Comparative Performance Analysis for Two Tanks Liquid Level Control System with Various Controllers using Matlab

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Abstract- Liquid level control in tanks and between tanks are basic industrial problem. Often the tanks are so coupled in interacting and non-interacting way they exhibit non-linear behaviour. This paper deals with the level control of two tank system which are connected in interacting and non-interacting mode to control the level of system. In interacting mode the level of first tank will depend on the level of second tank while in case of non-interacting mode level of first tank is independent of level of second tank. Here comparative analysis of the transient response obtained by different controllers- Conventional controller PID, Feed forward-feedback controller, IMC (Internal Model Controller) and Fuzzy Logic Controller has been done using MATLAB simulation. It has been observed that IMC performs better than other controllers for both interacting and non-interacting mode.

KEYWORDS- Level Control, PID, Feed forward-feedback, IMC, FLC, MATLAB

I.INTRODUCTION

The Control of liquid level in tanks and flow between tanks is the basic problem in process industries. In Process industry the liquid pumped and store in the tank and then pumped to another tank. Many times the liquid will be processed by chemical or mixing treatment in the tanks. The liquid should be processed such that the level of fluid in the tanks must be controlled and flow between the tanks must be regulated [1]. It is essential to understand that how the tank is controlled and how the level control problem solved. Here in this paper performance will be analysed on the basis of characteristics e.g. rise time (t_r), settling time (t_s), % overshoot ($\%M_p$).

There are different types of controllers for get the optimized response for any system. PID is one of the effective conventional controller that used from long years back. Ziegler Nichols- tuning method for PID controller is a popular tuning process [2]-[3]. The disadvantage of PID controller is that it is not suitable for higher order nonlinear system. Feed forward controller uses two loops in its structure which helps to minimize interaction coefficient of the system and improve the response [4]. IMC controller is used to minimize the disturbance of the system and to make the system internally stable. IMC gives better result than other implemented controllers [5]. Fuzzy Logic Controller (FLC) is an intelligent controller which uses IF and THEN rule to obtain optimized result. However FLC makes the system little sluggish [8]-[9].

II. MATHEMATICAL ANALYSIS

Here in this work two tanks are connected in interacting and non-interacting manner. Mathematical calculation for both the tank has been done to distinguish interacting and non-interacting connection [2] [6]. A disturbance has also been introduced in the considered system. Disturbance is nothing but an extra input for second tank.

Case I: Two Tank Interacting system

In this connection two tanks are connected together to form a coupled tank system. Here level of 1st tank will depend on level of 2nd tank.

Level of tank 1 is represented by h_1 and level of tank 2 is represented by h_2.

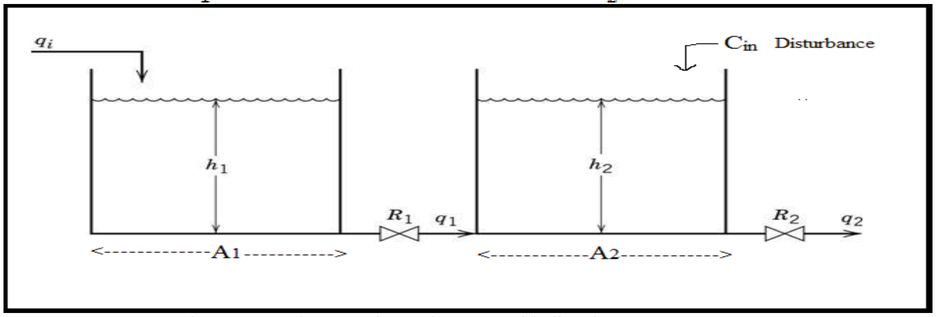

Fig.1 Two Tank Interacting tank system with disturbances

Here,

q_{in}=Volumetric flow rate in to tank 1(cm^3/sec)

q_1 =Volumetric flow rate from tank 1 to tank 2 (cm^3/sec)

q_0= Volumetric flow rate from tank 2(cm^3/sec) h_1=Height of the liquid level in tank 1 (cm) h_2=Height of the liquid level in tank 2 (cm)

A_1= Cross sectional area of tank 1 (cm^2)

A_2= Cross sectional area of tank 2 (cm^2)

R_1=Linear resistance of flow from tank 1 through valve 1 (sec/cm^2)

R_2=Linear resistance of flow from tank 2 through valve 2 (sec/cm^2)

For Tank 1:-

By Mass Balanced Equation;

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

By Torcilli equation linear resistance to flow is (R_1) and the relation between Volumetric flow rate into tank and linear resistance (R_1) can be given as

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

Putting the value of equation (2) in equation (1)

$$A_1\frac{dh_1}{dt} = q_{in} - (\frac{h_1-h_2}{R_1})$$

(3)

$$A_1R_1\frac{dh_1}{dt}=R_1q_{in} - h_1 + h_2$$

(4)

For Tank 2:-

By Mass Balanced equation;

$$A_2\frac{dh_2}{dt} = q_1 - q_0 \quad (5)$$

By Torcilli equation linear resistance to flow (R_2) through valve 2 and relation between output Volumetric rate (q_0) and Linear resistance to flow (R_2) can be given as;

$$q_0 = \frac{h_2}{R_2} \quad (6)$$

Putting the value of q_1 from equation (2) and q_0 from equation (6) in equation (5)

$$A_2\frac{dh_2}{dt} = \frac{h_1-h_2}{R_1} - \frac{h_2}{R_2} \quad (7)$$

$$A_2R_2\frac{dh_2}{dt}+h_2 + \frac{R_2}{R_1}h_2 = \frac{R_2}{R_1}h_1$$

(8)

By Laplace transform,

$$\frac{H_2(s)}{Q_{in}(s)} = \frac{R_2}{T_1T_2s^2+(T_1+T_2+A_2R_2)s+1}$$
(9)

Where; $T_1 = A_1R_1$

$T_2 = A_2R_2$

Disturbance analysis for two tanks interacting Water Level Tank System will be given as:

$$\frac{H_2(S)}{C_i(S)} = \frac{R_2}{(A_2R_2S+1)}$$
(10)

Table.1 Parameters value for two tank

Parameters	Value	Unit
A_1	250	Cm^2
A_2	250	Cm^2
R_1	0.01	Cm^2/sec
R_2	0.01	Cm^2/sec
H_1	30	Cm
H_2	15	Cm

Using the parameters shown in table 1 the final transfer function for the interacting system will be

$$\frac{H_2(s)}{Q_{in}(s)} = \frac{0.01}{6.25S^2+7.5s+1}$$
(11)

Transfer function for Disturbance will be given as;

$$\frac{H_2(s)}{C_i(S)} = \frac{0.01}{2.5s+1} \quad (12)$$

Case II: Two Tank Non- Interacting system

In Non-Interacting connection two tank will not be connected in series. The significant of non- interacting tank is that here the level of 1st tank will not depend on the level of 2nd tank.

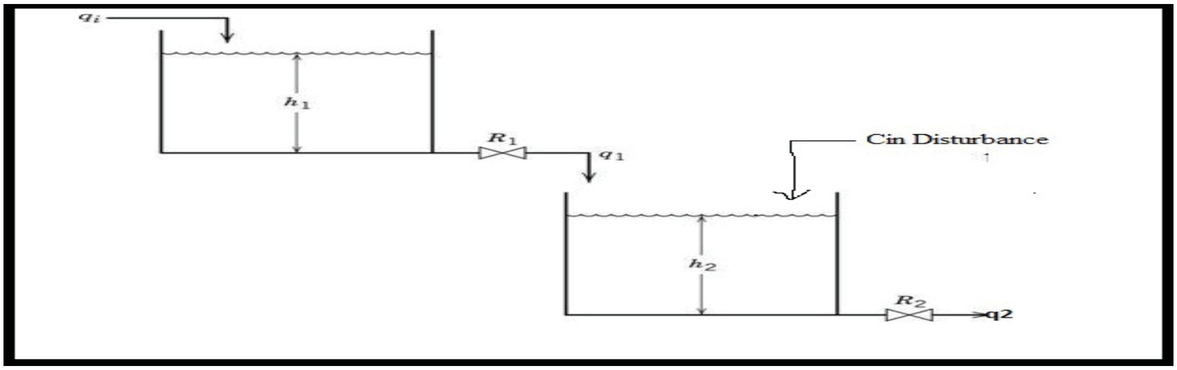

Fig.2 Two Tank Non-Interacting system with disturbance

For Tank 1:

From above figure Mass Balance Equation; $A_1 \frac{dh_1}{dt} = q_{in} - q_1$ (13)

By Torcilli equation the relationship between linear resistance of flow through valve 1 (R_1) and input flow rate of liquid (q_1) will be given as $q_1 = \frac{h_1}{R_1}$ (14)

Putting the value of q_1 in equation (13)

$$A_1 \frac{dh_1}{dt} = q_{in} - \frac{h_1}{R_1} \quad (15)$$

For Tank 2:

By Mass balance equation;

$$A_2 \frac{dh_2}{dt} = q_1 - q_2 \quad (16)$$

Again by Torcilli equation the relationship between linear resistance of flow through valve 2 (R_2) and output flow rate for tank (q_0) will be given as follow

$$q_0 = \frac{h_2}{R_2} \quad (17)$$

$$\therefore\ A_1 \frac{dh_1}{dt} = \frac{h_1}{R_1} - \frac{h_2}{R_2} \quad (18)$$

Using Laplace transform.

$$\frac{H_2(s)}{Q_{in}(s)} = \frac{R_2}{[T_1 s+1][T_2 s+1]} \quad (19)$$

Where; $T_1 = A_1 R_1$

$T_2 = A_2 R_2$

Using parameters value from table 1 transfer function for non-interacting system will be given as;

$$\frac{H_2(s)}{Q_{in}(s)} = \frac{0.01}{6.25S^2+5s+1}$$
(20)

III.CONTROLLERS DESIGN

(i)PID CONTROLLER

A PID controller is a controller that includes proportional gain (K_p), integral gain (K_I), and the derivative gain (K_d). Defining u(t) as the controller output, the final form of the PID algorithm is:

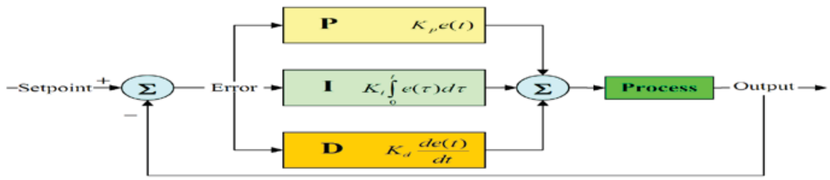

Fig.3 General Control Structure of PID

$$G_c(s) = \frac{U(s)}{E(s)} = MV(s) = K_p + \frac{K_i}{s} + K_d s$$

(21)

$K_p = 12,\ K_i = 4$ and $K_d = 7$ have been used for effective performance of the system. Major drawback of this method is that oscillation will be present in the system response.

(ii) FEED FORWARD-FEEDBACK CONTROLLER

Feed-forward controllers are always used along with feedback controller. Feedback controller is used to tracking the change in set point and also minimized the effect of disturbances which is unmeasured in nature and such type of disturbances are always present in the real plant. Conventional feedback control loops can never achieve perfect control. It is difficult for the conventional loops to keep the process output continuously at the desired set point value if the load or set point changes. This is because a feedback reacts only after it has detected a deviation in the value of the output from the desired set point. Unlike the feedback control systems, a feed forward control configuration measures the disturbance directly and takes the control action to eliminate its impact on the process output.

$$G_f = K_f \times \left|\frac{(\tau_1 s+1)}{(\tau_2 s+1)}\right|$$

(22)

Where,

K_f - DC gain of the controller

τ_1, τ_2 - Are the time constant of the controller

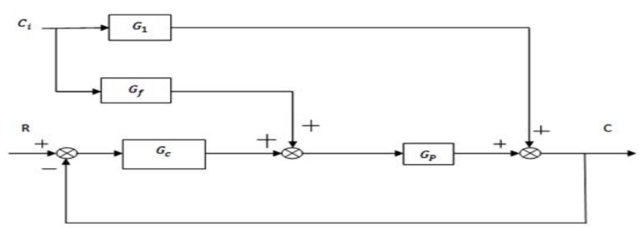

Fig.4 Block diagram of Feed forward –Feedback Controller

Where,

G_1 - transfer function between output and disturbance

G_f - transfer function of feed forward controller

G_c - transfer function of PID controller

G_p - transfer function of plant

Table. 2 Tuning rule for Feed-forward controller

Sr. No	Mode	τ_1	τ_2
1.	Lead	1.5 peak time	0.7 peak time
2.	Lag	0.7 peak time	1.5peak time

(iii) IMC CONTROLLER

The IMC design procedure is exactly the same as the open loop control design procedure. Unlike open loop control, the IMC structure compensates for disturbances and model uncertainties. The IMC filter tuning parameter “lem(λ)” is used to avoid the effect of model uncertainty. The normal IMC design procedure focuses on set point responses but with good set point responses good disturbance rejection is not assured, especially those occurring at the process inputs. A modification in the design procedure is proposed to enhance input disturbance rejection and to make the system internally stable.

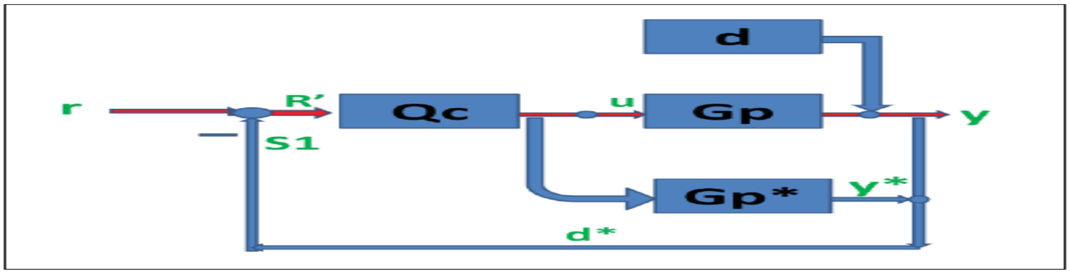

Fig.5 Basic Block Diagram Of IMC

$$Q_c(s)=Q_c{}^*(s).f(s)=\{inv[Gp^*(s)]\}f(s) \quad (23)$$

Where, f(s) is transfer function for LPF. Used to make the system at least semi-proper. Because Improper system has not stable response.

$$f(s) = \frac{1}{(1+\lambda s)^n}$$

where, λ is adjustable and n=total number of pole=2.

$$\lambda \propto {}^{1}/_{speed}$$

IMC design for 2nd order system:

$$G_p(s)=\frac{0.01}{6.25s^2+7.5s+1}$$
(24)

$$G_p{}^*(s)=G_{p+}{}^*(s).G_p{}^{-*}(s)=\frac{0.01}{(s+0.1528)(s+1.0472)}$$
(25)

Since here both poles are in left side of s-plane

$$\therefore \quad Q_c{}^*(s)=inv[G_p{}^{-*}(s)]=\frac{(s+0.1528)(s+1.0472)}{0.01}$$

Since here in this system there are two poles so value of n=2

$$Q_c(s) = Q_c{}^*(s) * f(s) = \frac{(s+0.1528)(s+1.0472)}{0.01\,(1+\lambda s)^2}$$

For, λ=0.5 and n=2

$$Q_c(s) = \frac{s^2+1.2s+0.16}{0.0025s^2+0.01s+0.01}$$
(26)

(iv) FUZZY LOGIC CONTROLLER

Fuzzy logic controller makes rules rather than complicated mathematical expressions; it also uses linguistic variables rather than numerical values. The linguistic variables are in the form of natural languages like very high, high, medium, low and very low. These rules are executed by the inference rule which convert the input data into linguistic values and thus fuzzification is done. Decision making is made by the controller with the set of rules and the variables. The controlled action from the controller is then defuzzified that gives a numerical value based on linguistic values. In this the input to the fuzzy logic controller is error and change in error; it is then fuzzified and converted to linguistic variables. The rules are framed by trials and error method and thus the desired response is obtained. The IF-THEN rules have been used here. The triangular membership functions for the input and output are chosen and their ranges are split.

Table.3 Rule base array for FLC (25)

E(n)/CE(n)	NB	N	Z	P	PB
NB	NB	NB	NB	N	Z
N	NB	NB	N	Z	P
Z	NB	N	Z	P	PB
P	N	Z	P	PB	PB
PB	Z	P	PB	PB	PB

IV. SIMULATION RESULTS

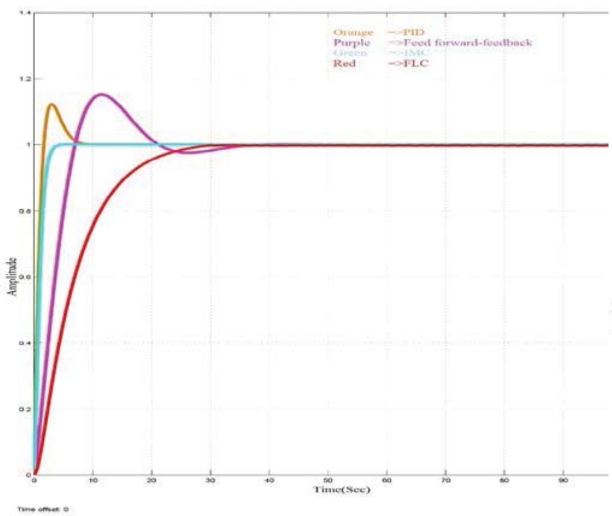

Fig.6 Comparison of responses for two tank interacting system for all controllers

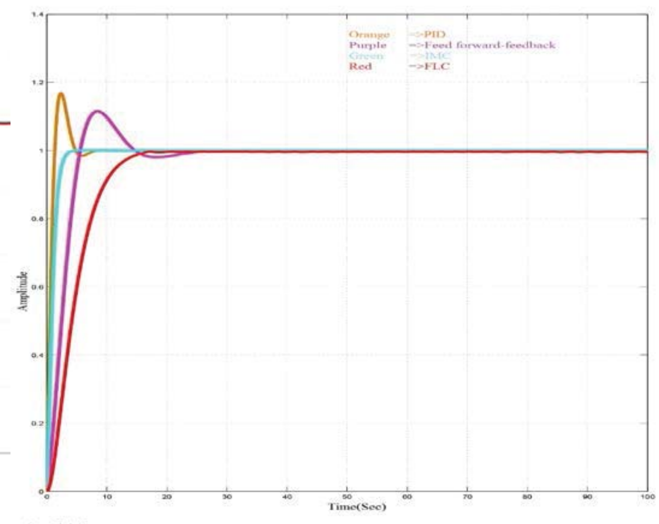

Fig.7 Comparison of responses for two tank non- interacting system for all controllers

V. PERFORMANCE ANALYSIS

Table.4 and Table.5 describe the performance analysis of all controllers. IMC has least settling time and no overshoot. Hence the IMC control scheme is the best suited for this system as it provides best overall performance.

Table.4 Comparative analysis for two tank interacting system

Controller	Rise Time(*sec*)	Settling time(*sec*)	%Overshoot
PID	1.24	6.5	12.3
Feed f/w-feedback	5.19	29.08	15.2
IMC	1.77	3.10	0
FLC	14.15	24.07	0

Table.5 Comparative analysis for two tank non-interacting system

Controller	Rise Time(sec)	Settling time(sec)	%Overshoot
PID	1.01	5.86	17
Feed f/w-feedback	4.05	14.73	11.5
IMC	1.77	3.10	0
FLC	8.4	14.1	0

VI. CONCLUSION

It has been observed that IMC controller performs better than other controllers. It has been found out that IMC rejects disturbance and provides a stable system. It has also been shown that non-interacting connection has better performance for different controllers except IMC where interacting and non-interacting both have similar characteristics.

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