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Internal Model Control and Fuzzy Based PID Controller for Non-Linear Spherical Tank

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ABSTRACT: In process industry the control of fluid level is required. The control of nonlinear process is difficult task. Numerous procedures are utilizing in spherical shaped tanks in contributes better waste for slurries and thick fluids. Thus, control of spherical shaped tank level is a testing undertaking because of its non-linearity and constantly changing cross-segment. This is because of connection between controlled variable level and controlled variable stream rate, which has a square root relationship. The primary goal is to execute the appropriate controller for spherical tank system to keep up the coveted level. System identification for the non-linear process is finished utilizing black box modeling and observed to be first order plus dead time (FOPDT) method. In this paper it is proposed to acquire the response of IMC based PID and fuzzy logic controller (FLC) based PID tuning for spherical tank system and to examine the system and the simulation results shows the Minimum rise time, Minimum peak time, minimum settling and Minimum integral square error (ISE).

KEY WORDS: First order plus dead time, IMC, PID, Spherical tank, Fuzzy, Integral square error, Nonlinear process.

I. INTRODUCTION

The control of nonlinear system has been a noteworthy research point and numerous methodologies have been proposed. In the majority of the process industry controlling of level, stream, temperature, flow and pressure is necessary. In Industry the process plant structure in the form of linear and non-linear. Control of process is a testing errand for a few reasons because of their nonlinear conduct, dubious and time differing parameters, imperatives on controlled variable, communication amongst controlled and controlled factors, unsettling influences, dead time on input and estimations [1]. The control of fluid level in tanks and stream between the tanks is a fundamental in process enterprises. In level control process, the tank structure like round and hollow, cubical are straight one, however that sort of tanks does not gives a total drainage. For complete drainage of liquids, a conical shaped tank or spherical tank is utilized as a part of a portion of the process industry, where its nonlinearity may be at the base just on account of spherical base tank. The drainage effectiveness can be enhanced further if the tank is completely spherical in shape. In numerous procedures, for example, refining segments, evaporators, re-boilers and blending tanks, the specific level of fluid in the vessel is of incredible significance in process task [5]. A level that is too high may response equilibria, make harm gear or result in spillage of important or unsafe material. On the off chance that the level is too low it might have terrible outcomes for the successive tasks. So control of fluid level is a vital and successive assignment in process ventures. Level of fluid is wanted to keep up at a consistent esteem. This is accomplished by controlling the input stream. The control variable is the level in a tank and the controlled variable is the inflow to the tank. Spherical tanks find wide applications in process industries like wastewater treatment industry.

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II. PROPOSED WORK

A. Experimental setup

The control of spherical tank is enormously nonlinear because of the variety of cross sectional territory. The inflow of the tank is controlled variable i.e., level is controller variable. The level in the process tank is utilized to detect by level sensor and sustained into the signal conditioning unit. The control process made with PCs. The spherical tank level process station is controlled by an assistance of programming experimental setup is shown in the Figure.1. The real time process is interface using LabVIEW software [2] [3]. The Figure.2 comprises of a process tank, supply tank, control valve, I to P converter, level sensor and pneumatic signals from the compressor. At the point when the process is switched on, the actual level is estimated by level sensors; fundamentally the signal is changed over to current signal in the standard range between 4 to 20mA.Thus the current signal is next given to the PC in course of data acquisition cord. Based on the controller parameters and the set point esteem, the PC will get subsequent control activity and the signal is transmit to I/P converter. Presently by utilizing I/P converter the signals are changed over to pressure signal and the pressure signal acts as a control valve and inlet stream of water on to the tank is controls [4].

Figure.1 Experimental setup of spherical tank

Capacitive type level sensor is utilized to detect the level from the process and converts into electrical signal. At that point the electrical signal is sustained to I/V converter which thus delivers equal voltage signal to the PC. The accurate storage tank of water level is detected by the level transmitter is feedback to the level controller and contrasted with a preferred level with produce the required control activity that will find the level control as expected to hold the coveted level. The control activity chooses by the controller and it is given to change over V/I and alongside I/P converter. The final control component (pneumatic control valve) is currently controlled by the resulting air pressure. This thus controls the inflow to the spherical tank and the level is maintained. The tank is made totally of stainless steel body and is develop over a stand vertically. From the top water enters the tank and leaves at the base of the tank reached to the storage tank [6] [7].

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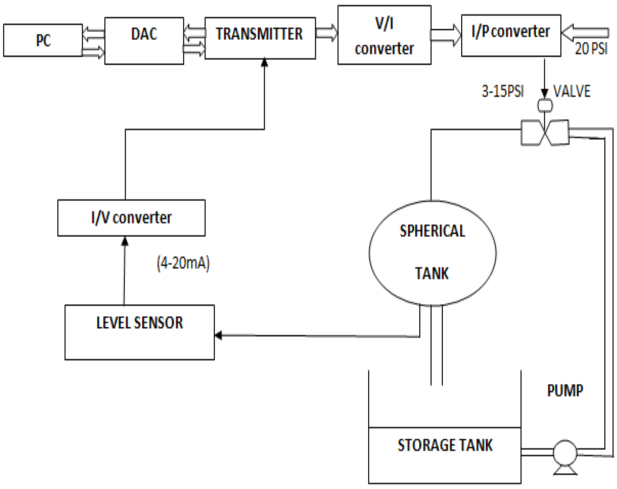

Figure.2 Level Control of Spherical Tank System

B. Mathematical Modelling

The spherical tank in Figure.2 is fundamentally a system with nonlinear dynamics. The nonlinear dynamics illustrated by first-order differential equation. Figure.3 shows the schematic model for spherical tank.

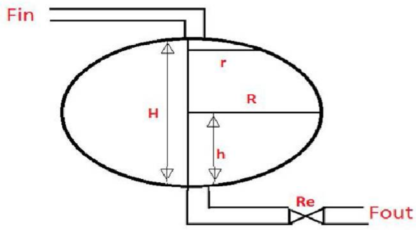

Figure.3 Schematic Diagram of Spherical Tank

$\frac{dv}{dt} = F_{in}\text{-}F_{out}$ … (1)

Where V is the volume of the tank, Fin is the inlet flow and Fout is the output flow.

Volume of sphere (V) = $\frac{4}{3}\pi R^{3}$ … (2)

Area of sphere (A) = $4\pi R^2$ … (3)

$V = \frac{1}{3}[AR] = \frac{1}{3}[Ah]$

Differentiating with respect to time (t)

$\frac{dv}{dt} = \frac{1}{3}\left[A\frac{dh}{dt} + h\frac{dA}{dt}\right]$ … (4)

From the diagram $\frac{R}{r} = \frac{h}{H}$

Area (A) = $4\pi\left(\frac{h}{H}r\right)^{2}$

Differentiating with respect to time (t)

$\frac{dA}{dt} = 8\pi\left(\frac{r}{H}\right)^{2} h\frac{dh}{dt}$ … (5)

Substitute 5 in 4

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$\frac{dv}{dt} = \frac{1}{3}[A\frac{dh}{dt} + 8\pi\,(\frac{r}{H})\,h^{2}\,\frac{dh}{dt}]$

$\frac{dv}{dt} = \frac{1}{3}\frac{dh}{dt}[A+8\pi\,(\frac{r}{H}h)^{2}$

$\frac{dv}{dt} = \frac{1}{3}\frac{dh}{dt}[A+8\pi R^{2}]$ $\quad (\frac{R}{r} = \frac{h}{\pi})$

$\frac{dv}{dt} = \frac{1}{3}\frac{dh}{dt}[A + 2A]$

$\frac{dv}{dt} = A\frac{dh}{dt}$ (Mass balance equation) … (6)

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

$F_{out} = \frac{Height}{resistance} = \frac{h}{Re}$

$F_{in} = A\frac{dh}{dt} + \frac{h}{Re}$

Taking Laplace transform

F_{in} (S) Re H(S) S + H(S)

$\frac{H(S)}{Fin(S)} = \frac{Re}{A(Re)s+1}$

$\frac{H(S)}{Fin(S)} = \frac{K}{\tau s+1}$ … (7) (K= Re, τ = ARe)

$\frac{H(S)}{Fin(S)} = \frac{Ke^{-\tau ds}}{\tau s+1}$ (τd = time delay)

C. Tank Specification

Height of the spherical tank	=	43cm
Diameter of the spherical tank	=	151.73 cm
The Measured values are,		
LRV (Lowe Range Value)	=	44cm
URV (Upper range value	=	87cm
Process variable	=	99.87%

Height of the spherical tank = URV-LRV=43 cm

D. Calculation of Process parameters

Maximum flow	=	1500 lph
Initial flow	=	438 lph
Final flow	=	468 lph
% of Change in flow	=	$\frac{30*100}{1500} = 2$
Maximum level	=	430mm
Initial level	=	200 mm
Final level	=	254 mm
Change in level	=	54mm

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% of change in level	=	$\frac{54*100}{430}$ =12.55
Kp = $\frac{\text{\% of change in level}}{\text{\% of change in flow}}$	=	12.55/2
	=	6.279
Kp	=	6.279
T = 1.5(t2-t1)	=	1.5(1841.89-1461.89)
T	=	570
Td	=	4.5s

E. Open loop test

The open loop response is the system response of the spherical tank without any feedback is shown in the Figure.4. The selection of the model could be founded on the state of the open-loop step response. The open loop step response is acquired by giving advance contribution to the inflow control valve to give ideal course through the control valve with the goal that the response can be approved for the entire range. The open loop response is plotted and the values obtained from plot like percentage change in level (Q%), delay time (t_d), the time taken by the level are used for getting mathematical model of the spherical tank [8].

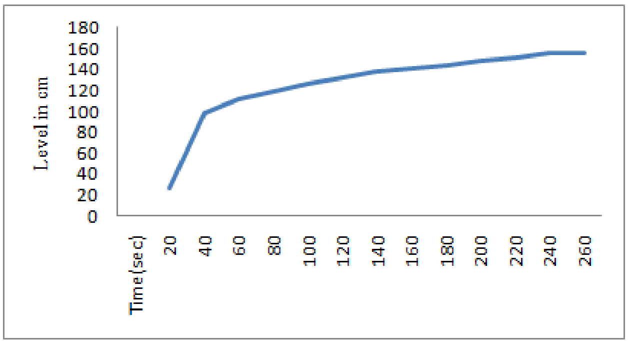

Figure.4 Open loop response

The First Order Process with Time Delay (FOPTD) model $G(s) = \frac{K_p e^{-t_d s}}{\tau s+1}$ … (7)

Time constant τ=570seconds

$$K_p = \frac{\text{\% change in output}}{\text{\% change in input}} = \frac{Q}{P} = 6.279$$

$$G(s) = \frac{6.278e^{-11s}}{570s + 1}$$

G(s) indicated above is the obtained mathematical model for the entire operating range of spherical tank system.

III. CONTROLLER DESIGN

A. IMC based PID tuning

Internal Model Control (IMC) is a normally used to gives a straightforward mode to the plan and tuning of different sorts of control. The ability of proportional-integral (PI) and proportional-integral-derivative (PID) controllers to meet the greater part of the control goals has prompted their across the board acknowledgment in the control industry is shown in the Figure.5.

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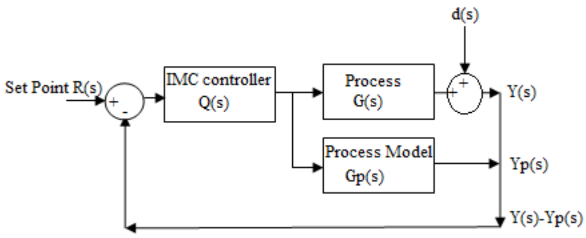

Figure.5 IMC structure

In industry PID control is simple and which gives inaccuracies. In proposed work IMC based PID tuning method is used. The IMC-based PID tuning provides good set point tracking compared to conventional tuning method. Hence, this method rejects the disturbance. The IMC design procedure is same like open loop procedure but it gives disturbance and some uncertainties to remove IMC filter parameter λ is used to minimize the uncertainties [9] [10].
Consider a process model Gp(s) is the actual process. The controller Q(s) is used to control the process in which the disturbances d(s) enter into the system.

$F(s) = \frac{1}{\lambda s+1}$ … (8)

λ is the filter tuning parameter to remove the uncertainties in the model,

$g(s) = \frac{Q'(s)}{1-Gp(s)q(s)}$ … (9)

PID equivalent,

$g(s) = \frac{Q(s)f(s)}{1-G(s)+(s)f(s)}$ … (10)

It is compared with conventional PID

$$PID = k_c\left(1 + \frac{1}{T_i s} + ST_d\right)$$

$$K_c = \frac{\tau + \frac{\theta}{2}}{K\left(\lambda + \frac{\theta}{2}\right)}$$

$$T_i = \frac{\theta}{2} + \tau$$

$$T_d = \frac{\frac{\theta}{2} + \tau}{2\left(\frac{\theta}{2} + \tau\right)}$$

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B. Fuzzy based PID tuning

In the proposed work the level control for spherical tank is done by PID, IMC based PID and Fuzzy based PID the Kp, Ki, Kd three parameters are tuned. The design of Fuzzy inference is done by SIMULINK [11] [13].

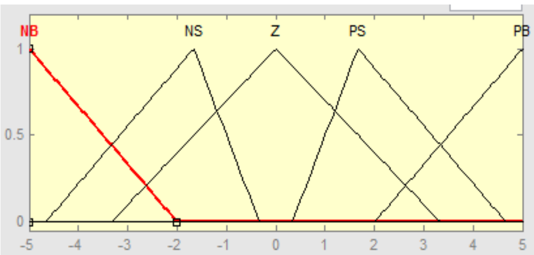

Figure.6 Membership function input variable “error”

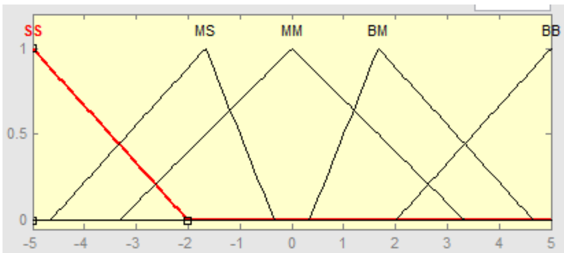

Figure.7 Membership function input variable “change in error”

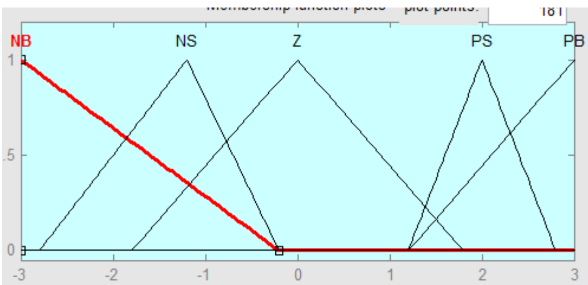

Figure.8 Membership functions output variable “controller”

The two variables input are designed in membership function error (e) and change in error (ce) and the output variable controller (u) is shown in the Figure.6, 7 and 8. The FLC method consists of four parts Fuzzification, membership functions, Rules and defuzzification. The fuzzy linguistic variables and membership function design is known as fuzzification. An inference is based on set of rules. The resultant output mapped to a crisp output of fuzzy using the membership function is known as defuzzification [12].

IV. SIMULATION RESULTS

The simulation result performances is done by MATLAB/SIMULINK the system identification by real time process of spherical tank and acquire the transfer function based on transfer function from the process station results taken.

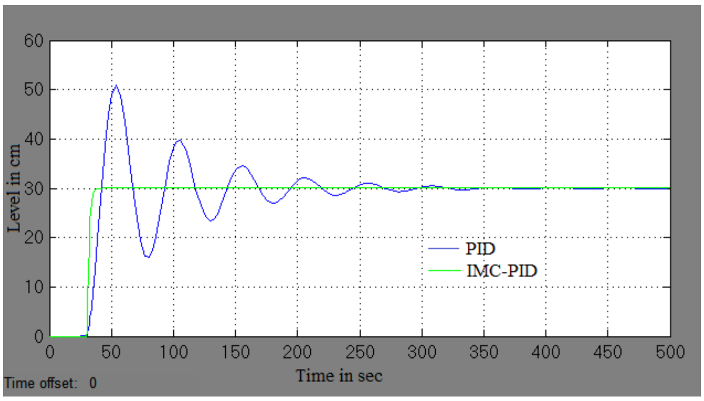

Figure.9 PID vs IMC-PID

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Figure.9 shows the comparison results of PID and IMC based PID control from the simulation result in PID oscillation is maximum and by filtering parameter λ there is no oscillation in IMC based PID tuning. In which the PID is tuned by Cohen-coon method.

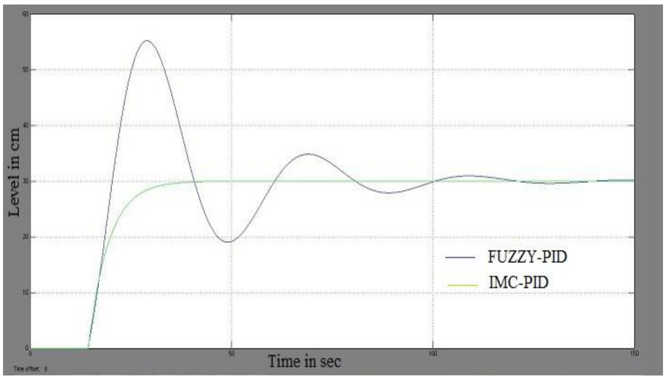

Figure.10 Fuzzy-PID vs IMC-PID

Figure.10 shows the comparison result of Fuzzy-PID and IMC based PID control from the simulation result the Fuzzy based PID control provides oscillation when compared to IMC there is no oscillation and the set point of IMC reaches at faster rates.

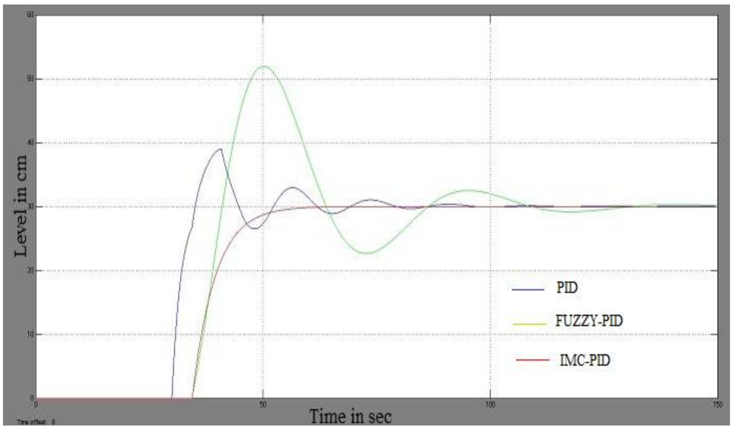

Figure.11 Comparison of PID, Fuzzy-PID, IMC-PID

Figure.11 shows the comparison results of three controllers based on the simulation result IMC based PID not provide oscillation when compared to Convention PID and Fuzzy based PID method. Table I shows the performance of three controllers.

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TABLE I. PERFORMANCE INDICES FOR LEVEL PROCESS

Parameters	IMC Based PID tuning	Fuzzy Based PID tuning	Cohen-coon tuning method
Rise time (sec)	7	10	12
Settling time (sec)	15	66	75
ISE	20.57	31.42	42

V. CONCLUSION

The gain of the PID tuning is done by using Cohen-coon tuning method. The above simulation result is simulated by using MATLAB/SIMULINK. The IMC provides better output by the filter parameter λ. Fuzzy provides good set point tracking but provides oscillation. The better performance and high control accuracy is achieved by using IMC controller. By using IMC the PID provides better settling point of faster response for the spherical tank process. The simulation result performance indices of the proposed PID by tuned IMC provides Minimum rise time, Minimum settling time and Minimum integral square error compared to Fuzzy tuned PID and Cohen-coon tuned PID.

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