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SPHERICAL TANK LEVEL CONTROL SYSTEM USING CONVENTIONAL & INTELLIGENT CONTROL STRATEGIES

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ABSTRACT*--The process industry frontages the problem of controlling the process parameters, which is considered as the most critical problem in the industrial scenario. Hence, in this paper, the liquid level control in spherical tank is considered as the control parameter. In spherical tank, the area of cross section of the tank varies nonlinear as the height of the tank changes, which changes the shape of the liquid level in a nonlinear manner in the spherical tank.Level control of this nonlinear process is done using conventional (PI) and intelligent controllers (fuzzy & neural). Here the performance of each type of controllers is evaluated using the time integral criteria. The process was modelled by deriving the mathematical model and further steps were implemented in matlab and labview out of the different controllers used, fuzzy controller outperforms PI and neural controllers in terms of smooth response to servo and regulatory changes and produces lower values of performance indices.*

Keyword -- *fuzzy, level ,math model, neural, PI controller, spherical tank.*

I. INTRODUCTION

The control problems in process industries presents many challenges due to their dynamic behavior, the presence of time varying parameters, uncertain parameter variations, constraints imposed on manipulated variable, interaction among manipulated and controlled variables, unmeasured and frequent disturbances, dead time on input and measurements.

The spherical tanks are most widely used in process industries to handle various liquids and gases. Since, the chemical process industries inherent the non linearity property, leads to the requirement of different control techniques. Spherical tanks are most widely used in oil and gas plants. As the shape of the spherical exhibits nonlinearity, control of level in a spherical tank is important.

The control of liquid level in a spherical tank is highly nonlinear. The PID control algorithm is used in the feedback control to control the non-linearity in spherical tank, PID control is the most widely used control strategy in industrial processes due to its wide range of operating conditions. PID fully eliminates steady state error, provides good stability and fast response. PID is approximated by a first-order time-delayed model. PID provides

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functional simplicity and evaluates the effects of uncertainties in the process parameters based on frequency domain approach using normalized open loop transfer function, remarkable efficacy and control system robustness.

Fuzzy Logic is a problem-solving control system methodology. It is a smart way to control process parameters. Fuzzy logic allows membership functions, or degrees of reliability and falsehoods. Not only 0 and 1with Boolean logic, but all the numbers that fall in between.

An Artificial Neural network (ANN) is an arrangement of collection neurons in a specific configuration. It is a **parallel processor** that can estimate or compute any function. Basically in an ANN, knowledge is stored in memory which is referred to as "NUMERIC DATA". **ANN is taught through training. All the way through repeated training of ANN,** a stage is reached where it has 'learned' a desired function.

A. MATHEMATICAL MODEL

The spherical tank system shown in Fig1 is in essence a system with nonlinear dynamics.

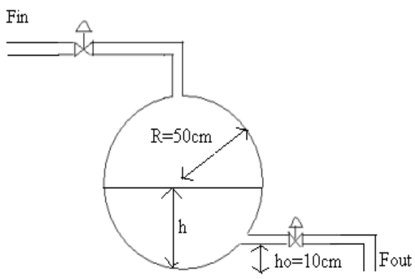

Figure 1: Spherical Tank

The spherical tank has a maximum height of 100cm and maximum radius of 50cm.

- R tank Radius
- h liquid level height in the tank
- Fin inflow to the tank
- F out outflow from the tank
- Ho height of the outlet Pipe from the ground

The mass balance equation for the tank level at any instant of time is givenas:

System accumulation is given by = inflow - outflow

(i.e) dv/dt = Fin–Fout -------(1)

Using the above equations we get our math model as follows :

$$\mathbf{dh/dt = (F_{in} - F_{out}) / \{ \pi R^2 [1 - (R-h)^2/R^2] \}}$$

Where Fout=cd *a *sqrt [2g(h-ho)] --(2)

II. STEADY STATE CHARACTERISTICS

In this paper, mathematical model for controlling the liquid level is derived for a spherical tank. Using this model the open loop response is taken such that for each inflow the liquid settles at a particular level. From the mathematical model derived above ,we have plotted the steady state graph (inflow vslevel,inflowvs time) in fig 1 and fig 2. This(parabolic curve) proves that spherical tank exhibits non linearity.

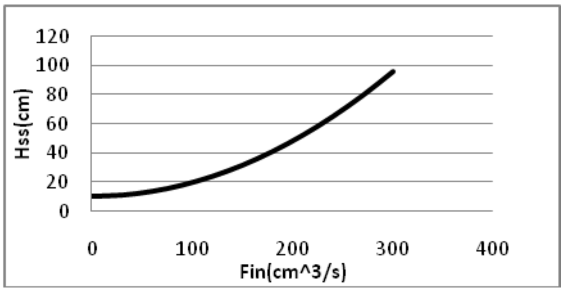

Figure 2.1: F_{in} VsHss

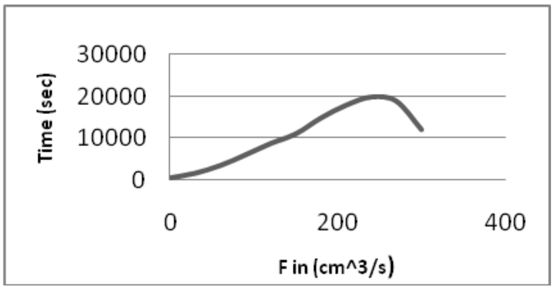

Figure 2.2: F_{in} Vs Time

III. P R O P O S E D C O N T R O L S C H E M E

A. PI CONTROLLER

To compute the "error" value, a basic A proportional–integral controller (PI controller) is used in the feedback control loopin industrial control applications The "error" value is taken as the variation between a measured process variable and a desired set point. The controller attempts to reduce the error by adjusting the process control inputs. Defining u(t), as the controller output, the final form of the PI algorithm is:

$$u(t) = Kp.e(t) + Ki.\int_{to}^{t} e(t)u(t) = Kp.e(t) + Ki.\int_{to}^{t} e(t)$$

where

Kp: Proportional gain, Ki: Integral gain

e(t): Error =SP-PV

t: instantaneous time

to: past time

The steady state graph (Fig 2.1) is linearised into many regions. For a non-linear system, Piece-wise linearization has to be done to implement the conventional PI controller. The linearization is done by dividing the whole non linear process into 4 linear regions by drawing tangents along the process reaction curve.

After this for each region the process parameters such as time constant, time delay , and the process gain are calculated separately and the transfer function for each region is obtained. The process parameters for each region is found using the following formulas and tabulated the readings as shown in table 1.

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Process gain $= \frac{Steady\ state\ output}{Steady\ state\ input}$

Time constant Tp = 1.5* (t1 - t2)

Time delay td = t2 – Tp

Where

t1 time at 28.3% of the max height

t2 time at 63.2% of the max height

Table 1: Process Parameters

REGION	HEIGHT	K	Tp	Td	TRANSFER FUNCTION
1	10-15	0.224	322.5	967.5	$\frac{0.224e^{-967.5s}}{322.5s+1}$
2	15-26	0.1997	900	800	$\frac{0.997e^{-800s}}{900s+1}$
3	26-52	0.249	2310	630	$\frac{0.249e^{-630s}}{2310s+1}$
4	52-99	0.321	3712.5	487.5	$\frac{0.321e^{-487s}}{3712.5s+1}$

IV. PI TUNING

For our process 'COHEN COON' tuning method is used to determine the control constants Kp& Ki for each region from the process parameters obtained.

They are given by the formulae:

Kp=1/K.tp/td.(0.9+td/12tp)

ti=td.((30+3td/tp))/((9+20td/tp))

Table 2: Tuning Parameters

REGION	RANGE	Kp	ti
1	10-15	1.71	0.00182
2	15-26	5.41	0.00102
3	26-52	13.59	0.00074
4	52-96	21.61	0.00078

Changes in the set point are given to the process and the change in set point is tracked by the outputand is observed as shown in fig 3

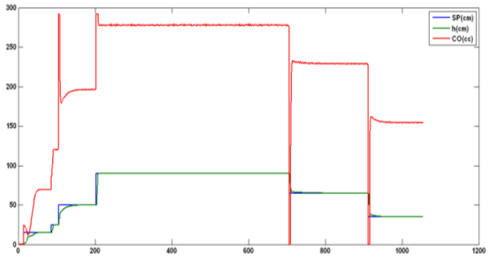

Figure 3: PI Response (multistep**)**

B. NEURAL CONTROLLER

In this type of controller, neural networks are regulated, or trained, so that a specific input leads to a specific target output. The neural network is adjusteduntil the network output matches the target. Typically, many such input/target match up are required to train a network.

The Neural network is constructed using Network/Data Manager of MATLAB using the n ntool command. The multiplexed format of the set point (SP), error(e) and integrated error(inte) are supplied as the input. The controller output(Fin)is set as the target data.

The trained network is associated to the mathematical model of spherical tank process.

Changes in the set point are given to the process and the change in set point is tracked by the output and is observed as shown in in Fig 5.

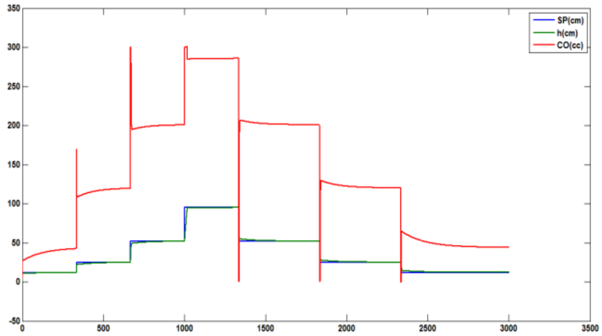

Figure 5: Neural Response (multistep)

C.FUZZY CONTROLLER

The nonlinear functions can be modeled using Fuzzy logic. Fuzzy logic is based on ordinary language and is easy to understand.

Initially, the membership functions are formed for each input variable (level and error at that instant of time) and output variable (flow). Using IF THEN ELSE the rule base is framed and the FUZZY INFERENCE SYSTEM(FIS) is used. The given input is mapped to a particular output using fuzzy logic. Using the process variables, the input and output variables, the data base is formed. By giving changes to input variables, the ranges are determined and are split into linguistic variables forming the membership functions and fuzzy rule base is developed.(Refer Fig 3 and Table 3)

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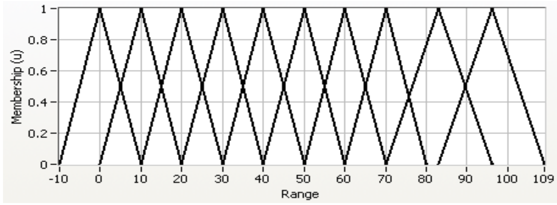

Figure 3.1: Memebership Function For Level(L)

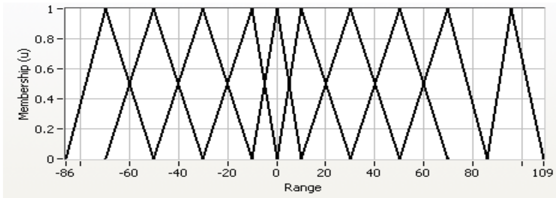

Figure 3.2: Membership Function For Error(E)

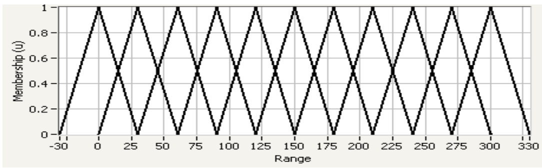

Fig 3.3: Membership Function For Flow(F)

Table 3: Rule base of fuzzy logic controller

	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**
L1	*	*	*	F1	F3		F11	F11	F11
L2	*	*	*	F1	F1	F11	F11	F11	F11
L3	*	*	*	F1	F5	F11	F11	F11	F11
L4	*	*	F1	F1	F6	F9	F11	F11	F11
L5	*	*	F1	F1	F7	F9	F11	*	*
L6	*	F1	F1	F1	F8	F9	F10	F11	*
L7	*	F1	F1	F1	F9	F9	F10	F11	*
L8	F1	F1	F1	F1	F10	F10	F10	F11	F11
L9	F1	F1	F1	F1	F11	F11	F11	F11	F11

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L10	F1	F1	F1	F1	F11	F11	F11	F11	F11

*Not Applicable

Each of the rule in the rule base is used to fire a particular control action, in order to control the spherical tank level (i.e. reach the desired set point).

Changes in the set point are given to the process and the change in set point is tracked by the output and is observed as shown in Fig 4.

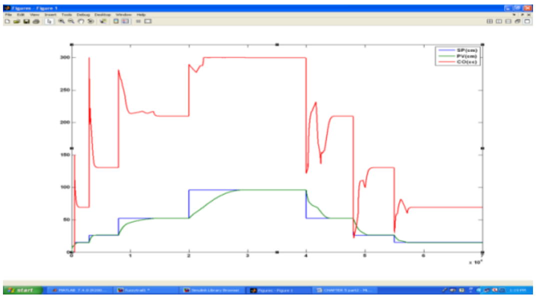

Figure 4: Fuzzy Response (multistep)

V. PERFORMANCE ANALYSIS

The performance of the controllers for the process is evaluated using the Time Integral Performance criteria. some of them include:

- IAE= $\int|e(t)|dt\int|e(t)|dt$

- Integral of the Absolute value of the Error

- ITAE= $\int t.|e(t)|dt\int t.|e(t)|dt$

-Integral of the Time weighted of the Absolute Error.

The values of each performance criterion for PId,fuzzy and neuro controllers are computed and tabulated in Table Once the values are calculated they are compared with each other and the controller that gives a better performance out of the three controllers used is chosen as the optimum controller.

Table 4: Performance Analysis

REGION		PI	NEURO	FUZZY
I(SP=12)	IAE	24350	57010	9600
	ITAE(10^5)	2093	114000	165.9
II(SP=20)	IAE	95100	125000	11510
	ITAE(10^5)	9700	249900	259
III(SP=45)	IAE	240000	234500	41690

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	ITAE(10^5)	103000	468900	2943
IV(SP=80)	IAE	304000	331800	216900
	ITAE(10^5)	65410	663500	28020

It is based on the response obtained as a result of servo and regulatory changes and also the IAE and ITAE values.\

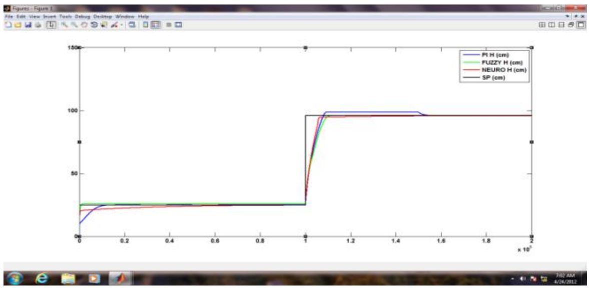

Figure 6.1: Set Point Tracking (Comparison**)**

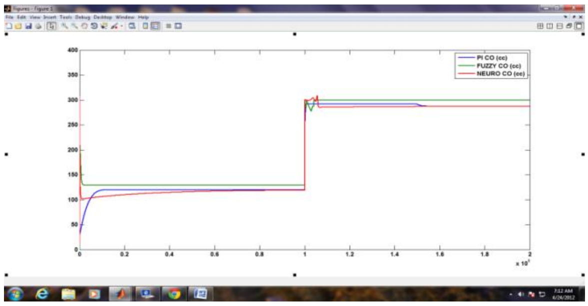

Figure 6.2: Controller Output (Comparison)

VI. CONCLUSION

In our paper a non-linear system of first order with known parameters i.e. the "spherical tank level control system" was examined. The performance report of the three types of controllers, namely **conventional PI, Fuzzy and Neural** was achieved by implementing them in the same level control system.

The **PI controller** evidences appropriate results in terms of response time and accuracy but, the linearization of the non-linear spherical process demands for four appropriate PI controllers.

The **Neural controller** overwhelms this and can be trained to learn the process behavior. But, the values of performance indices i.e. IAE and ITAE are not satisfactory for our process.

The **Fuzzy** controller does not require linearization. Fuzzy has many flexible parameters. The well chosen parameters, give a response that has great time domain characteristics. The experimental results proved that compared to PI and Neural controllers, the Fuzzy controller gives stable response for both servo and regulatory changes. The IAE and ITAE values are estimated to be the least in Fuzzy controller validating its optimum performance. Thus, it is concluded that among Neural, PI and FUZZY controllers, the Fuzzy controller is the optimum controller for the level control of a nonlinear spherical tank system.

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