ISSN(Online): 2320-9801
ISSN (Print) : 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering
(A High Impact Factor, Monthly, Peer Reviewed Journal)
Website: www.ijircce.com
Vol. 6, Issue 1, January 2018

Control and Performance Analysis of Three Tank Flow Control System Using Linear & Non-Linear Controller

Arnob Senapati[1], Akash Maitra[2], Snehanjaly Batabyal[3], Abhishek Kumar Kashyap[4]
UG Student, Dept. of ICE, Calcutta Institute of Engineering and Management, West Bengal, India[1, 2]
UG Student, Dept. of EE, Calcutta Institute of Engineering and Management, West Bengal, India[3]
Assistant Professor, Dept. of ICE, Calcutta Institute of Engineering and Management, West Bengal, India[4]

ABSTRACT: The control of liquid level in tanks and flow between tanks is a basic problem in the process industries. Most of the industry uses different type of tank systems of different shape such as cylindrical tank, conical tank and spherical tank to control the flow rate and liquid level. In our design process, we have taken spherical tank because it is inexpensive and no product loss at the end point and thus most efficient Here all the tanks under a study have their own type of manipulated variables, and thus we can control the flow rate of three tank non-interacting process by regulating the variables for our desired output. Often the tanks are so coupled together that the levels also interact and this must also be controlled. So it is necessary to analyze the response in non-interacting mode of various tanks with applying step input. There are many alternative controller design theories that can be used to control the flow of liquid on tanks. Here, the three-tank system that taken is in cascade connection and thus the overall system becomes a MIMO system and non linearity increases. Proportional integral derivative (PID) control is one of a kind of control strategies that uses to control the level and flow of liquid. But to implement high- performance control system when the plant dynamic characteristics are poorly known or when large and unpredictable variations occur, a new class of control systems called nonlinear control systems have evolved which provide potential solutions. For this reason, it is desirable to introduce other type of controller such as artificial conventional fuzzy logic controller and IMC controller.

KEYWORDS: PID Controller, Fuzzy Controller, IMC Controller, Z-N tuning, AMIGO tuning, 3Tank Non Interacting Process, Flow Control.

I. INTRODUCTION

The core process of our problem is the three tank system which simply consists of three tanks with two inlet flows and three level outputs. The process industries require liquids to be transferred or transferred pumped to another tank. Many times the liquids will be processed by mixing treatment in the tanks but always the level of fluid in the tanks must be controlled, and the flow between tanks must be regulated.

In this project, the transfer function of three tank system has been formulated. Three tank systems with different cross section area within put and output flow rate is shown in fig.1. Almost all process industries, the fluid handling systems depend upon tank flow rate and level control systems. Vital industries where liquid and flow control are essential include petro chemical industries, paper making industries and water treatment industries.

II. MATHEMATICAL MODELLING OF THREE TANK NON INTERACTING TANK

Mathematical modeling of three tanks non-interacting system. This system is said to be non-interacting the dynamic behavior of the first system will affect the dynamic behavior of the second system and second system affect the third system while the

DOI: 10.15680/IJIRCCE.2018. 0601057

Dynamic behavior of the second system does not affect the first system and third system does not affect the second system.

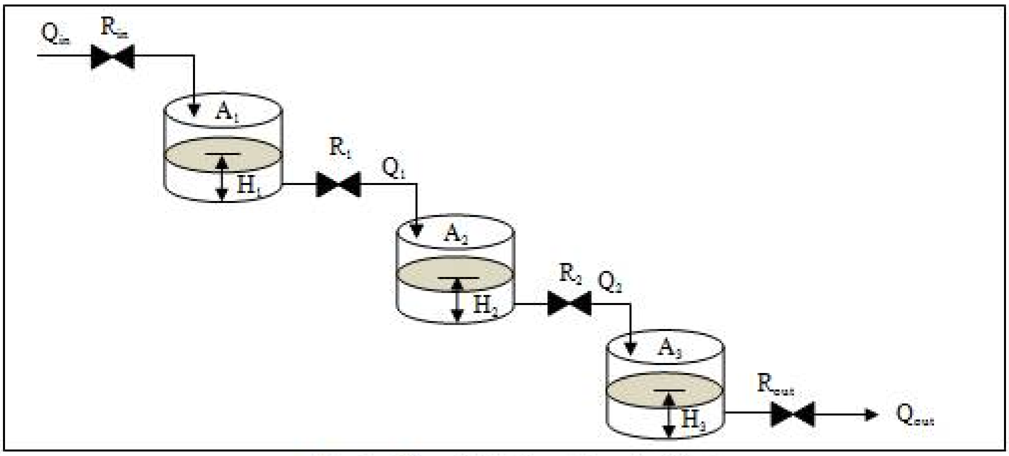

Fig: 1 – Three Tank Non-Interacting System

Let us define,

H_1= height of the tank1.

H_2= height of the tank2.

H_3= height of the tank3.

A_1= Area of the tank1.

A_2= Area of the tank2.

A_3= Area of the tank3.

R_{in} = Resistance of the inlet valve.

R_1 = Resistance of the valve1.

R_2 = Resistance of the valve2.

R_{out} = Resistance of the outlet valve.

V = total volume of the tank.

Q_{in} = Volumetric flow rate of the inlet stream (lph).

Q_1 = Volumetric flow rate of the tank1 (lph).

Q_2 = Volumetric flow rate of the tank2 (lph).

$Q_{out}(s)$ = Volumetric flow rate of the outlet stream (lph).

As we know that,

$$Q_{in} - Q_1 = A_1 * \frac{dH1}{dt} \quad \text{-------- (i)}$$

$$Q_1 - Q_2 = A_2 * \frac{dH2}{dt} \quad \text{-------- (ii)}$$

$$Q_2 - Q_{out} = A_3 * \frac{dH3}{dt} \quad \text{--------- (iii)}$$

Specifications of the three tanks non-interacting tank:

R_1 (Resistance of the valve1)	5 ohm
R_2 (Resistance of the valve2)	4 ohm
R_{out} (Resistance of the outlet valve)	2 ohm
A_1(Area of the tank1)	1 m^2
A_2(Area of the tank2)	1 m^2
A_3 (Area of the tank3)	1.5 m^2

Table: 1 - Specifications of the three tank non-interacting tank

According to equation (i), (ii), (iii) & as per the values of the constant we get the equation

$$\frac{Qout}{Qin}\,(G_t) = \frac{1}{60s^3+47s^2+12s^1+1} \text{ ---------------- (iv)}$$

III. FLOW CONTROL USING LINEAR CONTROLLER

PID (proportional–integral–derivative) controller used as a linear controller for control process with good response. A PID controller is widely used in industrial control systems. It is a generic control loop feedback mechanism and used as feedback controller. PID working principle is that it calculates an error value from the processed measured value and the desired reference point. The work of controller is to minimize the error by changing in the inputs of the system.

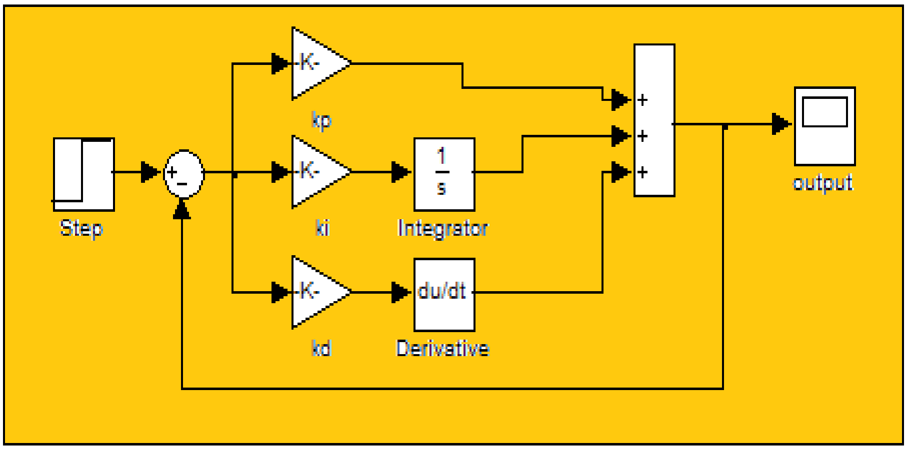

Fig: 2 – PID controller

A. Tuning of PID controller:

PID controllers are probably the most widely used industrial controller. PID tuning method is a popular method of tuning PID controller. In closed loop tuning method, a critical gain K_c is induced in the forward path of the control system. The high value of the gain takes the system to the verge of instability. It creates oscillation and from the oscillations, the value of frequency and time are calculated. Open loop tuning method which is known as process reaction curve method, in this method a process reaction curve is generated in response to a disturbance. This process curve is then used to calculate the controller gain, integral time and derivative time. The method is performed in open loop so that no control action occurs and the process response can be isolated. Here, all the tuning rules are compared on the basis of Rise Time (T_r), Settling Time (T_s), Maximum Overshoot (M%) and their corresponding Performance Indices (PI) like Integral Square Error (ISE), Integral Time Square Error (ITSE), Integral Absolute Error (IAE), and Integral Time Absolute Error (ITAE).

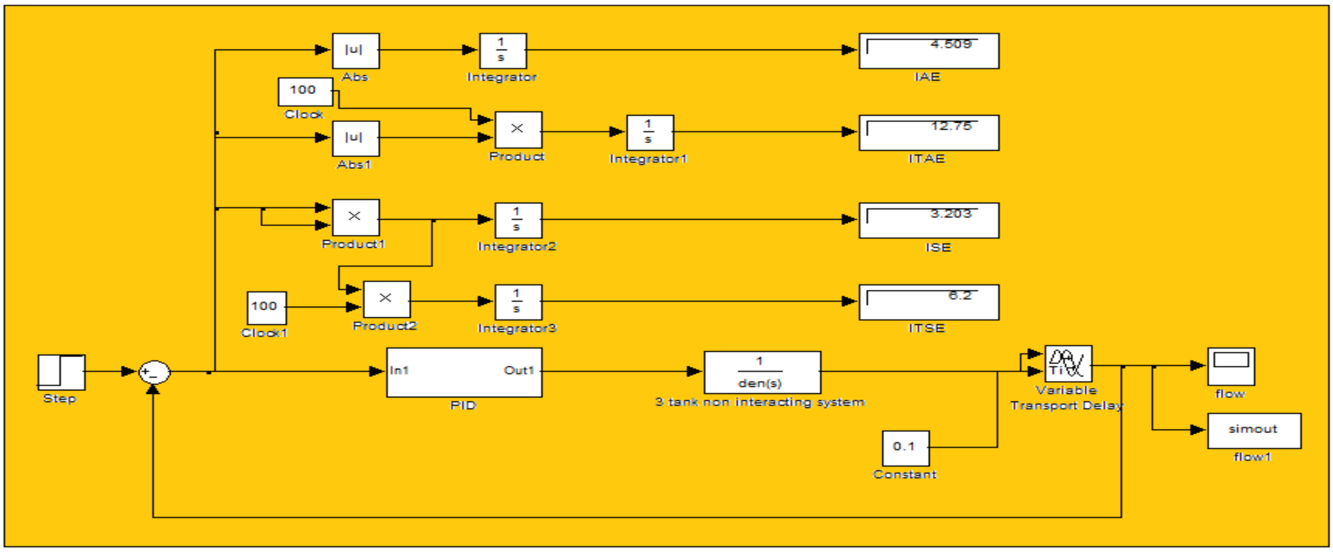

Fig: 3 – Simulink model of the Three Tank Non-Interacting System

I) **Ziegler and Nichols tuning method:** Ziegler and Nichols proposed rules for determining values of K_p K_d and K_i based on the transient response characteristics of a given plant. Closed loop oscillation based PID tuning method is a popular method of tuning PID controller. In this kind of tuning method, a critical gain K_c is induced in the forward path of the control system. The high value of the gain takes the system to the verge of instability. It creates oscillation and from the oscillations, the value of frequency and time are calculated.

Controller	K_p	T_i	T_d
P	$0.5K_c$	-	-
PI	$0.45K_c$	$T_u/1.2$	-
PID	$0.6K_c$	$T_u/2$	$T_u/8$

Table: 2 - Ziegler and Nichols Table

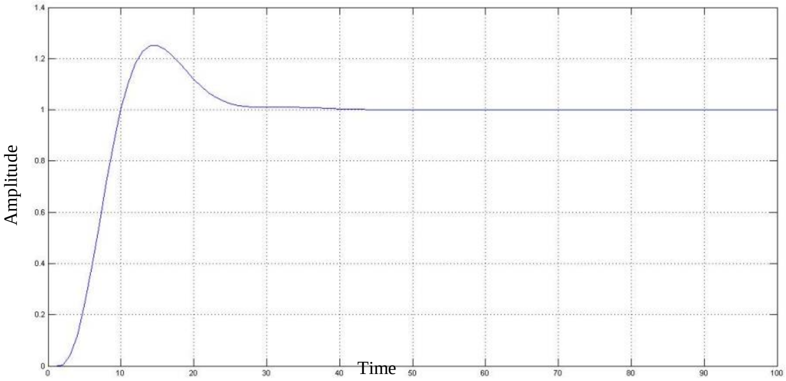

Fig: 4 - Ziegler and Nichols PID Response

From the close loop oscillation method we find the ultimate gain Kc = 4.825 and ultimate period $T_u = 19$. Which implies $K_p = 2.825$, $K_i = 0.3047$, $K_d = 6.875$. The corresponding Amplitude vs. Time Plot for PID is shown in Figure 4, obtained for the controller parameters calculated in the above Table 2.

II) AMIGO (Approximate M- constraint Integral Gain Optimization) Tuning Rule: The Z-N rule does not give the satisfactory control. Therefore there have been many modifications of the method that retain the simplicity but give improve the robustness. The AMIGO (Approximate M-constraint Integral Gain Optimization) tuning rule designed to maximize the controller integral gain subjected to robustness constraints express by maximum sensitivities. The process models were then approximated by simple models and relations between model parameter and controller parameter.

Controller	Kp	Ti	Td
PI	0.16Ku	$\frac{Tu}{1+4.5v}$	-------
PID	(0.3 – 0.1v^4)Ku	$\frac{0.6Tu}{1+2v}$	$\frac{0.15(1-v)T}{1-0.95v}$

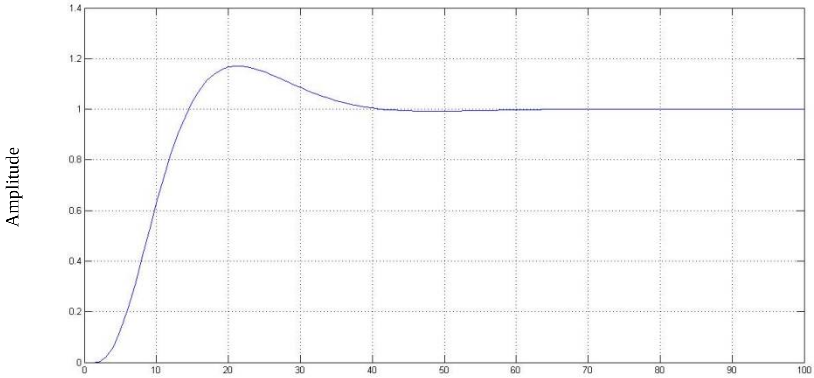

Table: 3 - AMIGO Table

Fig: 5 - AMIGO PID Response

From the close loop oscillation method we find the ultimate gain $K_c = 4.825$ and ultimate period $T_c = 19$ where, v = $(1/K_p*K_c)$. Which implies $K_p = 1.4466$, $K_i = 0.1794$, $K_d = 4.06963$. The corresponding Amplitude vs. Time Plot for PID is shown in Figure 5, obtained for the controller parameters calculated in the above Table 3.

Performance Analysis:

Here performance of linear controller with different tuning rules is analyzed. The result shows that the linear controller with different tuning rule achieves better performance while tuning the controller gains for different cases such as eliminating overshoot, rise time and steady state error. Performance Analysis data obtained from the simulation and responses have been tabulated in Table 4.

Transfer Function	Linear controller with Tuning Rule	Rise Time (Tr) (sec)	Settling Time (Ts) (sec)	Maximum Overshoot (M %)	Integral Absolute Error (IAE)	Integral Time Absolute Error (ITAE)	Integral Square Error (ISE)	Integral Time Square Error (ITSE)
Three Tank Non-Interacting System	PID with Ziegler and Nichols Rule	9	30	25	8.093	57.28	4.964	17.89
Three Tank Non-Interacting System	PID with AMIGO Rule	13	42	17.1	10.34	96.28	6.396	28.14

Table: 4 - Performance Analysis of Three Tank Non-Interacting System with Linear Controller

IV. FLOW CONTROL USING NON LINEAR CONTROLLER

Nonlinear control theory is the area of control theory which deals with systems that are nonlinear, time-variant, or both. Control theory is an interdisciplinary branch of engineering and mathematics that is concerned with the behaviour of dynamical systems with inputs, and how to modify the output by changes in the input using feedback. Fuzzy logic controller, IMC controller, Model predictive controller, Model reference adaptive controller which gives expert output in automatic control strategies. In this project we discussed on Fuzzy logic controller, IMC controller and analyzed the performance by applying on Three Tank Non-Interacting System.

A. Fuzzy Logic Controller:

The Fuzzy Logic Controller is intended to have two Fuzzy state Variables and one control variable for accomplishing flow control of the Three Tank Non-Interacting system. Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value. The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and their placement. In Figure 6 shows a block diagram of Fuzzy logic based control system.

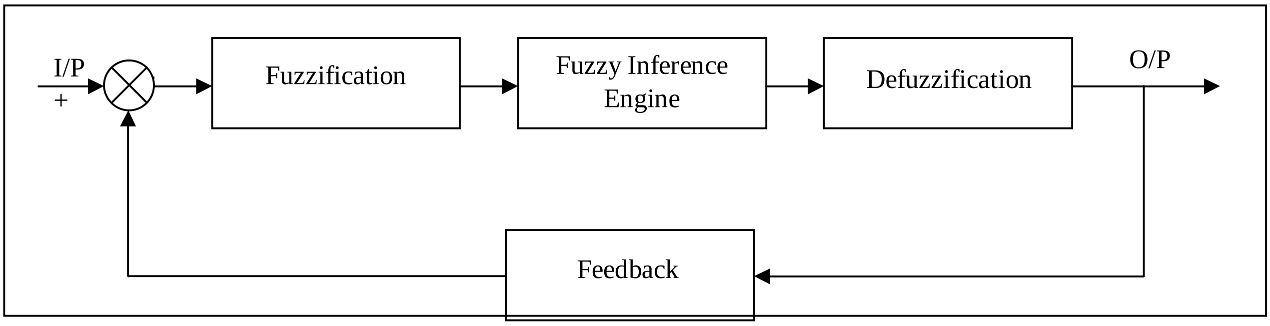

Fig: 6 - Block Diagram of Fuzzy Logic Based Control System

For the fuzzy logic controller the input variables are error (E) and rate change of error (ΔE), and the output variable is controller output (Speed). Triangular membership functions are used for input variables and the output variable. Each variable has 5 membership functions. Thus, there were total 49 rules generated. The universe of discourse of error, rate of error and output are [0, 1], [0, 1] and [0, 1.5] respectively. The rule base framed for DC motor is tabulated in Table 5. Linguistic variables for error, rate of error and controller output are tabulated in Table 6.

NL	NM	NS	ZE	PS	PM	PL
Negative Large	Negative Medium	Negative Small	Zero Error	Positive Small	Positive Medium	Positive Large

Table: 5 - Linguistic variables

E/ΔE	PL	PM	PS	ZE	NS	NM	NL
PL	NL	NL	NL	NL	NM	NS	ZE
PM	NL	NL	NL	NM	NS	ZE	PS
PS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NM	ZE	PM	PM	PL
NS	NM	NS	ZE	PS	PM	PL	PL
NM	NS	ZE	PS	PM	PB	PL	PL
NL	ZE	PS	PM	PB	PB	PL	PL

Table: 6 - Rule Base Framed for DC Servomotor

Figure (7) shows the Fuzzy logic controller designed in MATLAB Simulink by using the rule base designed above in table 6. It shows the Simulink model for Three Tank Non-Interacting System.

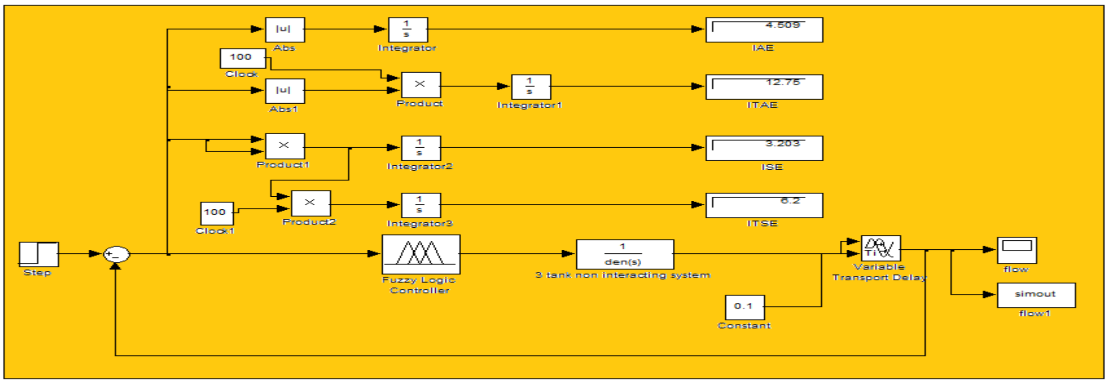

Fig: 7 - Simulink Model of the Three Tank Non-Interacting System with Fuzzy Logic Controller

The corresponding Amplitude vs. Time Plot for Fuzzy Logic Controller shown in Figure (8).

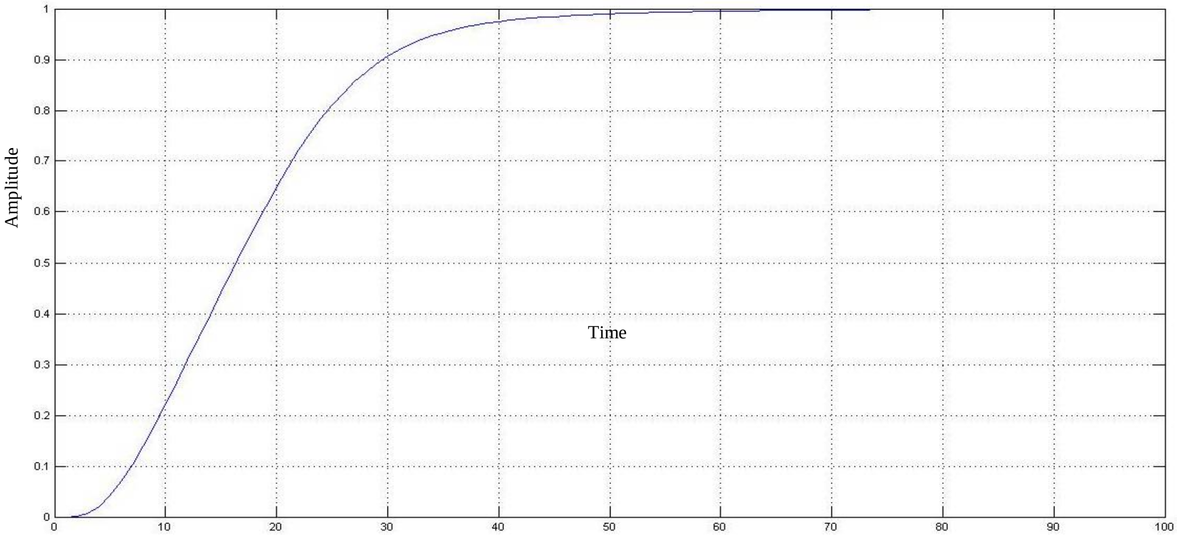

Fig: 8 - Fuzzy Logic Controller Output

B. PID Fuzzy Controller:

The main motivation for design PID Fuzzy controller was to control some known nonlinear systems, such as robotic manipulators, which violate the conventional assumption of the linear PID controller. This controller is developed by first describing the discrete-time linear PID control law and then progressively deriving the steps necessary to incorporate a fuzzy logic control mechanism into the modifications of the PID structure. PID controllers are designed for linear systems and they provide a preferable advantage. However, the existence of nonlinear property limits their performance. Fuzzy Logic Controllers are effectively applied to non-linear system because of their knowledge based nonlinear structural characteristics. The FLC methodology used in this paper is applied in the form of Fuzzy Set Point Weighting Controller (FSPWC). The idea of multiply the set point value for the proportional action by a constant parameter less than one is effective in reducing the overshoot but has the disadvantage of increasing the rise time. To achieve both the objective of reducing the overshoot and decreasing the rise time, a PID-FLC can be used to modify the weight depending on the current output error and its time derivative. To overcome these difficulties inherent in controlling a system that is both nonlinear and time dependent parameters, a controller based on PID-FLC was implemented. PID-FLC is known for their ability to provide very good control of this type of system.

Figure (9) shows the PID-Fuzzy logic controller designed in MATLAB Simulink by using the rule base designed above in table 6 and Figure (2). It shows the Simulink model for Three Tank Non-Interacting System.

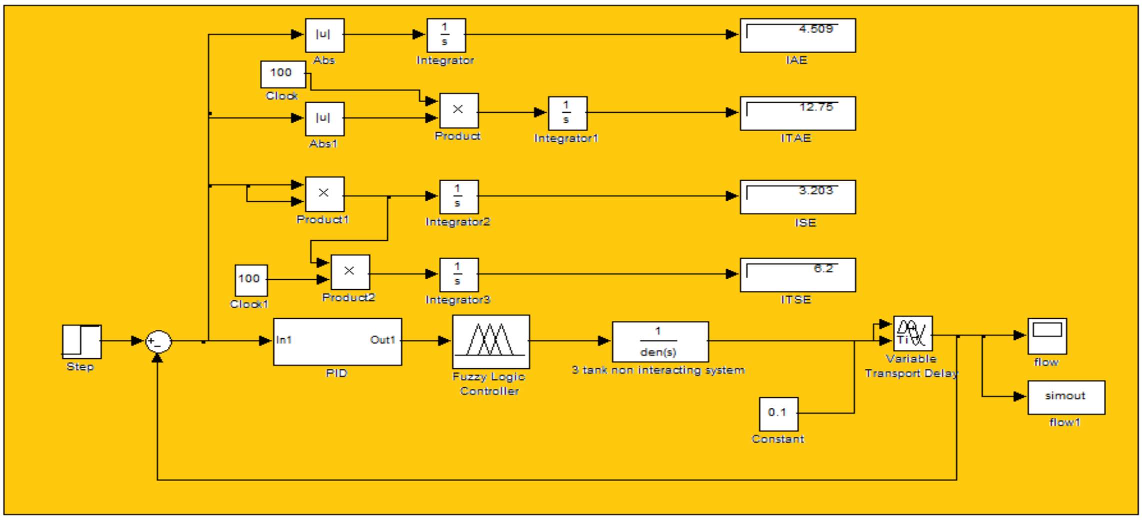

Fig: 9 - Simulink Model of the Three Tank Non-Interacting System with PID-Fuzzy Logic Controller

The corresponding Amplitude vs. Time Plot for PID-Fuzzy Logic Controller shown in Figure(10).

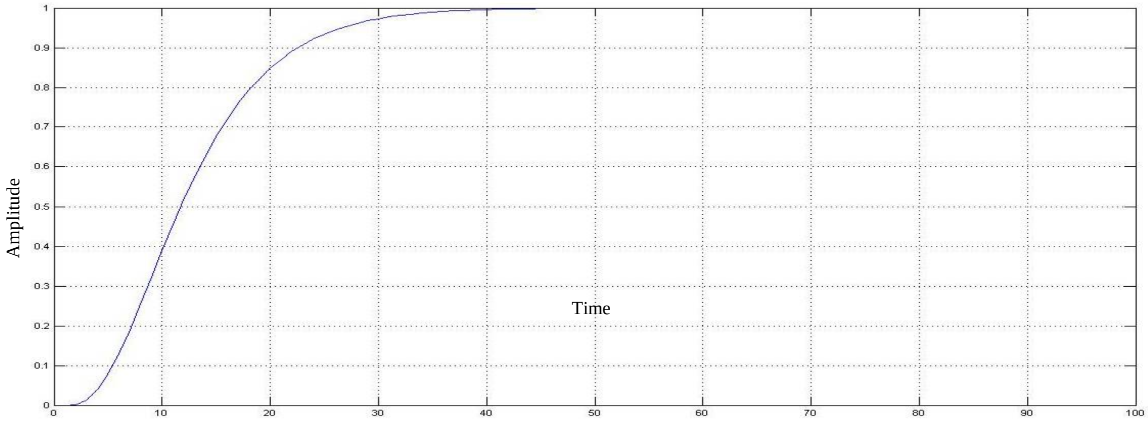

Fig: 10 – PID-Fuzzy Logic Controller Output

C. Internal Model Control:

The theory of Internal Model Controller states that “control can be achieved only if the control system encapsulates, either implicitly or explicitly, some representation of the process to be controlled”. The Internal Model Controller is based on the inverse of the process model we are trying to control. If we cascade the process transfer function with a controller which is the exact inverse of the process, then effectively the gain becomes unity and we have perfect set-point tracking. The main feature of internal model controller is that the process model is in parallel with the actual process. Figure (11), shows the scheme of IMC. Internal model controller provides a transparent framework for control system design and tuning. Figure (12) shows the equivalent block diagram of the IMC controller which is implies in MATLAB simulink block.

ISSN(Online): 2320-9801
ISSN (Print) : 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijircce.com

Vol. 6, Issue 1, January 2018

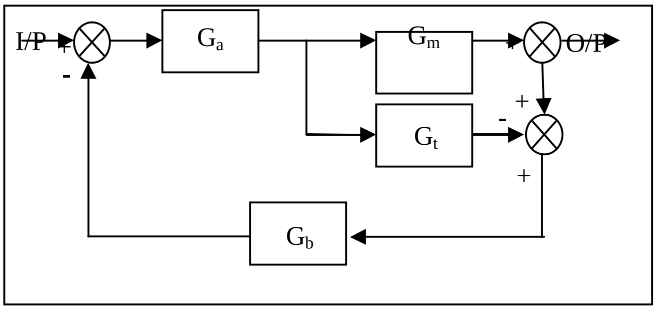

Fig: 11 - Internal Model Controller

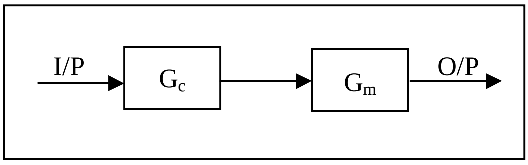

Fig: 12 - Equivalent Block diagram of IMC

Here G_t is the transfer function of Three Tank Non-Interacting process (G_t) = $\frac{1}{60s^3+47s^2+12s^1+1}$
G_m is the model of the Three Tank Non-Interacting process & G_b is the feedback which is unity.
G_a is the low pass filter is $G_a = \frac{1}{1+\tau s}$ where τ is the time constant here we choose the value is 1.5.
$G_c = \frac{60s^3+47s^2+12s^1+1}{(1+1.5s)\text{^}2}$ which is the controller transfer function.
According to the IMC controller block diagram designed in MATLAB simulink. In Figure 13 shows the simulink model of the Three Tank Non-Interacting process with IMC controller.

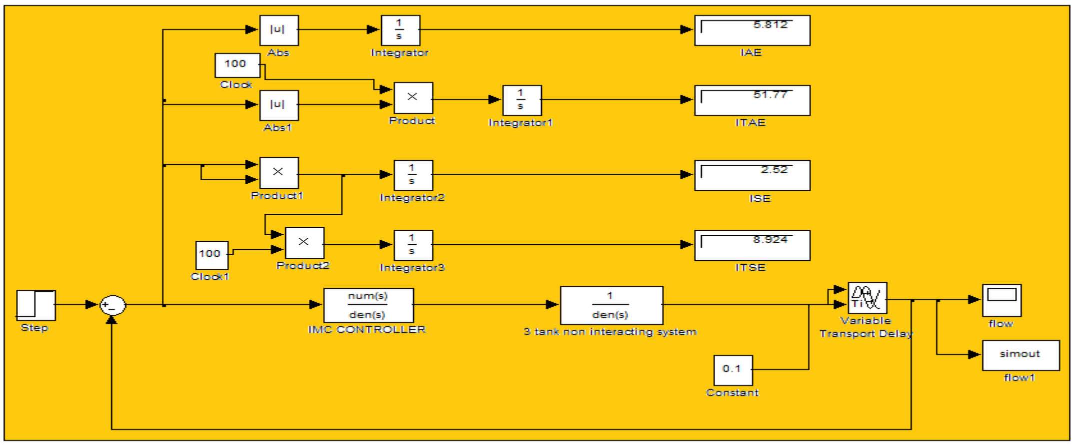

Figure 13: Simulink Model of the Three Tank Non-Interacting process with IMC Controller.

The corresponding Amplitude vs. Time Plot for Internal Model Controller shown in Figure (14)

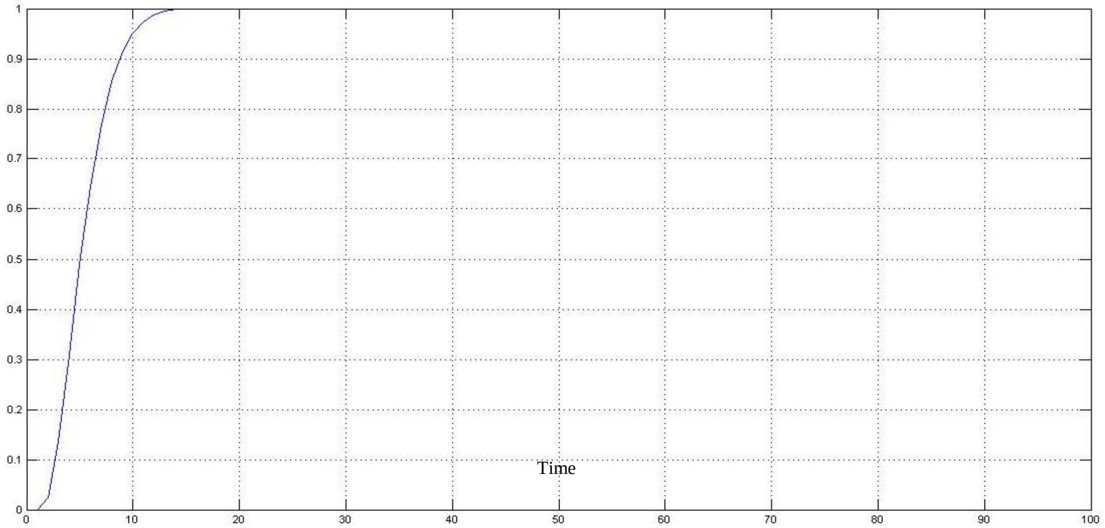

Fig: 14 - IMC Controller Output

Transfer Function	Non linear Controller	Rise Time (T_r) (sec)	Settling Time (T_s) (sec)	Maximum Overshoot (M %)	Integral Absolute Error (IAE)	Integral Time Absolute Error (ITAE)	Integral Square Error (ISE)	Integral Time Square Error (ITSE)
Three Tank Non-Interacting System	Fuzzy Logic Controller	25	37	0	16.8	181.1	11.59	85.36
Three Tank Non-Interacting System	PID-Fuzzy Logic Controller	19	29	0	12.15	98.2	8.341	43.96
Three Tank Non-Interacting System	Internal Model Controller	8	11	0	4.059	12.75	3.203	6.2

Table: 7 - Performance Analysis of Three Tank Non-Interacting process with Non Linear Controllers

Here performance of the different non linear controllers is analyzed. The results shows that the different nonlinear controllers achieve better performance while tuning the controller gains for different cases such as eliminating overshoot, rise time and steady state error. Performance Analysis data obtained from the simulation and responses have been tabulated in Table 7.

V. CONCLUSION

This paper discusses the design of the linear and nonlinear controller for the Three Tank Non-Interacting process flow control system. Here linear controller as PID controller with Three popular methods implemented and analyzed using MATLAB to create a friendly environment for study each method techniques and effect on the system response performance. Final results show that each method has its specific advantage over the others. For the chosen Three Tank Non-Interacting process transfer function, it has been shown that the Ziegler-Nichols gives faster system response with acceptable overshoot with oscillation while AMIGO yields lower overshoot with greater settling time with acceptable system transient response.

The non linear controller with Fuzzy Logic controller and Internal Model Controller are hereby implemented and analyzed for the flow performance of Three Tank Non-Interacting process using MATLAB. Final results show that each method has its specific advantage over the others. In this paper, comparative studies of performance of different non linear controllers as fuzzy logic controller, PID-Fuzzy Logic Controller and IMC controller have been studied. After the comparison of results and simulations, it is found that the PID- Fuzzy Logic Controller gives better response than Fuzzy Logic Controller and IMC gives better performance than PID-Fuzzy Logic Controller. Here Fuzzy Logic Controller, PID-Fuzzy Logic Controller and IMC have zero overshoot but PID-Fuzzy settles earlier than Fuzzy and IMC settles earlier than PID-Fuzzy. After careful investigation it is found that its performance index is satisfactory for IMC. Hence it is concluded that the proposed IMC Controller provides better performance characteristics and improves the flow control of Three Tank Non-Interacting process.

In this paper we studied both linear and non linear controller and we conclude that non linear controller gives better performance than linear controller as it takes into account the other non- linearity associated with the controller and plant. But in small scale industries like food and beverage industries linear controller can be work with good accuracy and it is not highly expensive, so there no needs of use non linear controller. Now in case of high scale industries like thermal power plant or steel plant non linear controller works with good accuracy where linear controllers are not give satisfactory result.

ACKNOWLEDGMENT

I hereby express my sincere gratitude to the Assistant prof. A.K.Kashyap, Dept. of Instrumentation and Control Engineering for providing us with the necessary arrangement for the completion of my project. Without his valuable guidance and support the project would not have been a success. I thank him for the good will and encouragement extended to us.

REFERENCES

[1] K. Astr¨om and T. H¨agglund, PID Controllers: Theory, Design and Tuning. New York: ISA, 1995.

[2] N.Sianandam, S.Sumathi and S.N.Deepa, "Introduction to Fuzzy Logic using MATLAB(Springer,2007)".

[3] Visioli.A. (2000) Tuning of PID controllers with Fuzzy Logic

[4] Visioli, A. (2004) Fuzzy logic based setpoint weighting for PID controlers.

[5] Based Tuning of PID Controller Parameters", NationalConference on New Frontiers for Women in Science and Technology March 20- 21, 2013, JiwajiUniversity, Gwalior (M.P.).

[6] IEEE MELECON 2002, May 7-9, 2002, Cairo, EGYPT "Nonlinear PID controller using Fuzzy logic" Abdel-Azim S.Ibrahi

[7] 2010 International Conference on Computer Design And Applications (ICCDA 2010) "Design and Simulation of a Fuzzy-PID Composite Parameters' Controller with MATLAB" Changhua Lu and Jing Zhang.

[8]. Hassoun, M.H., "Fundamentals of Artificial Neural Network", Printice-Hall of India.

[9] Ravi V R, Thyagarajan T, "A De-centralized PID Controller for Interacting Non linear Systems," Proc. Of IEEE international Conference on Emerging trends in Electrical and Computer Technology, pp. 297-302, 2011.

[10]. Macleod, C. "An Introduction to Practical Neural Networks and Genetic Algorithms for Scientists and Engineers".

[11]. Maier, H.R., (1995), "A review of Artificial Neural Network.", Research Report no. R131. Dept. of Civil andEnv. Engg. The University of Adelaide.

[12] Gude. J.J, "Modified Ziegler-Nichols method for fractional PI controllers", international conference on Emerging Technologies and Factory Automation (ETFA), 2010, pp.1-5

[13] Ravi V R, Thyagarajan T, "Gain scheduling Adaptive Model Predictive Controller for Conical Tank Interacting Level system" proc. of IEEE international conference on computing communication and network technologies, pp. 1-7, 2012.