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CONTROL OF A NON LINEAR SYSTEM USING IMC-PID CONTROLLER

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***Abstract*:- The level control of non-linear tank is the massive challenge in process control and it cannot be effectively controlled by means of conventional linear PID controller. This paper deals with the controlling of the non-linear system using fractional order IMC PID controller. The IMC PID controller does good set-point tracking but poor disturbance response mainly for the process which has a small time delay or time constant ratio. Here conical tank system is taken as non-linear system. The mathematical model for conical tank system is developed. The response of conical tank system for IMC PID closed loop is simulated using MATLAB. The performance of IMC-PID is compared with PID using time response analysis.**

***Keywords:*- IMC PID, non linear system, MATLAB, Fractional order.**

I. INTRODUCTION

Measurement of level, temperature, pressure and flow parameters are very vital in all Process Industries. Real time systems provide many challenging control problems due to their dynamic behavior, uncertainty and time varying parameters, constraints on manipulated variables, dead time on input and measurements, interaction between manipulated and controlled variables and unmeasured frequent disturbances. Because of the inherent nonlinearity, most of the chemical process industries are in need of modern control techniques.

Nonlinear systems like conical tanks find wide applications in gas plants and petrochemical industries. They are preferred because of the advantages like better disposal of solids, easy mixing and complete drainage of solvents such as viscous liquids in industries. In conical tank non-linearity exists due to its variation in cross-sectional area. Because of the non-linearity, level control is a challenging task in conical tank and it demands for implementation in real time. The nonlinearities also exists due to the saturation-type introduced by maximum or minimum allowed level in tanks, valve geometry, flow dynamics, pumps and valves.

The most basic and pervasive control algorithm used in the feedback control is the Proportional Integral and Derivative (PID) control algorithm. PID control is a widely used control strategy to control most of the industrial automation processes because of its remarkable efficiency, simplicity of implementation and broad applicability. Long history of its practical use and proficient working dynamics are some of the pivotal reasons behind the large acceptance of the PID control. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then providing a corrective action that can adjust the process accordingly.

In this paper, the modeling of the system, calibration of various transmitters associated with the conical tank system, tuning of PID parameters for the level control of a conical tank setup is considered. The open loop test is performed to obtain Process Reaction Curve and mathematical model of the process. Based on the mathematical model, gain tuning of the PID controller is done using Cohen Coon tuning method which is implemented in the real time system to get optimum settling time and rise time.

The IMC design procedure can be used to solve quite a few critical problems especially at the industrial level (using the concept of designing a model of the actual plant process). It also gives good solutions to processes having a significant time delay which actually happens when working in a real time environment. For tuning the controller the filter tuning parameter λ (lambda) value is varied, and it also compromises the various effects of

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discrepancies that enter the system, and thus best performance is achieved. Hence, a good filter structure is one for which the optimum λ value gives the best PID performance.

The IMC structure can be rearranged to design feedback controllers of the PID-type. When a process has no time delays we obtain same performance for both IMC based PID controller as well as the IMC .Existence of a RHP zero implies that a RHP zero must also be present for the specified closed loop response and IMC based PID procedure gives a satisfactory method to handle this. Also standard IMC filter has the advantage of good set point tracking. Although IMC design procedure is like the design procedure of open loop control system, the implementation of IMC is such that it results in being implemented as a feedback system. Thus, IMC has the added advantage of ability to compensate for model uncertainty and disturbances that open loop control does not have. But detuning of the IMC is also important if there is model uncertainty for assured stability and performance.

The implementation of the Internal Model Control in water tank level control system can be used to overcome this problem. By doing some modifications the problem can be solved by using cheapest and simplest possible controller for a given application. The basic idea is still the same and the modification will be made depending upon the design expectation. One interesting feature of this water tank system is that the tank empties much more slowly than it fills up because of the specific value of the outflow diameter pipe. By testing the system in this simulation area, the expected output from the input can be set earlier based on the rules set. Using MATLAB card is significant in order to integrate the software and hardware parts of the system.

II. PROPOSED WORK

The level process station was used to conduct the experiments and collect the data. The computer acts as a controller [3].It consists of the software used to control the level process station. The setup consists of a process tank, reservoir tank, control valve, I to P converter, level sensor and pneumatic signals from the compressor. When the set up is Switched on, level sensor senses the actual level values initially then signal is converted to current signal in the range 4 to 20mA.This signal is then given computer through data acquisition cord. Based on the values entered in the controller Settings and the set point the computer will take control action the signal sent by the computer is taken to the station again through the cord. This signal is then converted to pressure signal using I to P converter. Then the pressure signal acts on a control value which controls the flow of water in to the tank there by controlling the level.

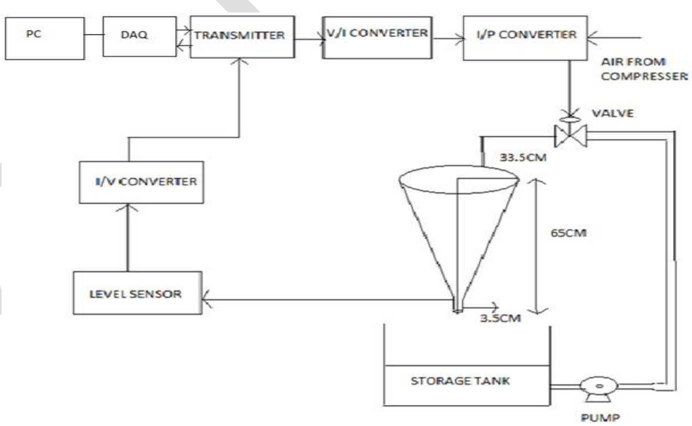

Figure 1: Level Control of Conical Tank System

A. Description of the Conical –Tank Level Process

The tank is made up of stainless steel body and is mounted over a stand vertically. Water enters the tank from the top and leaves the bottom to the storage tank. The System specifications of the tank are as follows,

Table 1 Specifications of Proposed System

S.NO.	PART NAME	DETAILS
1.	Conical Tank	Material: Stainless Steel ; Diameter: 610 mm; Height: 640 mm (LRV= 727 mmH_2O, URV=1367 mmH_2O) ; Volume: 42 liters
2.	Pump	Monoset , 1Φ , Size:25x25mm , kW/HP: 0.37/0.5 , V/A: 220V/2.5A, 50Hz.
3.	DPT for level measurement (LT)	Yokogawa: EJA 110A, supply: 10.5-42V DC, Output: 4 to 20 mA +HART, Range: 0 to 1000mmH_2O.
4.	Flow meters (Electromagnetic)	Inlet side: Yokogawa-SE202MJ, Supply: 200-240V AC, 47 to 63 Hz, Output: 4 to 20mA +HART, Outlet side: AXF015G Supply: 100-120V AC, 50/60Hz Output: 4 to 20mA
5.	Control valves	Inlet side: Linear, Air to open, Body: 1”, Trim 3/4”
		Outlet side: Equal %, Air to open, Body: 3/4”, Trim: 1/2”
6.	Rotameter	0 to 30 lpm
7.	E/P converter	Yokogawa: PK200 Input:4-20 mA, 20 psi Output: 3 to 15 psi
8	NI USB 6211 DAQ	Analog input: 8, Analog output: 2, Resolution: 16 bits, Sampling rate: 250kS/s Input & Output voltage:10V to +10V

B. Mathematical model for conical tank system

The conical tank system exhibits non-linear behavior due to variation on its shape. The layout of the system is shown in the Figure 2. (Process Tank 2 i.e. top right side tank is considered for the proposed work)

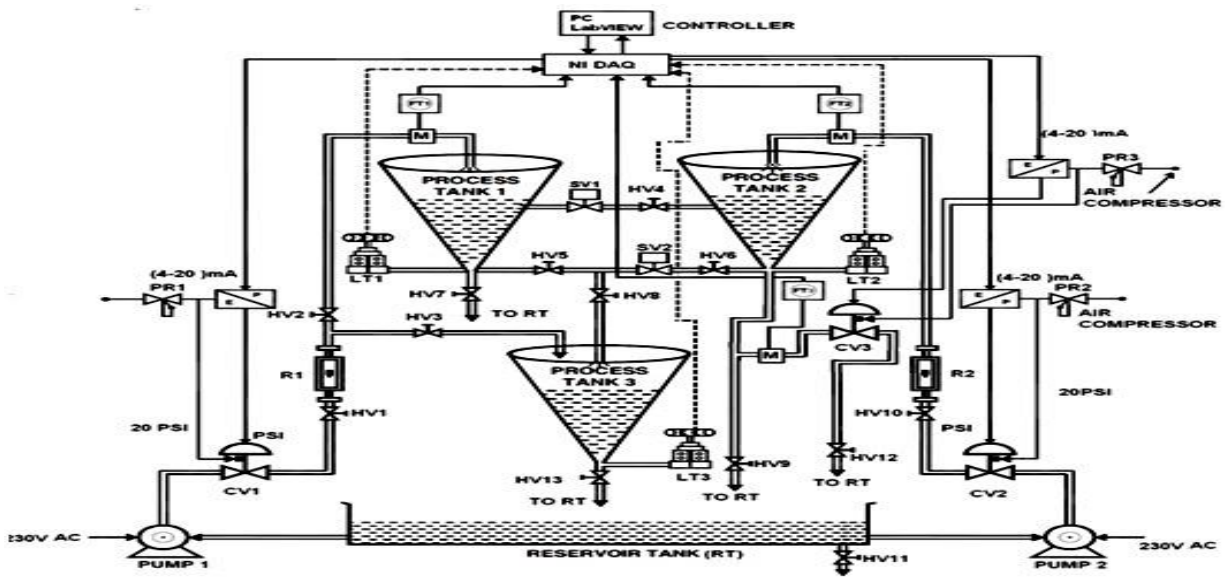

Figure 2. Layout of Conical Tank System.

C. Conical tank system

The real time system consists of one input (inflow) and one output (level of the tank). The inflow is taken from a reservoir tank through a centrifugal pump with single phase motor. The inlet pipe has a Rotameter, Electromagnetic type flow meter called as Flow Transmitter (FT1), air-to-open type pneumatic Control Valve (CV) and a hand valve to monitor and control the flow rate. The outlet has a hand valve, Electromagnetic type flow meter called as Flow Transmitter (FT2) and air-to-open type pneumatic CV.

The tank level is measured using a DPT, called as Level transmitter (LT). The level in the tank is directly proportional to the pressure created by liquid in it. LT measures the level by measuring pressure at bottom of the tank with reference to the atmosphere and coverts into an electrical quantity (4 to 20 mA). The LT is energized with 24V DC source and Lower Rage Value (LRV) & Upper Range Value (URV) are set using a Highway Addressable Remote Transducer (HART) communicator. The system is interfaced to the computer through NI USB 6211 data acquisition card (NI DAQ) and it can handle a maximum of 10 V, so the DPT outputs (4 to 20 mA) are converted into 2 to 10V using a 500Ω resistances and scaled up using LabVIEW. The controller signals (0 to 10V) from computer via NI DAQ is converted into 4 to 20 mA using a voltage to current convertor and given to current to pressure (E/P) convertor. The pneumatic line from the compressor is connected to an air regulator and its output is given as constant inputs (20 psi) for two different E/P converters. The CVs are operated based on the pneumatic outputs from E/Ps.

D. Process Modeling

The process modeling of the conical tank system is given by mathematical mass- balance equation (5)

Volume of the cone:

$$V = \frac{1}{3}\pi r^2 \mathrm{h} = \frac{1}{3}\mathrm{Ah} \qquad ------\rightarrow \qquad (1)$$

Where area of the circle:

$$A = \pi r^2 \qquad ------\rightarrow \qquad (2)$$

Differentiating the equation (1) with respect to time t,

$$\frac{dv}{dt} = \frac{1}{3}\left[A\frac{dh}{dt} + h\frac{dA}{dt}\right] \quad ------\rightarrow \quad (3)$$

From the figure 3, by applying similarity theorem

$\tan\theta = \frac{R}{H}$ and $r = \frac{Rh}{H}$

By substituting R in equation (2) and A in equation (3)

$$\frac{dv}{dt} = A\frac{dh}{dt} \quad ------\rightarrow \quad (4)$$

Change in volume

$$=F_{in} - F_{out} = \frac{dv}{dt} = A\frac{dh}{dt} \quad ------\rightarrow \quad (5)$$

$$F_{in} - \frac{h}{R_v} = A\frac{dh}{dt}$$

$$F_{in} = A\frac{dh}{dt} + \frac{h}{R_v} \quad ------\rightarrow \quad (6)$$

Taking Laplace transform for the equation (6)

$$F_{in}(s) = AsH(s) + \frac{H(s)}{R_v} \quad ------\rightarrow \quad (7)$$

Rearranging equation (7)

$$\frac{H(s)}{F_{in}(s)} = \frac{R_V}{1 + AR_v s} = \frac{k}{1 + \tau s}$$

Where R_v= valve resistance F_{in} = input flow rate, F_{out} = output flow rate, C= Valve constant, A= cross sectional area, H = overall height of the tank, h= Actual level of liquid, R = Radius of the tank, r = Variable radius with respect to actual level of liquid

E. System Identification

The step response based open loop test is commonly adopted procedure for system identification. The process reaction curve is obtained by performing an open loop step test on the real time process and model parameters are identified from the curve. LabVIEW platform is used to code the logic and the process is allowed settle at 0 mm by assigning random gain to the PI controller in closed loop and the LabVIEW Program stores flow rate with the help of FT1. Now the loop is made open and flow rate is increased by P% from the stored value using LabVIEW based soft switching, which isolates the controller and the level starts increasing from 0 mm after a considerable delay called delay time. Each 400 millisecond the level is stored in a file for further analysis and it is allowed to settle through self regulation. The flow increment P% is selected therefore to make the level to reach more than half of the tank (>21.5 mm) for obtaining single mathematical model or only one set of PID parameters for the conical tank system.

The First Order Process with Time Delay (FOPTD) model

$$G(s) = (K_p e^{(-tds)})/(1+\tau s)$$

K_p= $(\%\ change\ in\ \ output\ )/\ (\%\ change\ in\ input\ )$

$=Q/P$= 64.08

Time constant (τ)=960 seconds

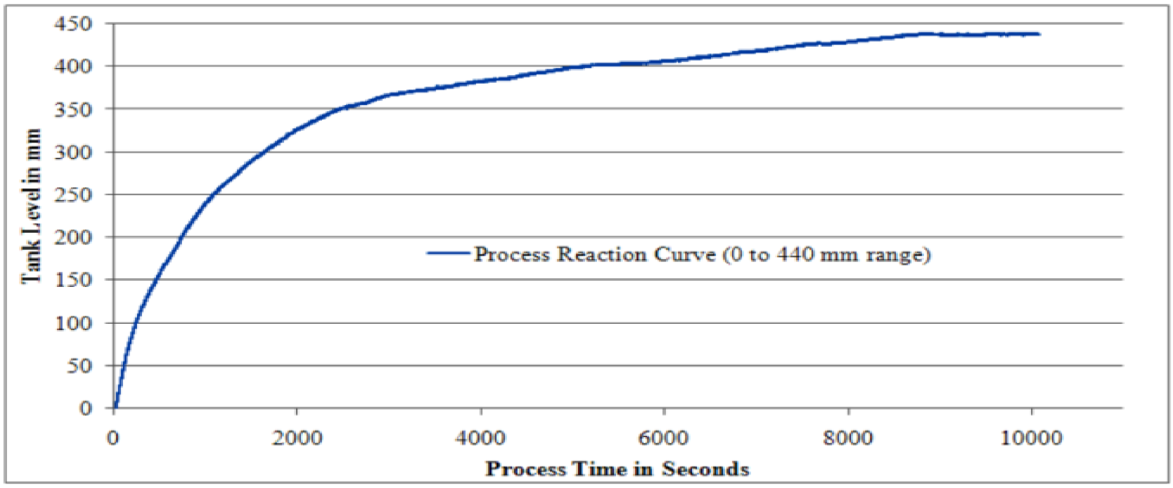

Figure 3. open loop response of conical tank system for 0 to 440mm range

F. Coohen Coon Tuning for PID parameters

Proportional gain:

$$K_c = \frac{1}{K}\frac{\tau}{\tau_d}\left(\frac{4}{3}+\frac{\tau_d}{4\tau_d}\right)$$

=0.91186

Integral Gain

$$\tau_I = \tau_d \frac{32 + 6\,\frac{\tau_d}{\tau}}{13 + 8\frac{\tau_d}{\tau}}$$

=0.01865

Derivative Gain,

$$\tau_D = \tau_d \frac{4}{11 + 2\frac{\tau_d}{\tau}}$$

Table 2 Comparison between PID, IMC, and IMC based PID

Set point(cm)	Controller	Rise time(secs)	Settling time(secs)
30	PID	12	65
	IMC	12	16
	IMC based PID	4	11

III. IMC BASED PID CONTROLLER

The ability of proportional-integral (PI) and Proportional-Integral-Derivative (PID) controllers to meet most of the control objectives has led to their widespread acceptance in the control industry. It is because, for practical applications or an actual process in industries PID controller algorithm is simple and robust to handle the model inaccuracies. This error becomes severe for the process with time delay. For this I have taken transfer function with time delay.

The distinguishing characteristic of IMC structure is the incorporation of the process model which is in parallel with the actual process or the plant

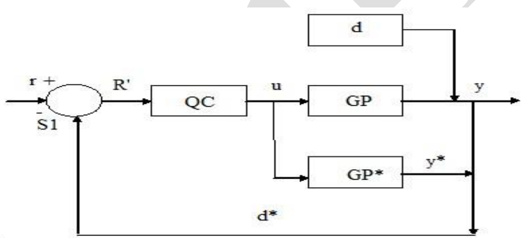

Figure 4 schematic diagram for IMC process.

IV. SIMULATION RESULT

The Simulation for Conventional (PID) controller, Internal model Controller and Internal model controller based PID controller for liquid level control is as shown in the figure

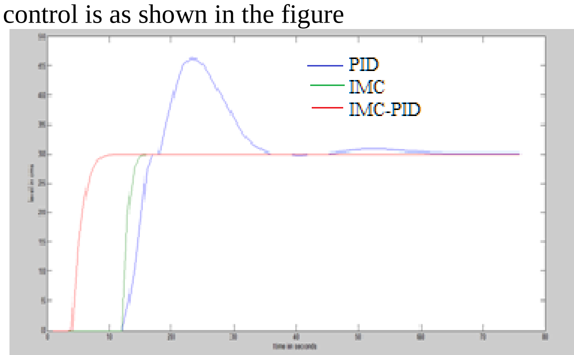

Figure 5 Simulink graph model for using PID controller, Internal model Controller and Internal Model Controller based PID controller

V.CONCLUSION

The mathematical model for the conical tank system is derived using process reaction curve method. The gain of the PID controller is tuned using Cohen Coon method. The PID, IMC and IMC based PID controller performance are simulated in MATLAB. For practical applications or an actual process in industries IMC based PID controller algorithm is simple and robust to handle the model inaccuracies and hence using IMC- PID tuning method a clear trade-off between closed-loop performance and robustness to model inaccuracies is achieved with a single tuning parameter. It also provides a better solution to the process with significant time delays which is actually the case with working in real time environment. The IMC PID controller achieve better performance by tuning the optimum filter tuning factor λ (lambda). Thus, what we mean by the best filter structure is the filter that gives the better PID performance for the optimum λ value. Also the standard IMC filter results in good set point response performances. The simulation results shows the IMC based PID controller have minimum settling time and rise time in order to reach steady state value when compare to conventional controller.

FUTURE SCOPE

The future scope is to analyse the process reaction curve method using system identification tool in MATLAB and to implement the IMC-PID in the real time non-linear process. In order to achieve robustness the IMC-PID controller is extended with the fractional order IMC-PID controller for the non-linear process.

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