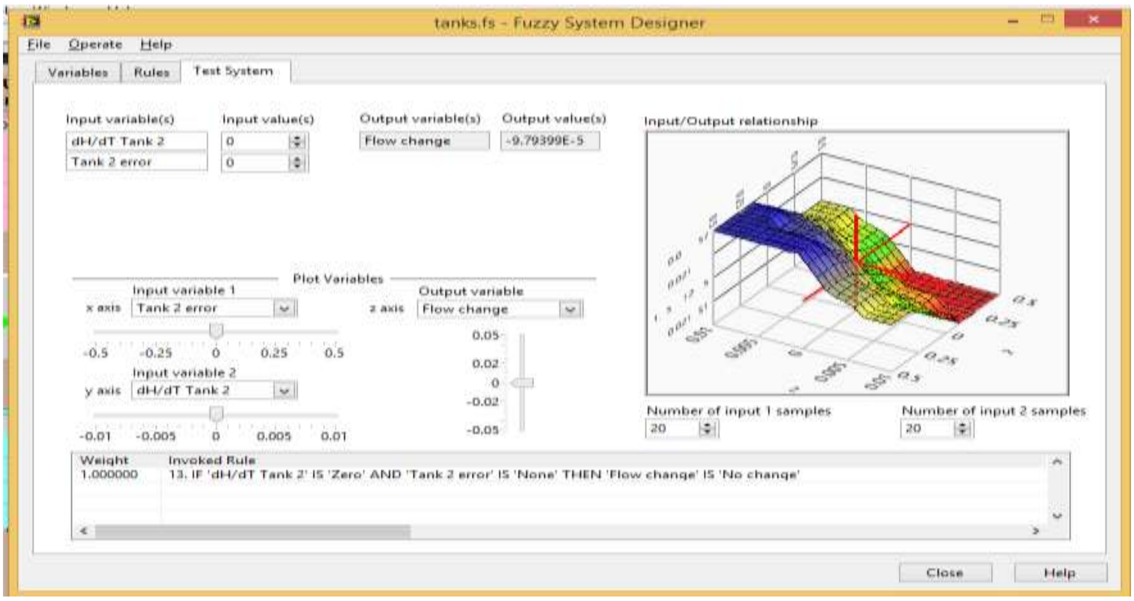

Fig.4 Fuzzy logic controller using surface viewer

The working diagram of the fuzzy logic controller of the couple tank system is shown in the Fig.5

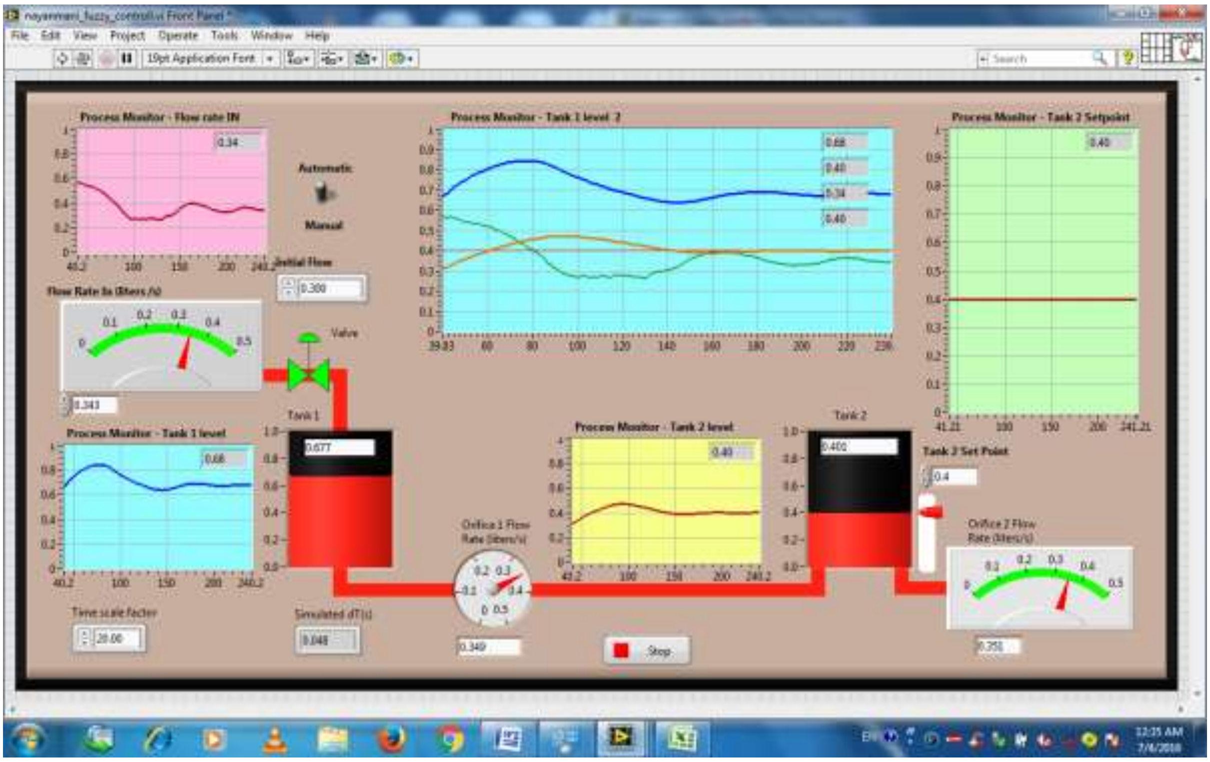

Fig. 5 Fuzzy logic controller of the couple tank system

In fig. 6 the set point is fixed at 0.4. The level has reached to 0.4 , and it is fixed at that level. So there is no steady state error.

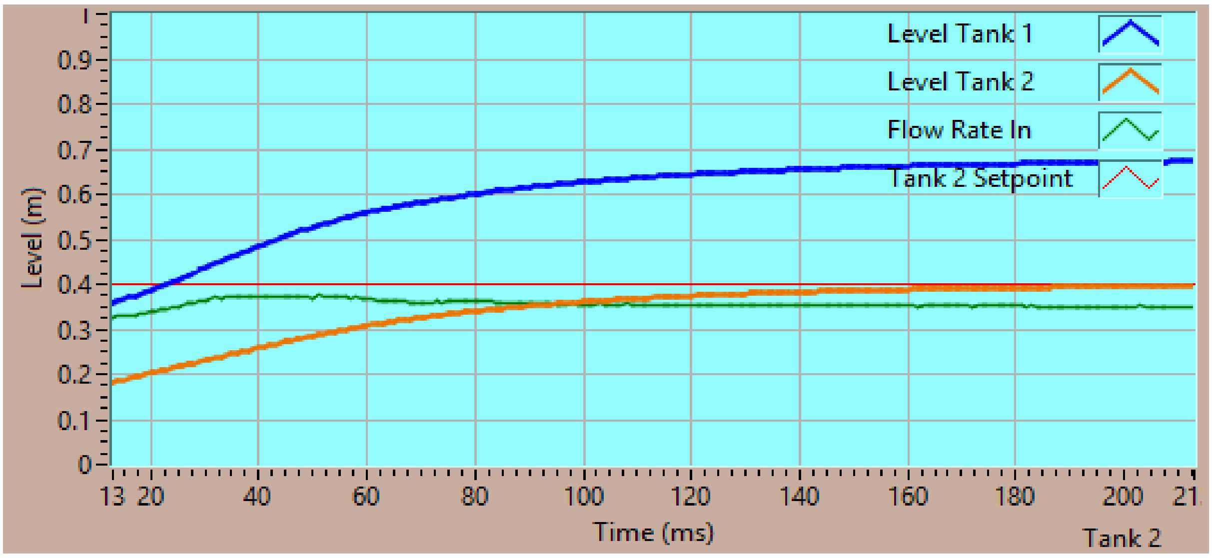

Fig.6 Response of the fuzzy controller with set point 0.4 unit

For any process disturbances like leakage in the tank, the level automatically attains the pre set value immediately. If the setpoint is change from the pre set value to a new value in a step change, then the controller responds to the setpoint change and attains the new reference level within a short time. Fig.7 shows the set point tracking capability of the fuzzy controller system. The controller accurately tracks the new set point without any steady state error.

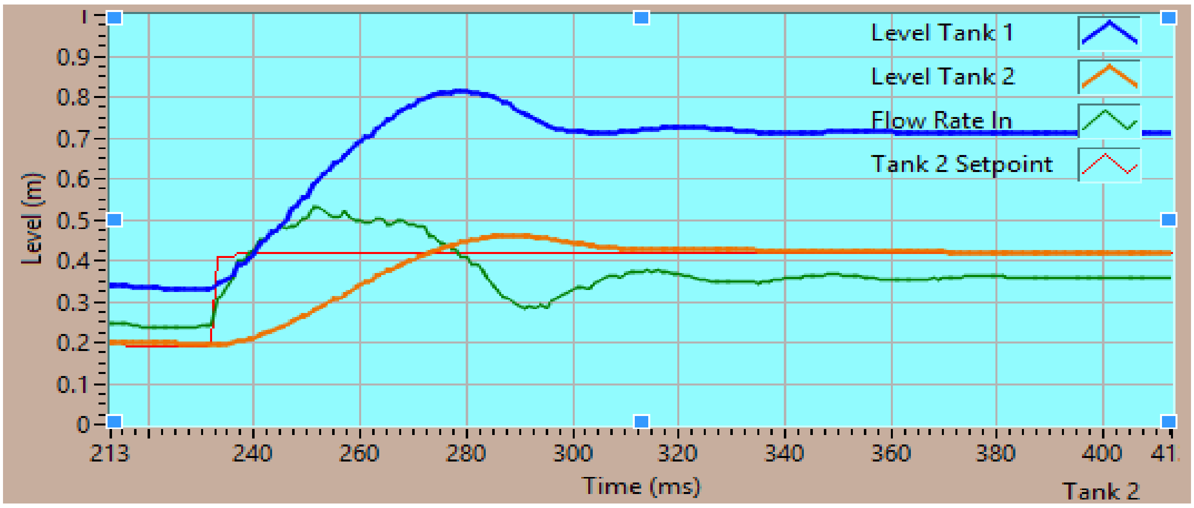

Fig.7 Set Point Tracking of the Fuzzy Controller

CONCLUSION

In industries the liquid level of container is maintained at higher accuracy. After proper analysis, the performance of fuzzy system is found better the PID controller. The controller system works accurately when the set point is changed, so there is some robustness in the controller. Also the disturbance rejection response for the fuzzy controller system is very fast. The fuzzy controller based system is found to be 1.8 times faster than the PID based controller. So the result of fuzzy based system is excellent and it can be further implemented in hardware by the industries. The PID controller for interacting system is not suitable for controlling the wide range of the process variables. This is because of the nonlinearities of the system. So sometimes manual operation has to be conducted in case of PID controller for better results.

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