Optimized PID Controller for pH Neutralization Process
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Abstract— The common problem in pH reactors to
determination and control and concerning chemical-based
industrial processes by virtue of the non-linearity observed
in the titration curve. The pH control had always drawn
attention of chemical engineers because of its connotation in
various fields as medicine, where the effect of pH on the
enzymes and blood is acutely investigated, and the industry
which is perturbed with manufacturing of textile dyes, and
bleach products. The high non-linearity in pH is an
immeasurable challenge in process control and it cannot be
effective controlled by the linear PID controller. Hence
advanced tuned PID controllers are best suited which are
designed and developed for a pH control process in order to
control the plant to the desired set point with high quality
performance over the entire operating range. The
mathematical model of pH process is obtained to ensure the
dynamic modifications and stability enhancement. The ZN
tuned PID, automatic tuned PID and PSO PID controller is
implemented in simulation. The simulation is done using
MATLAB software and the results are compared.

Key words: pH control, Proportional Integral Derivative,
Zeigler Nichols, Particle Swarm Optimization, Auto tuning

I. INTRODUCTION

In recent years the industrial application of advanced control
techniques for the process industries has become more
demanding, mainly due to increasing complexity of the
process themselves as well as to enhanced requirements in
terms of product quality and environmental factors.
Therefore the process industries require more reliable,
accurate, robust, efficient and flexible control systems for
the operation of process plant. In order to fulfill the above
requirements, there is a continuing need for research on
improved forms of control. Control of industrial process is a
challenging task for several reasons due to their non-linear
dynamic behavior, uncertain and time-varying parameters,
constraints on manipulated variable, interaction between
manipulated and controlled variables, unmeasured and
frequent disturbance, dead time on input and measurements.

Control of the pH neutralization process plays an important
role in different chemical plants, such as chemical and
biological reaction, waste water treatment, electrochemistry
and precipitation plants, production of pharmaceuticals,
fermentation, and food production. However, it is difficult to
control a pH process with adequate performance point due
to its nonlinearities, time-varying properties and sensitivity
to small disturbances when working near the equivalence
point.

II. pH PROCESS STATION

The pH process consist of various tanks, controller and
sensor parts as shown in fig. 1. The pH value of the process
tank is sensed by using pH transmitter. The pH that is
sensed by the pH sensor is converted into corresponding
current in the range of (4-20) mA by pH transmitter. This
sensor measures the current pH value of the solution in
which it is partially dipped.

The sensed pH value is converted to (4-20) mA
current. The sensed pH value will be given to the PID
controller. Depending upon the pH value, controller takes
the corrective action through control valve by opening or
closing the control valves. Control valve directly controls
the amount of acid and base solution added in the process
tank. So, pH value will be maintained in the process tank.
The desired pH value can be precisely adjusted by the
addition of acid or alkali. An absolute must, particularly in
neutralization processes with stringent requirements for
reliability and accuracy. ProMinent

Fig. 1: Control and monitoring of pH process

A. Experimental Set Up

The pH process station is shown in fig.3. The controlling
variable is the inflow rate of the process tank. The outflow
rate of the process tank is kept constant. The inflow rate
of the process tank comprises of outflow rate from acid and
base tank. The inflow rate can be controlled either manually
using hand valves or automatically using controller. The
controlled variable is the pH of the process fluid and is
measured with the help of pH electrode. The pH value is
converted into an current signal and transmitted to the
controller. Based on the pH value, controller takes an action
either on acid flow or base flow to maintain the pH value.
This paper endeavors to design a system using two methods
process reaction curve method and skogestad method of
obtaining PI values Process reaction curve method is also
known as first method, we obtain experimentally the
response of the plant to a unit-step input. If the plant
involves neither integrator(s) nor dominant complex-
conjugate poles, then such a unit step response curve may
look S-shaped curve. Such step response curve may be
generated experimentally or from a dynamic simulation of
the plant. The S-shaped curve may be characterized by two
constants, delay time L and time constant T.
III. MATHEMATICAL MODEL

In science, computing, and engineering, a black box is a device, system or object which can be viewed in terms of its input, output and transfer characteristics without any knowledge of its internal workings. Its implementation is "opaque" (black). Almost anything might be referred to as a black box: a transistor, an algorithm, or the human brain.

The "black box" portion of the system contains formulas and calculations that the user does not see any need to know to use the system. Black box systems are often used to determine optimal trading practices. These systems generate many different types of data including buy and sell signals.

It does not use any particular prior knowledge of the character or physics of the relationships involved. It is therefore more a question of "curve-fitting" than "modeling". In this presentation several examples of such black-box model structures will be given. Both linear and non-linear structures are treated. Relationships between linear models, fuzzy models, neural networks and classical non-parametric models are discussed. Some reasons for the usefulness of these model types are also given. Ways to fit black box structures to measured input-output data are described, as well as the more fundamental (statistical) properties of the resulting models.

A. Modeling of PH Process

The requirements are:

- Acid solution - HCL (1 pH) (0.1N)
- Base solution - NaOH (13 pH) (0.1M)
- Process solution - Distilled water (7 pH)

<table>
<thead>
<tr>
<th>Time(sec)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>7.00</td>
</tr>
<tr>
<td>5.57</td>
<td>5.65</td>
</tr>
<tr>
<td>6.00</td>
<td>5.71</td>
</tr>
<tr>
<td>7.00</td>
<td>5.64</td>
</tr>
</tbody>
</table>

Table 1: Time Vs. pH for acid solution

Table 1 denotes the variation of pH with respect to time by the addition of acid solution.

Fig. 3: Open loop response of acid added in process fluid

The Open loop response of pH process by the addition of acid in process tank is shown in Fig. 3. Here the acid is added to process fluid say distilled water, as the acid is mixed the pH value of process fluid is adjusted between the range of 3 to 7. Hence the acidic nature of the process fluid increases.

<table>
<thead>
<tr>
<th>Time(sec)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>8.4</td>
</tr>
<tr>
<td>40</td>
<td>10.14</td>
</tr>
<tr>
<td>80</td>
<td>10.63</td>
</tr>
<tr>
<td>100</td>
<td>10.76</td>
</tr>
<tr>
<td>320</td>
<td>10.88</td>
</tr>
<tr>
<td>440</td>
<td>11.059</td>
</tr>
<tr>
<td>560</td>
<td>10.97</td>
</tr>
<tr>
<td>630</td>
<td>11.14</td>
</tr>
</tbody>
</table>

Table 2: Time Vs. pH for alkaline solution

The variation of pH with respect to time by the addition of alkaline solution shown in Table 2. From the tabulation of pH values for alkaline solution the titration curve is drawn for the open loop response of base added in the process fluid, where it becomes alkaline in nature.

Fig. 4: Open loop response of base added in process fluid
The Open loop response of pH process by the addition of alkaline in process tank is shown in Fig.4. Here the base is added to process fluid say distilled water, as the base is mixed the pH value of process fluid is adjusted between the range of 7 to 14.

The alkaline nature of the process fluid increases. The Fig.4 explains the open loop response of base added in the process tank, where the titration curve is drawn by plotting the graph between Time Vs. pH value of acid.

The procedures followed to obtain the transfer function for both acid and base are as follows. The open loop response is also called as manual mode in which manually stem position of 40% opening is made to reach the steady state value. Empirical modeling or black box modeling was performed. Keeping stem position at a constant 40% opening, the characteristics of pH versus time was studied. The readings are noted till the system attains its steady state value. The values shown in Table 1 and Table 2 were loaded in system identification toolbox and the transfer functions were obtained. The transfer functions obtained are:

For acid : \( G_p(s) = \frac{0.0714}{100s+1} \) \( \ldots (1) \)

For base : \( G_p(s) = \frac{0.04912}{320s+1} \) \( \ldots (2) \)

The transfer function is obtained from the parameters identified by system identification tool box. Here we get input and output parameters. The transfer function is obtained which is the Laplace transform of output to the Laplace transform of input under zero initial conditions.

IV. CONTROLLER DESIGN

![Block Diagram of Closed loop PID controller](image)

Fig. 5: Block Diagram of Closed loop PID controller

Proportional-Integral-Derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A general PID controller shown in Fig.5 calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D.

Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process.

By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point.

Some applications may require using only one or two actions to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action.

A. Tuning of Controller

There are several methods for tuning a PID loop. The most effective methods generally involve the development of process model, by choosing P, I, and D based on the dynamic model parameters. Manual tuning methods can be relatively inefficient, particularly if the loops have response times on the order of minutes or longer.

The Ziegler Nichols tuning method is a heuristic method of tuning a PID controller. The “P” (proportional) gain, \( K_p \) is then increased (from zero) until it reaches the ultimate gain, \( K_u \). The oscillation period \( T_U \) at which the output of the control loop oscillates with a constant amplitude, \( K_u \) and the oscillation period \( T_U \) are used to set the P, I, and D gains depending on the type of controller used.

To determine PID controller parameters, reduce the integrator and derivative gains to 0. Increase \( K_p \) to some critical value \( K_p=K_c \), at which sustained oscillations occur. Note the value \( K_c \) and the corresponding period of sustained oscillation \( T_c \).

The formulae for Ziegler Nichols is given in Table 3.

<table>
<thead>
<tr>
<th>Control Type</th>
<th>( K_p )</th>
<th>( K_i )</th>
<th>( K_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0.50( K_u )</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>0.45( K_u )</td>
<td>1.2( K_p/\text{P_u} )</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>0.60( K_u )</td>
<td>2( K_p/\text{P_u} )</td>
<td>( K_pP_u/8 )</td>
</tr>
</tbody>
</table>

Table 3: ZN Formula

B. Particle Swarm Optimization

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling.

PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control.
C. Tuned Parameters for PID Controllers

<table>
<thead>
<tr>
<th>Controller</th>
<th>Kp</th>
<th>Ki</th>
<th>Kd</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZN tuned PID</td>
<td>0.63</td>
<td>0.05</td>
<td>1.96</td>
</tr>
<tr>
<td>Auto tuned PID</td>
<td>23.922</td>
<td>0.296</td>
<td>-177.31</td>
</tr>
<tr>
<td>Optimized PID</td>
<td>72.56</td>
<td>0.721</td>
<td>23.25</td>
</tr>
</tbody>
</table>

Table 4: Tuned value for PID controller

Various controllers like ZN tuned PID, Auto tuned PID, Optimized PID controllers are employed to find their respective values of Kp, Ki, Kd as shown in Table 4.

<table>
<thead>
<tr>
<th>Population Size</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of iterations</td>
<td>50</td>
</tr>
<tr>
<td>Variables/Dimension of the problem</td>
<td>03</td>
</tr>
<tr>
<td>W</td>
<td>0.7</td>
</tr>
<tr>
<td>c₁</td>
<td>1.5</td>
</tr>
<tr>
<td>c₂</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 5: Parameters of PSO algorithm

The various parameters of PSO algorithm is shown in Table 5 where, W denotes the best particle, c₁ and c₂ indicates the learning parameters of PSO algorithm.

V. SIMULATION RESULTS AND DISCUSSIONS

A. PID Controller Using ZN Tuning Method

The closed loop response of ZN tuned PID controller as shown in Fig.6 shows that the rise time and settling time is maximum. The non-linear pH process settles at 1280 seconds with an absolute error of 8940.

B. PID Controller Using Automatic Tuning Method

The closed loop response of Auto-tuned PID controller as shown in Fig.7. shows that the rise time and settling time value is minimum compared to ZN tuning. The non-linear pH process settles at 250 seconds with an absolute error of 1222.

C. PID Controller with PSO

The closed loop response PSO as shown in Fig.8 shows that rise time and settling time value is very less compared to auto-tuning and ZN tuning. The non-linear pH process settles at 140 seconds with an absolute error of 481.

VI. CONCLUSION AND FUTURE ENHANCEMENT

The simulation results for PID controller using ZN tuning, automatic method and PSO method are compared to find the better performance of controller. The rise time and settling time value is maximum for ZN tuned PID, reduced in Auto tuned PID and minimum in Optimized PID as shown in Table 6. The value of ISE is also very high for ZN tuned PID and Auto tuned PID compared to Optimized PID controller. From the above results, the PSO tuned PID controller seems to provide optimum control over ZN an automatic tuned PID controller.

<table>
<thead>
<tr>
<th>Controller</th>
<th>Rise time (sec)</th>
<th>Settling Time (sec)</th>
<th>ISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZN tuned PID</td>
<td>465</td>
<td>1280</td>
<td>8940</td>
</tr>
<tr>
<td>Auto tuned PID</td>
<td>105</td>
<td>250</td>
<td>1222</td>
</tr>
<tr>
<td>Optimized PID</td>
<td>43</td>
<td>140</td>
<td>481</td>
</tr>
</tbody>
</table>

Table 6: Comparison Table

The split range controller can be implemented to obtain the optimum control of pH value.

REFERENCES


