SPHERICAL TANK LEVEL CONTROL SYSTEM USING CONVENTIONAL & INTELLIGENT CONTROL STRATEGIES

R. Sudha, Gunaselvi Manohar, Pearley Stanley, Lakshmi R, Sunanthini V

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 non-linear as the height of the tank changes, which changes the shape of the liquid level in a non-linear manner in the spherical tank. Level control of this non-linear 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 non-linear. 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
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 1 with 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](image)

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
- \( Fout \) 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 given as:

System accumulation is given by = inflow - outflow

(i.e) \( \frac{dv}{dt} = Fin - Fout \)

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

\[
\frac{dh}{dt} = \frac{(Fin - Fout)}{\pi R^2 \left[ 1 - \left(\frac{R-h}{R}\right)^2 \right]}
\]

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 vs level, inflow vs time) in fig 1 and fig 2. This (parabolic curve) proves that spherical tank exhibits non linearity.

![Figure 2.1: F\textsubscript{in} Vs H\textsubscript{ss}](image)

III. PROPOSED CONTROL SCHEME

A. PI CONTROLLER

To compute the “error” value, a basic A proportional–integral controller (PI controller) is used in the feedback control loop in 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:

\[
u(t) = K_p \cdot e(t) + K_i \cdot \int_{t_0}^{t} e(t) dt = K_p \cdot e(t) + K_i \cdot \int_{t_0}^{t} e(t) dt
\]

where

- \( K_p \): Proportional gain
- \( K_i \): Integral gain

\( e(t) \): Error = SP - PV

\( t \): instantaneous time

\( t_0 \): 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.
Process gain = \( \frac{\text{Steady state output}}{\text{Steady state input}} \)

Time constant \( T_p = 1.5 \times (t_1 - t_2) \)

Time delay \( t_d = t_2 - T_p \)

Where

\( t_1 \) time at 28.3% of the max height

\( t_2 \) time at 63.2% of the max height

<table>
<thead>
<tr>
<th>REGION</th>
<th>HEIG HT</th>
<th>K</th>
<th>Tp</th>
<th>Td</th>
<th>TRANSFER FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10-15</td>
<td>0.224</td>
<td>322.5</td>
<td>967.5</td>
<td>( \frac{0.224e^{-t/322.5}}{322.5s + 1} )</td>
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<tr>
<td>2</td>
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<td>0.1997</td>
<td>900</td>
<td>800</td>
<td>( \frac{0.99e^{-t/900}}{900s + 1} )</td>
</tr>
<tr>
<td>3</td>
<td>26-52</td>
<td>0.249</td>
<td>2310</td>
<td>630</td>
<td>( \frac{0.249e^{-t/2310}}{2310s + 1} )</td>
</tr>
<tr>
<td>4</td>
<td>52-99</td>
<td>0.321</td>
<td>3712.5</td>
<td>487.5</td>
<td>( \frac{0.321e^{-t/3712.5}}{3712.5s + 1} )</td>
</tr>
</tbody>
</table>

### IV. PI TUNING

For our process ‘COHEN COON’ tuning method is used to determine the control constants \( K_p \& K_i \) for each region from the process parameters obtained.

They are given by the formulae:

\[ K_p = \frac{1}{K.t_p/t_d.(0.9+t_d/12t_p)} \]

\[ t_i = t_d.((30+3t_d/t_p))/((9+20t_d/t_p)) \]

<table>
<thead>
<tr>
<th>REGION</th>
<th>RANGE</th>
<th>Kp</th>
<th>ti</th>
</tr>
</thead>
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<tr>
<td>2</td>
<td>15-26</td>
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<td>3</td>
<td>26-52</td>
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<tr>
<td>4</td>
<td>52-99</td>
<td>21.61</td>
<td>0.00078</td>
</tr>
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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 3.
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 adjusted until the network output matches the target. Typically, many such input/target match ups are required to train a network.

The Neural network is constructed using Network/Data Manager of MATLAB using the nntool 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.

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)
Figure 3.1: Membership Function For Level(L)

Figure 3.2: Membership Function For Error(E)

Figure 3.3: Membership Function For Flow(F)

Table 3: Rule base of fuzzy logic controller

<table>
<thead>
<tr>
<th></th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E5</th>
<th>E6</th>
<th>E7</th>
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<tr>
<td>L1</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>F</td>
<td>F3</td>
<td>F1</td>
<td>F1</td>
<td>F1</td>
<td>F1</td>
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<tr>
<td>L2</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>F</td>
<td>F1</td>
<td>F1</td>
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<tr>
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<td>F1</td>
</tr>
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<td>F1</td>
<td>F1</td>
<td>F1</td>
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</tbody>
</table>
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.

V. PERFORMANCE ANALYSIS

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

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

The values of each performance criterion for PI, fuzzy and neuro controllers are computed and tabulated in Table 4. 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>
<thead>
<tr>
<th>REGION</th>
<th>IAE</th>
<th>ITAE(10^5)</th>
<th>IAE</th>
<th>ITAE(10^5)</th>
<th>IAE</th>
<th>ITAE(10^5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I(SP=12)</td>
<td></td>
<td></td>
<td>PI</td>
<td>NEURO</td>
<td>FUZZY</td>
<td></td>
</tr>
<tr>
<td>I(SP=20)</td>
<td></td>
<td></td>
<td>PI</td>
<td>NEURO</td>
<td>FUZZY</td>
<td></td>
</tr>
<tr>
<td>I(SP=45)</td>
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<td></td>
<td>PI</td>
<td>NEURO</td>
<td>FUZZY</td>
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</table>
It is based on the response obtained as a result of servo and regulatory changes and also the IAE and ITAE values.

<table>
<thead>
<tr>
<th>IV(SP=80)</th>
<th>ITAE(10^5)</th>
<th>IAE</th>
<th>ITAE(10^5)</th>
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<td></td>
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<td>468900</td>
<td>2943</td>
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<tr>
<td>IAE</td>
<td>304000</td>
<td>331800</td>
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<tr>
<td>ITAE(10^5)</td>
<td>65410</td>
<td>663500</td>
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</tr>
</tbody>
</table>

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.
REFERENCES


