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Control of Level in Two Interacting Tank System using Fuzzy Logic Controller

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Abstract— **The liquid level control is done by manipulating input and output flow, mostly PID control is used for controlling purpose. Industry consists of interacting as well as non-interacting tank system. In interacting tank, flow between the tanks is affected by level of liquid in both the tanks. This interaction of parameter in tank system makes control of system complicated .In this paper we take an interacting tank system in consideration for study. Mathematical modeling of the system is obtained by mass balance equation and flow resistance is also calculated depending on the difference of liquid level. After the open loop transfer function is found various control scheme are deployed to control the level of tank2 like PID and Fuzzy logic control (FLC). Paper also presents various methods for tuning of PID parameter. Further comparison between various control schemes is done according to their performance.**

Keywords—Interacting Tank, PID, Fuzzy logic control, Level Control

I. INTRODUCTION

In process industries mainly four parameters are measured and control that are pressure, temperature, flow and level. All the above mentioned parameters are interlinking to each other in process industries and have overall effect on process. This paper deals with measurement and control of liquid level in interacting tank system. The process industries required liquids to be pumped, stored in tank and then pumped to another tank [1]. Level and control of level is essential for safety of boilers and overflow and spill prevention of tanks and silos. Volume measurement is important to determine quantity. Point Level Measurement is a measurement identified where the only concern is whether the amount of material is within the desired limits. This measurement is one commonly used to sound an alarm or to determine when to activate a control device to increase or decrease the level. This is a level that is critical to maintain or to report its status. Example would be a safety backup to a process control of level if the controls were to fail. Continuous Level Measurement is a method to track the changes of a level over a range of values to monitor inventory or for determining when to add or remove material from containers. Examples of continuous level measurement could include maintaining a level at a safe level when transferring material, or the water level of a boiler must be known at all times to prevent a low-water condition that could result in boiler damage or an explosion.

- Point level measurement is a measurement identified where the only concern is whether the amount of material is within the desired limits.
- Continuous level measurement is a method to track the changes of a level over a range of values to monitor inventory or for determining when to add or remove material from containers.

Conventional controllers are widely used in industries as they are simple easy to implement and familiar to field operator. Still the performance of system can be improved by implementation of intelligent control schemes. The paper present the implementation of Fuzzy logic control (FLC) and comparison of response of system based on conventional PID controller and FLC.

II. PROCESS DESCRIPTION

For the primary collection of input and output data, take a real system in consideration. Fig. 1 shows the diagram of process model on which data is collected.

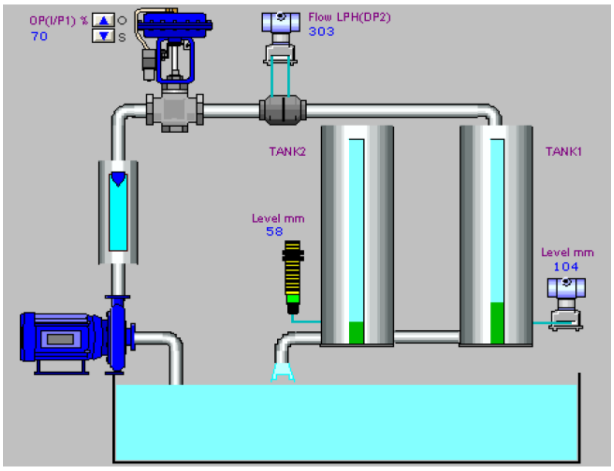

Fig.1 Schematic of interacting tank system

It consist of reservoir, pump, control valve, two process tank, level transmitter, rotameter, two differential pressure transmitter five manual operated valve, compressor pump to provide compressed air for operation of pneumatic control valve, I to P converter and instrumentation panel that supply power to the various component in the process an collect data from the process.

Fig.2 Experimental setup of system

A. Working Principle

The primary aspect of the process is level of liquid in tank2. Water is pump with the help of motorized pump which flow through rotameter, control valve, tank1and then tank2. Level of water in tank2 is measure with the help of level transmitter and level in tank1 is measure with the help of differential pressure transmitter. The entire output signal is fed to data acquisition system (DAS). The output of all transmitters is (4-20mA) that is fed to DAS. In this system control variable is height of liquid in tank2 and manipulated variable is flow of water in process. Flow can be visualize through rotameter and it can also be measured using assembly of orifice and differential pressure transmitter which gives flow in electrical quantity (4-20 mA) that can feed to DAS. According to reading obtained, graph is plotted and required calculations are made and various parameter of process is evaluated.

B. Mathematical modelling of a two-tank interacting level Process

As explained, process have two tank.tank1 and tank2 that is shown in fig.2 with input flow rate Q_{in} and output flow rate Q_{out} . The height of water level in tank is represented by h1 for tank1 and h2 for tank2

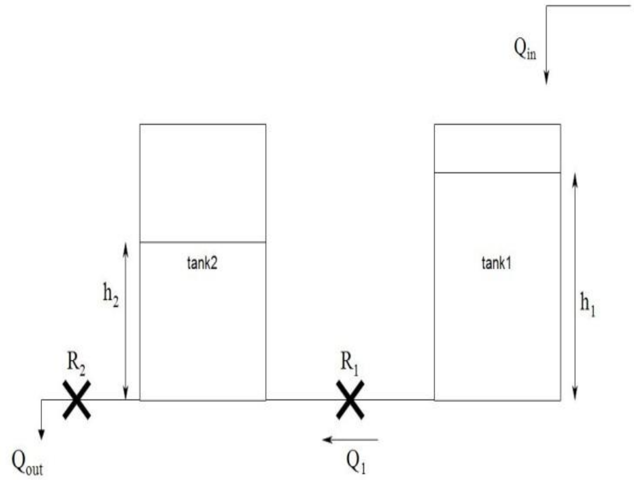

Fig.3 Schematic diagram of process

Q_{in} = Input flow rate in m^3/sec
Q_{out} = Output flow rate in m^3/sec
Q_1 = flow between tank1 and tank2 in m^3/sec
h_1 = Height of liquid in tank1 in m
h_2 = Height of liquid in tank2 in m
A_1 = Area of tank1 in m^2
A_2 = Area of tank2 in m^2

$$A_1 \frac{dh_1}{dt} = Q_{in} - Q_1 \tag{1}$$

The linear flow resistance is given by

$$Q_1 = \frac{h_1 - h_2}{R_1} \tag{2}$$

Substituting above expression of Q1 in equation we get

$$A_1 \frac{dh_1}{dt} = Q_{in} - \frac{(h_1 - h_2)}{R_1} \tag{3}$$

$$R_1 A_1 \frac{dh_1}{dt} + h_1 = R_1 Q_{in} + h_2 \tag{4}$$

Time constant $T_1 = A_1 R_1$

$$T_1 \frac{dh_1}{dt} + h_1 = R_1 Q_{in} + h_2 \tag{5}$$

Taking Laplace transformation on both side

$$T_1 s h_1(s) + h_1(s) = R_1 Q_{in}(s) + h_2(s)$$

$$h_1(s)(T_1 s + 1) = R_1 Q_{in}(s) + h_2(s) \quad (6)$$

Now for tank2

$$A_2 \frac{dh_2}{dt} = Q_1 - Q_{out} \quad (7)$$

Resistance of flow in tank 2 is R_2 that is given as

$$Q_{out} = \frac{h_2}{R_2} \quad (8)$$

$$R_2 A_2 \frac{dh_2}{dt} + h_2 = \frac{R_2 (h_1 - h_2)}{R_1} \quad (9)$$

$$R_2 A_2 \frac{dh_2}{dt} + h_2 + \frac{R_2 h_2}{R_1} = \frac{R_2 h_1}{R_1} \quad (10)$$

Time constant $T_2 = A_2 R_2$

$$T_2 \frac{dh_2}{dt} + h_2 + \frac{R_2 h_2}{R_1} = \frac{R_2 h_1}{R_1} \quad (11)$$

Taking Laplace transform on both sides

$$T_2 s h_2(s) + h_2(s) + \frac{R_2}{R_1} h_2(s) = \frac{R_2}{R_1} h_1(s)$$

$$h_2(s)(T_2 s + 1 + \frac{R_2}{R_1}) = \frac{R_2}{R_1} h_1(s) \quad (12)$$

Above equation gives the relationship of h_1 and h_2 in terms of R_1, R_2 and T_2 Substituting value of h_1 in term of h_2 in equation (5) and rearranging the term

$$\frac{h_2(s)}{Q_{in}(s)} = \frac{R_2}{T_2 s + 1 + T_2 T_1 s^2 + \frac{R_2}{R_1} T_1 s + T_1 s} \quad (13)$$

Submitting the value of T_1

$$\frac{h_2(s)}{Q_{in}(s)} = \frac{R_2}{T_2 s + 1 + T_2 T_1 s^2 + \frac{R_2 R_1 A_1}{R_1} s + T_1 s} \quad (14)$$

$$\frac{h_2(s)}{Q_{in}(s)} = \frac{R_2}{T_2 s + 1 + T_2 T_1 s^2 + R_2 A_1 s + T_1 s} \quad (15)$$

$$\frac{h_2(s)}{Q_{in}(s)} = \frac{R_2}{T_2 T_1 s^2 + (T_2 + T_1 + R_2 A_1) s + 1} \quad (16)$$

Above expression give the relationship between the inflow of liquid and height of liquid in tank2 [4] To obtain the value of R_1 and R_2, it is needed to perform experiment and collect experimental data [3].

C. Procedure to obtain R_1 and R_2

- First of all setup the interacting tank system as shown in fig.2
- Give constant input liquid flow to the system say 300 lph and wait for the level to settle down at steady state. This is said initial state of system
- Take down the reading of liquid level in tank1 and tank2 also note down the flow
- Now give a step change in flow e.g. 400 lph
- Again note down the reading of liquid level in tank1 and tank2. This is final state of system

Performing above procedure we get following values

TABLE II. DATA OF PROCESS

Flow in lph	Height in tank1 (mm)	Height in tank2 (mm)
193	56	35
305	102	55

Now

$$R_1 = \frac{dh_1}{dQ}$$

Substituting the values from above table

$$R_1 = \frac{(102 - 56)\ mm}{(305 - 193)\ lph}$$

That result in R_1 = 1478.57 sec/m^2
Similarly for R_2

$$R_2 = \frac{dh_2}{dQ}$$

Substituting the values from above table

$$R_2 = \frac{(55 - 35)\ mm}{(305 - 193)\ lph}$$

That result in R_2 = 642.86 sec/m^2
Now time constant is given as $T_1 = A_1 R_1$ and $T_2 = A_2 R_2$
That result $T_1 = 21.42$ and $T_2 = 9.31$
Finally substituting this value in expression (16) we get

$$\frac{h_2(s)}{Q_{in}(s)} = \frac{643}{199.42\, s^2 + 40.04\, s + 1}$$

Above is transfer function of system in s- domain, that present gain of system is 643 with two poles at -0.029 and -0.171 damping coefficient is 1.41 and damped natural frequency is 0.0708 rad

D. Open loop response of two-tank interacting system

The Simulink model for the open loop step response is shown in Fig.4. The step response of open loop system for the same is shown in Fig.5 below with settling time and rise time

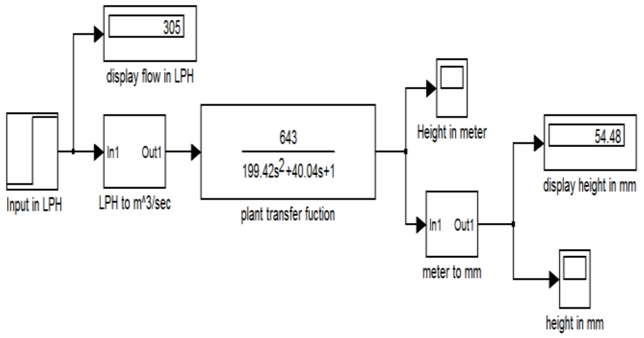

Fig.4 Simulation block for Open loop response of system

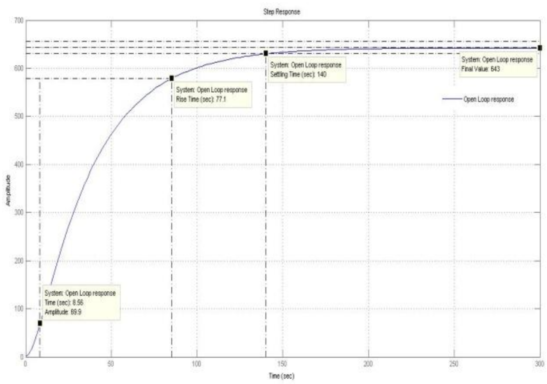

Fig.5 Simulated Open loop response of system

The root locus plot of system that indicate its pole –zero plot for different gain. From the graph it can be seen that for any gain system does not cross imaginary axes hence system is stable. The system has over damp response when the distinct real poles are present and when poles are at imaginary position system result in underdamped response

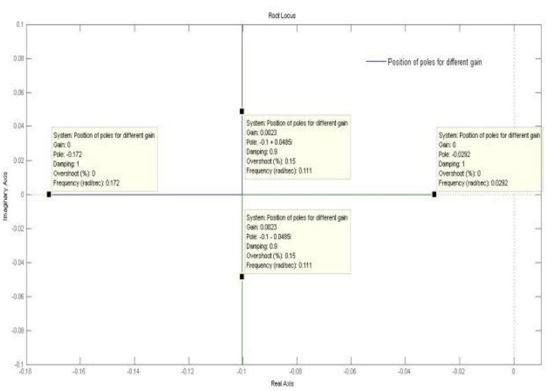

Fig.6 Root locus plot of system

III. CONTROL SCHEMES

A. PID tuning methods

There present various method for PID tuning, here two method are used to tune the PID for and the performance of system is compared

- Ziegler-Nichols Method
- Good Gain method

Ziegler-Nichols Method mostly used for PID tuning [5]. Two classical methods for determining the parameters of PID controllers were presented by Ziegler and Nichols in 1942. These methods are still widely used, either in their original form or in some modification. They often form the basis for tuning procedures used by controller manufacturers and process industry.

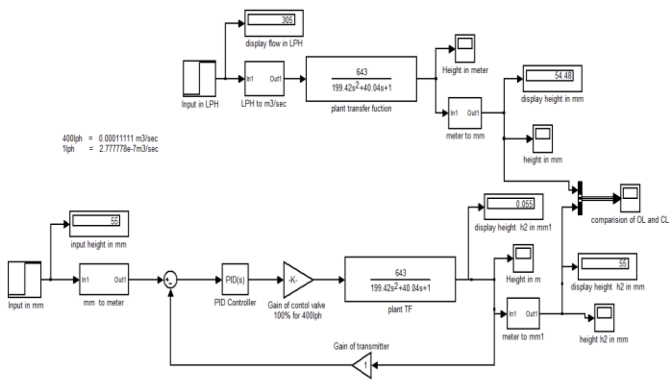

Fig.7 Implementation of PID controller

1) Reaction curve method for PID tuning

The process reaction curve methods [6] works by generating a process reaction curve (below) in response to a disturbance. Controller gain, integral time and derivative time can be calculated using this curve. The process reaction curve is identified by performing in an open loop step test of the process and finding model parameters for initial step disturbance P (%). These parameters are as follows:

- Put the controller in manual mode
- Wait until the process value reaches steady state
- Collect the data
- The Process Gain K
- Slope R
- Delay L

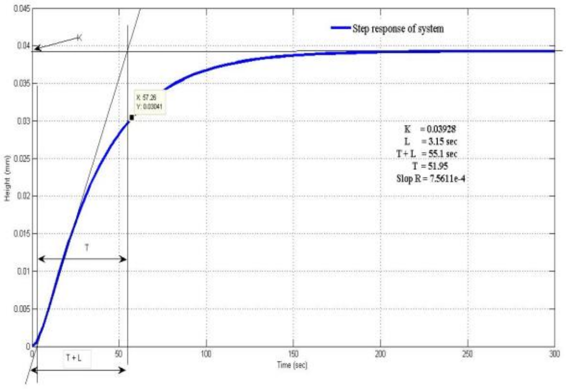

Fig.8 Step response of tuning of PID parameter

2) Good gain method

The Good Gain method [7] is a simple, experimental method which can be used on a real process (without any knowledge about the process to be controlled), or simulated system (in this case you need a mathematical model of the process).

- Bring the process to or close to the normal or specified operation point by adjusting the nominal control signal u0 (with the controller in manual mode)[2].
- $K_p = 0$, $T_i = 0$, $T_d = 0$
- Gradual increase value of K_p , until you observe a slight overshoot
.
- Calculate T_{out} , T_{ou} is the time between the overshoot and the undershoot of the step response
- Set the integral time $T = 1.5T_{out}$
- Set the D term $T_d = T_i /4$

The value of PID parameter obtained from good gain method are Kp = 12000, Ti = 17.805 and T_d = 4.451, after submitting these value in PID controller below response of system can be observed

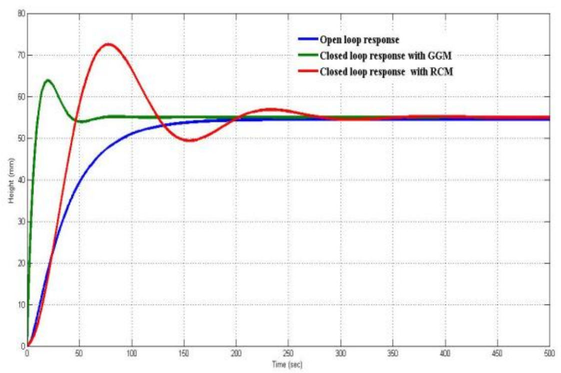

Fig.9 Simulated response of system for tuned PID

B. Fuzzy Logic Control

Fuzzy logic control for two interacting tank system is shown in Fig.9. Fuzzy logic controller is designed with two input error and change in error and one output variable. The Mamdani-type inference is used to build FLC. Inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be making.

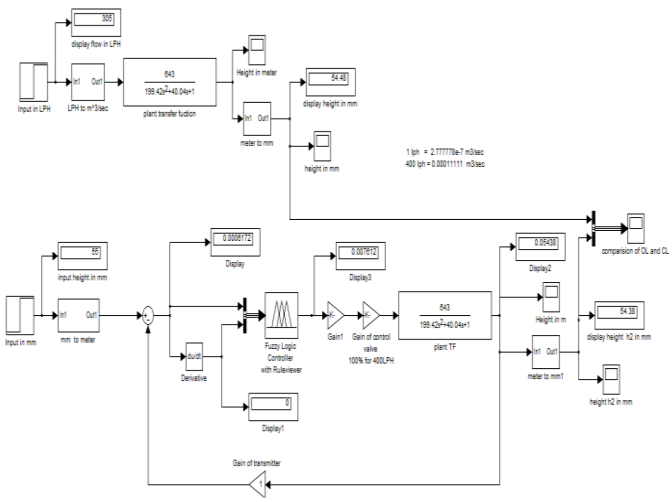

Fig.10 implementation of Fuzzy Logic control

Table III show the rules that is used to implement FLC for the system.for implementation of FLC five member are used.

TABLE III
FUZZY RULES

(Δ)e / E	MN	N	Z	P	MP
MN	MN	MN	N	N	Z
N	MN	N	N	Z	P
Z	N	N	Z	P	P
P	N	Z	P	P	MP
MP	Z	P	P	MP	MP

MN-More negative, N- Negative, Z-Zero, P-Positive and MP-More positive

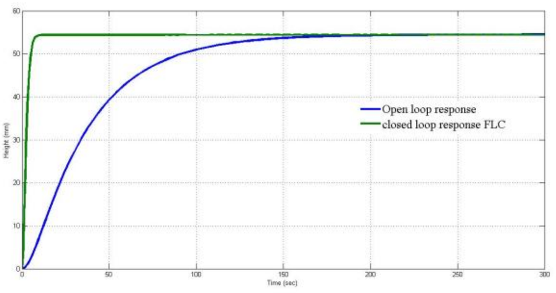

Fig.11 Simulated response of system with FLC

IV. RESULT

Response of system is compare after implementation of control schemes on the basis of rise time settling time and peak overshoot. Below table present numerical data for comparison

TABLE IV
COMPARISON OF PERFORMANCE WITH RCM AND GGM

Tuning Methods	Transient Parameters		
	Rise Time (sec)	Settling Time (sec)	Peak Overshoot (%)
PRCM	55.07	270.24	41
GGM	11.31	71.89	15.9

Table IV presents comparison between two methods used to tune PID based on performance of system which is controlled by PID. Table V presents comparison between performance of system based on PID which is tuned by GGM and FLC.

TABLE V
COMPARISON OF PERFORMANCE WITH PID AND FLC

Tuning Methods	Transient Parameters		
	Rise Time (sec)	Settling Time (sec)	Peak Overshoot (%)
FLC	7.39	12.8	0.001
PID	11.31	71.89	15.9

IV. CONCLUSION

With the help of simulation results and the data presented in above table, it can be concluded that response of system is better when PID controller parameter is tuned by GGM instead of PRCV. The result also reveals that application of intelligent control like FLC to the system can give a better performance than conventional controller

Other intelligent control schemes can be used to control the system like neural and combination of neural and fuzzy that may result in better performance of system.

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