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

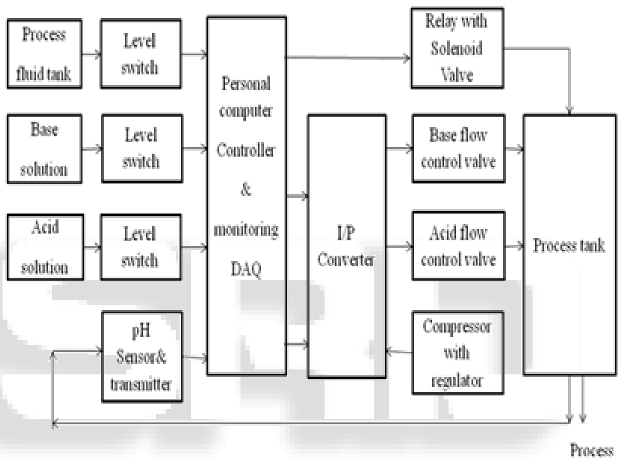

Fig. 1: Control and monitoring of pH process

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.

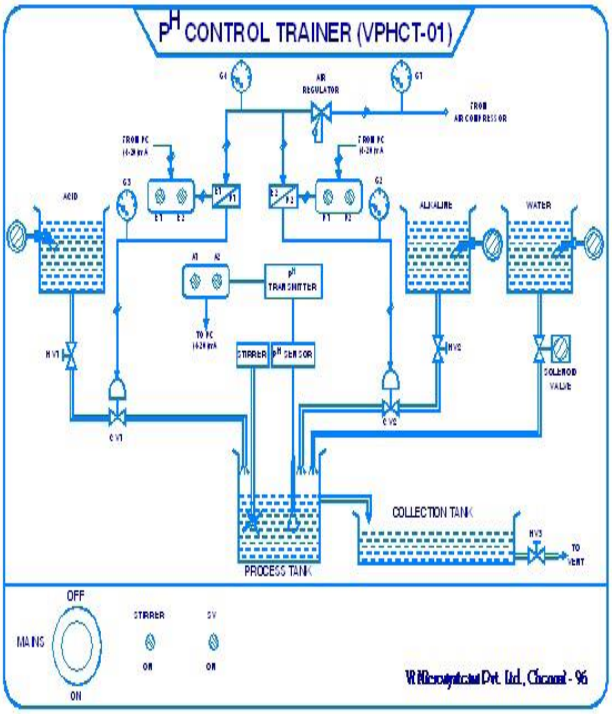

Fig. 2: Experimental set up of pH process

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)

Time(sec)	pH
0.00	7.00
5.57	5.65
6.00	5.71
7.00	5.64
10.00	5.54
20.00	5.56
30.00	5.10
40.00	2.83
50.00	2.00
60.00	2.54

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.

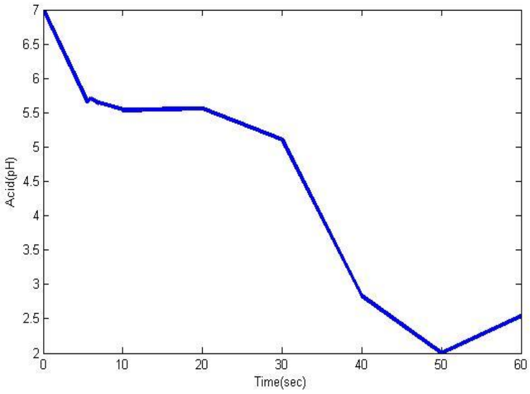

Fig. 3: Open loop response of acid added in process fluid

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.

Time(sec)	pH
0	7
10	8.4
40	10.14
80	10.63
100	10.76
320	10.88
440	11.059
560	10.97
630	11.14

Table 2: Time Vs. pH for alkaline solution

The variation of pH with respect to time by the addition of alkaline solution shown in Table2.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.

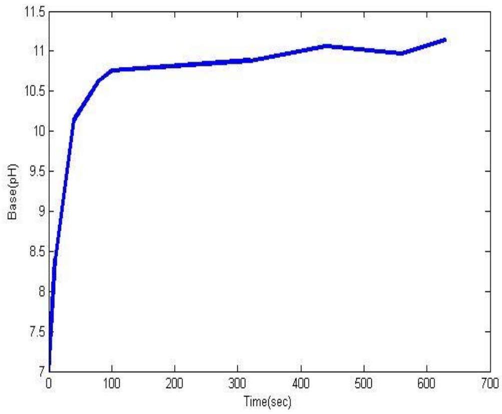

Fig. 4: Open loop response of base added in process fluid

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:

$$\text{For acid}: \quad G_p(s) = \frac{0.0714}{(100s+1)} \qquad \text{.......(1)}$$

$$\text{For base}: \quad G_p(s) = \frac{0.04912}{(320s+1)} \qquad \text{.......(2)}$$

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

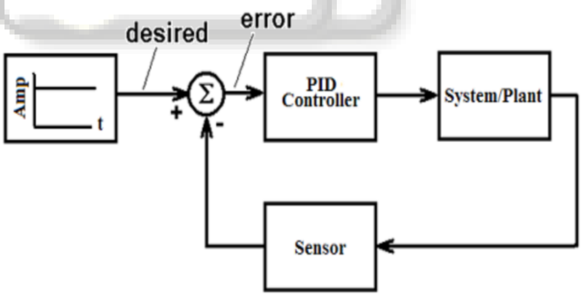

Fig. 5: Block Diagram of Closed loop PID controller

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 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 Kp from 0 to some critical value Kp=Kc at which sustained oscillations occur. Note the value Kc and the corresponding period of sustained oscillation Tc .The formulae for Zeigler Nichols is given in Table 3.

Control Type	K_p	K_i	K_d
P	$0.50K_u$	-	-
PI	$0.45K_u$	$1.2K_p/P_u$	-
PID	$0.60K_u$	$2K_p/P_u$	$K_pP_u/8$

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

Controller	**Kp**	**Ki**	**Kd**
ZN tu ned PID	0.63	0.05	1.96
Auto tuned PID	23.922	0.296	-177.31
Optimized PID	72.56	0.721	23.25

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.

Population Size	10
Number of Iterations	50
Variables/Dimension of the problem	03
W	0.7
c_1	1.5
c_2	1.5

Table 5: Parameters of PSO algorithm

The various parameters of PSO algorithm is shown in Table 5 where, W denotes the best particle, c_1 and c_2 indicates the learning parameters of PSO algorithm.

V. SIMULATION RESULTS AND DISCUSSIONS

A. PID Controller Using ZN Tuning Method

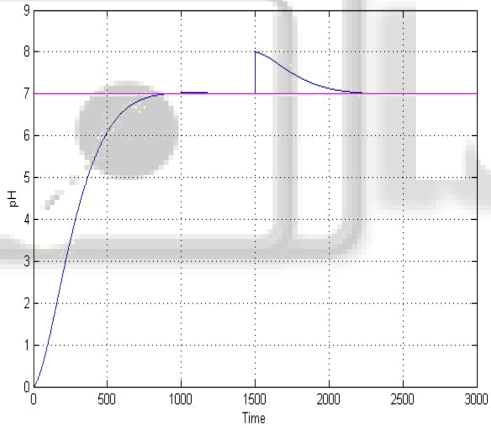

Fig. 6: Closed loop response of ZN tuned PID controller

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

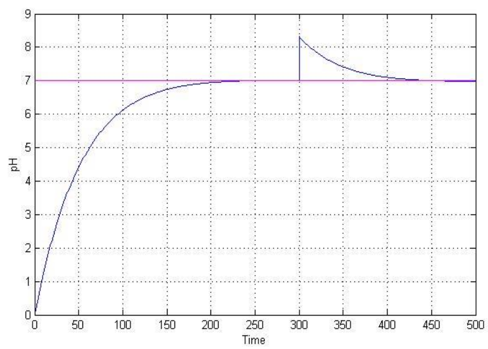

Fig. 7: Closed loop response of Auto-tuned PID Controller

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

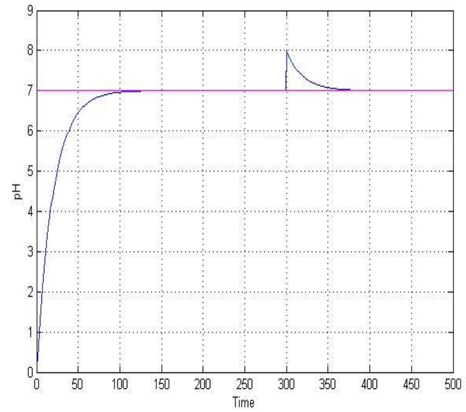

Fig. 8: Closed loop Response of Optimized PID Controller

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 ANF 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.

Control	**Rise time (sec)**	**Settling Time (sec)**	**ISE**
ZN tuned PID	465	1280	8940
Auto tuned PID	105	250	1222
Optimized PID	43	140	481

Table 6: Comparison Table

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

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