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Heuristic Algorithm Based Controller Optimization for a Real Time pH Neutralization Process System

M.Kandasamy[1]*, S.Vijayachitra[2], K.Saravanan[3]

[1]Department of Electronics and Instrumentation Engineering, Erode Sengunthar Engineering College, Erode -638057, India.
[2]Department of Electronics and Instrumentation Engineering, Kongu Engineering College, Erode -638052, India
[3]Department of Chemical Engineering,Kongu Engineering College, Erode -638052, India

Abstract: The nonlinearity and time varying characteristics of pH neutralization is a highly challenging control in the chemical process industries. In this paper, a real time pH neutralization process is studied by using Bacterial Foraging optimization (BFO) based PI controller. The real time pH neutralization process is represented in First Order plus Dead Time (FOPDT) Model. The controller parameters such as K_p, K_i and K_d are designed for the model using BFO optimization technique and its results are validated against Ziegler and Nichols (ZN) Method and Genetic Algorithm based optimization techniques. The performance of the processes are carried out in the simulation environment and also implemented on LabVIEW based real time pH process. The results indicate that the Bacterial Foraging optimization (BFO) Algorithm based PI controller has faster settling time, better set point tracking and high disturbance rejection for the pH neutralization process.
Keywords: pH, PI Controller, Optimization, Ziegler and Nichols (ZN) Method, Genetic Algorithm (GA) and Bacterial Foraging Algorithm optimization (BFO).

1 Introduction

Control of pH is necessarily to be carried out in many industries such as biological reaction, waste water treatment, electrochemistry and precipitation plants, production of pharmaceuticals, fermentation, and food production such as in vegetable oil, refining. 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 [1]. Especially in textile wastewater it is tough to control pH due to the presence of weak organics (acid or base), so the pH value of wastewater can influence the property of pollutants. The pH in the range of 4 to 11 for treatment of textile industrial wastewater is neutralized by using either H_2SO_4 or NaOH to adjust the pH of the solution [2]. Many attempts on pH-neutralization dynamics and control are carried out by researchers since the year 1970s [3,4]. However the pH neutralization process is highly nonlinear characteristics and uncertainty, research is still reported by many scholars but using recent emerging control strategies [5].

Now s days many of chemical process industries use PID controllers for linear, non linear, stable and unstable process. The merits of the PID controllers includes (a) provides an optimal and robust performance for a variety of processes; (b) Variety of structures such as series, parallel etc. are available; (c) The structure can be easily implemented in analog/ digital formats; (d) The controller supports online/offline tuning techniques. [6,7,8].

The controller parameters such as K_p K_i and K_d determine the performance of the PID controller. Many research works have been attempted to find out the optimum values of controller parameters by various tuning methods include Particle Swarm Optimization (PSO), Neural Networks (NN), Genetic Algorithm (GA), Simulated Annealing (SA) and Fuzzy Logic (FL) for the different close loop system problems.

Genetic algorithm is a search heuristic that mimics the process of natural selection [9]. This heuristic is routinely used to generate useful solutions to optimization and search problems. Genetic algorithm belongs to the larger class of Evolutionary Algorithms (EA), which helps to find out solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover [10].

Bacterial Foraging optimization Algorithm has proposed by Passino in the year 2002 for a liquid level control problem with an adaptive controller[11]. The perception of foraging activities of Escherichia coli (E. coli) bacteria is used for the optimization technique to find out the best fitted PI controller parameters by a set of artificial bacteria in the "D" dimensional search space [12].

In this proposed work, Bacteria Foraging Optimization algorithm is proposed to identify optimized PI controller parameters for the model of pH neutralization process. The obtained result is validated against Z-N method and Genetic algorithm method. The performance of BFO and GA based PI controller are finally tested on a real time nonlinear pH neutralization system.

The further part of the paper is organized as follows: Section 2 presents the overview of the real time pH neutralization system and mathematical modeling of the setup. The section 3 gives a description of Z-N method, GA and BFO based optimization. The simulated & real time system result is discussed in the section 4 and followed by the conclusion of the present work in the section 5.

2 Experimental Setup

The laboratory type real time experimental setup of pH neutralization is shown in Figure 1. The system consists of pH Transmitter, Control Valve with Positioner, Electro Pneumatic Convertor, Process Tank, Solution Tanks, Stirrer, Solenoid Valve, Level Switch, Pressure Regulator, Pressure Gauge, Digital Panel Meter and a personal computer (PC). The pH transmitter is connected with the computer through USB module interface (VUDAS – 100). This module has 16 channel ADC port for inputs & 8 channel DAC port for outputs. The Table 1 shows the specification of the pH neutralization process system.

The solution tank-1 is filled with strong acid (Hydro Choleric Acid, HCL, 0.1N) and solution tank-2 is filled with strong base (Sodium Hydride NaOH, 0.1N). The control valve-1 (CV-1) is used to adjust the acid flow and the control valve-2 (CV-2) is used to adjust the base flow rate. Both the control valves are of equal percentage category and it is operating by pneumatic signal of (3-15) psi. The "Yokogawa" make pH sensor is used to measure the pH of the process tank and the measured value is converted by its transmitter into (4-20) mA. It is proportional to pH (0-14) of the solution. The pH transmitter is connected with the computer through USB module interface. The LabVIEW based PI Controller controls the process. According to the given set point and current value of the pH, the PI controller takes necessary control action on control valves to adjusting the flow rate of strong acid and strong base in accurate. This procedure brings the pH of the process tank according to the set point.

Figure 1. Real Time Experimental Setup of pH Neutralization

Mathematical Model of pH Process Tank

The process tank is filled with strong base as initial process and its pH is measured as 12.62. The solution tank -1 and solution tank - 2 are filled with strong acid (Hydro Choleric Acid, HCL, 0.1N) and strong base (Sodium Hydride NaOH, 0.1N) respectively. The control valve CV-2 which controls the flow rate of base is fixed at 50% open and remains constant for the entire process. The control valve CV-1 controls the flow rate of acid is positioned at 10% open by setting the DAC output and there by new steady state is achieved in the process tank. The steady state of the pH is noted against DAC value. This procedure is repeated for consecutive every 10% additional DAC value to the maximum of 100% (until 100% opening of CV-1). The % of DAC and corresponding steady state pH is plotted in the graph to obtain the pH Neutralization Curve and it is shown in Figure 2.

Table 1. Specification of Experimental Setup of pH Neutralization

Description of components	Specifications
pH Transmitter	Make : Yokogawa Range : (0 to 14) pH Output : (4 to 20)mA DC Accuracy : ± 0.5% of full scale
Control Valve with Positioner	Make : RK controls Type : Globe control valve Size : 3/4 “flanged Plug Chance : Equal % Valve action : Air to open
Electro Pneumatic Convertor	Make : Watson Smith Supply : 20 Psi constant pressure Input Signal : (4 to 20)mA DC Output : Pneumatic signal (3 to 15) psi.
Process Tank	Material : Acrylic Height : 300mm Diameter : 160 mm
Solution Tank (Acid, Base and Water)	Material : Acrylic Height : 300mm Diameter : 160 mm
Stirrer	Make : Pranshu Supply : 8VDC Torque : 1.5 kg /cm2
Solenoid Valve	Make : Compare Supply : 230V AC Medium : Air/Water Operating range : (0-2) bar
Pressure Regulator	Make : PLACKA Instruments & Controls/ABB. Maximum input: 18kg / cm2 Output : (0.2 -1) Kg / cm2
Pressure Gauge	Make : Waaree/manometer Body material : SS Size : 2.5"
Digital Panel Meter	Make : MECO/ Nippen Range : (0-200) mA Supply : 230V AC/50Hz

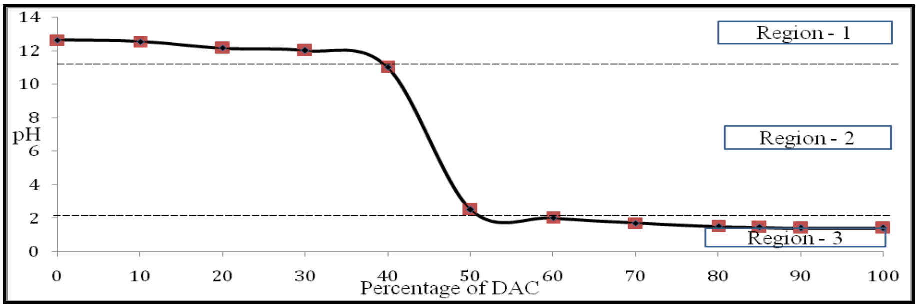

Figure 2. Process of pH Neutralization

From the Figure 2 it is shown that the pH neutralization process is highly non-linear. The objective of the proposed work is to obtain the three different models at various operating regions as in the Figure 2. The pH neutralization process tank is represented in the form of First Order Plus Dead Time (FOPDT) Model such as.

$$G(s) = \frac{K_p e^{-\theta s}}{\tau_p s + 1} \quad (1)$$

The mathematical model is obtained at pH value of 12 for the region-1 by open loop transient response. Initially pH 12 is maintained by regulating the acid flow rate by control valve CV-1. Then a step change with a magnitude +10% DAC output is given to the control valve CV-1. The transient response is obtained by plotting graph of pH variation with respect to time and it is shown in Figure 3. The process gain K_p and time constant τ_p are obtained by the process reaction curve [13,14] from the transient response.

The similar procedure is repeated to obtain the process gain (K_p) and time constant (τ_p) at the operating point pH 7 and pH 2 for the region 2 and region 3 respectively. The process delay (θ) is approximately consider as 20 % of the time constant τ_p [14,15]. The obtained FOPDT model parameters are reported in the Table 2.

Table 2. FOPDT model parameter for three operating regions

pH Regions	Model parameters		
	Process Gain K_p (% / %)	Time Constant τ_p (Min.)	Process Delay θ (Min.)
Region – 1 (At pH: 11)	6.117	8.75	1.75
Region – 2 (At pH: 7)	3.686	7.50	1.50
Region – 3 (At pH: 2)	0.2137	9.50	1.90

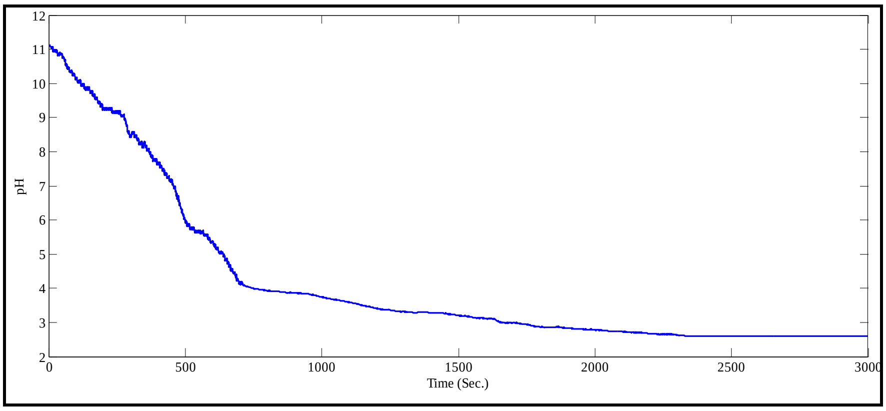

Figure 3. Transient response for step magnitude of +10 % of DAC at operating point pH 11

3 Ethods of Pi Controller Tuning

Ziegler and Nichols (ZN) method, Genetic Algorithm (GA) method, Bacterial Foraging Optimization algorithm are used to find out the values of parameters K_p and K_i of the PI controller to confirm the minimum time domain specifications and error values in this study.

(i) Ziegler and Nichols (ZN) Method

In 1942, Ziegler and Nichols have proposed simple mathematical procedures for tuning PID controllers. These procedures are widely accepted and treated as standard in control systems practice. In this method, Integral gain K_i and derivative gain K_d are set with zero and proportional gain K_p is increased to specific critical value to make sustained oscillation output [16]. From the procedure, the optimum controller parameters for the PI controller are obtained

(ii) Genetic Algorithm (GA) Method

Genetic Algorithm (GA) is an adaptive heuristic search algorithm. It is based on the evolutionary ideas of natural selection and genetics. It is one of the most effective and efficient technique to solve optimization problems in engineering. GA is exploiting historical information to direct the search into the region of better performance within the search space. After an initial population is randomly generated, the algorithm consists of important three stages such as Selection, Crossover and Mutation. These stages involve creating new individuals which may be better than their parents. This algorithm is recurring for more generations to reach the individuals that represent the optimum solution for the problem. The process of the genetic algorithm is described as follows:

Initialization: The initial population of individual solutions is usually generated randomly across the entire range of search space.

Evaluation: The fitness values of the candidate solutions are evaluated after the population is initialized or an offspring population is created.

Selection: Selection allocates more copies of those solutions with higher fitness values and thus imposes the survival-of-the-fittest mechanism on the individual solutions. The important of the selection process is to prefer better solutions to worse ones with the help of many selection procedures.

Recombination: This process creates new and possibly better solutions (i.e. offspring) by combining parts of two or more parental solutions. Many kinds of method followed to achieve this, and competent performance based on a properly designed recombination mechanism. The offspring created by this process will not be identical to any particular parent and will instead combine parental traits in a novel manner.

Mutation: During recombination process on two or more parental chromosomes, mutation is performed locally however the solution will be modified randomly. Again, there are many variations of mutation, but it usually involves one or more changes being made to an individual's trait or traits.

Replacement: The offspring population created by above process such as selection, recombination and mutation replace original parental population.

Termination: The steps from Evaluation to Replacement are continued till the termination condition is achieved. The termination condition can be either the number of generations or the solution satisfying an optimum criterion [17, 18].

In order to obtain the controller parameters K_p and K_i for the pH neutralization process the following parameters are considered. Population size is selected as 20, generation size is chosen as 150, crossover probability is set to 50%, and mutation probability is considered as 0.2%. Roulette wheel based selection criterion is considered in this study.

(iii) Bacterial Foraging Optimization Algorithm

Bacterial Foraging Optimization (BFO) algorithm is a new division of biologically inspired computing technique introduced by Passino in 2000. It is based on mimicking the foraging methods for positioning, handling and ingesting food behaviour of Escherichia coli (E. coli) bacteria living in human intestine [19]. The algorithm has advantages of high computational efficiency, simple design procedure, and stable convergence.

Chemo-taxis: This process simulates the movement of an E.coli cell towards the food source with swimming and tumbling action via flagella. The bacteria can move in a particular path by swimming and can modify the direction of search during tumbling action. These two modes of operations are endlessly executed by a bacteria its whole lifetime to reach the sufficient amount of positive nutrient gradient.

Swarming: This process is carried out by the bacteria to acknowledge the information about optimum path of the food source with other bacteria. An attraction signal is produced for this communication between the cells in the E-coli bacteria. Another repellent signal is also produced for noxious reserve. This process helps them to increase the bacterial density at the identified food position in the chemotaxis. The attraction signal is represented by the below equation (2).

$$J_{cc}(\theta(i,j,k,l)) = \sum_{i=1}^{s} J_{cc}(\theta,\theta^i(j,k,l)) = X + Y$$

Where

$$X = \sum_{i=1}^{s}\left[-d_{att}\exp\left(-w_{att}\sum_{m=1}^{n}(\theta_m-\theta_m^i)^2\right)\right] \text{ and} \quad (2)$$

$$Y = \sum_{i=1}^{s}\left[-h_{rep}\exp\left(-w_{rep}\sum_{m=1}^{n}(\theta_m-\theta_m^i)^2\right)\right]$$

Where "s" = Total number of bacterium, "n"= Total parameters to be optimized, d_{att} = Depth of attractant signal released by a bacteria, "W_{att}" = Width of attractant signal, "h_{rep}" = height of repellent signals between bacterium, "W_{rep}" = weight of repellent signals between bacterium and J_{cc}(θ,(i,j,k,l)) is the objective function value. "*θ*" is the point in the n dimensional search domain till the j^{th} chemotactic, k^{th} reproduction and l^{th} elimination. Also "θ_m" is the m^{th} parameter of global optimum bacteria

Reproduction: In swarming process, the bacteria gathered as groups in the positive nutrient gradient and which may increase the bacterial density. Later, the bacteria are arranged in descending order based on its health values. The least healthy bacteria eventually expire while healthier bacteria asexually split into two bacteria and maintain the predefined population.

Elimination-Dispersal: This is the closing phase in the bacterial search. The bacterium population may decrease either gradually or suddenly depend on the environmental criteria such as change in temperature, and availability of food etc. Significant local rise of temperature may kill a group of bacteria that are currently in a region with a high concentration of nutrient gradients. Actions may take place in such a way that all the bacteria in a location are killed and eliminated (local optima) or a group is relocated (dispersed) into a new food source. The dispersal possibly compresses the chemo-taxis advancement. After dispersal, some bacteria may be located near the superior nutrient and this process is called "Migration". The above events are continued until the entire dimensional search converges to optimal solutions or total number of iterations is reached

Bacterial Foraging optimization (BFO) Method for PI Tuning

Initially, the boundary values of PI is to be assigned to guide the optimization algorithm and to attain the good accuracy. Many researchers have proposed the Multiple Objective Performance Index (MOPI) such as overshoot (M_p), settling time (t_s), steady state error (e_{ss}), rise time (t_r), gain margin (GM) and phase margin (PM) for PI controller optimization [20]. The following equation describes the parameters selected for MOPI to find the controller Parameter K_p and K_i by BFO algorithm.

$$J_{\min}(K_p,K_i) = (w_1.ISE) + (w_2.IAE) + (w_3.M_p) + (w_4.t_s) + (w_5.t_r) \quad (3)$$

Where $J_{\min}(K_p,K_i)$ - Performance criterion

ISE - Integral Square Error

IAE - Integral Absolute Error

M_p = Peak Overshoot is the difference between maximum peak value of the response curve c(t_p) and final value of c(t)

t_s = Settling time is time required for the response curve to reach and stay within 2% of the final value.

t_r = Rise time is time required for the response to rise from 0% to 100% of its final value.

w_1, w_2, w_3, w_4 and w_5 are weighting functions of the MOPI parameters and the value of "W" varies from 0 to 10.

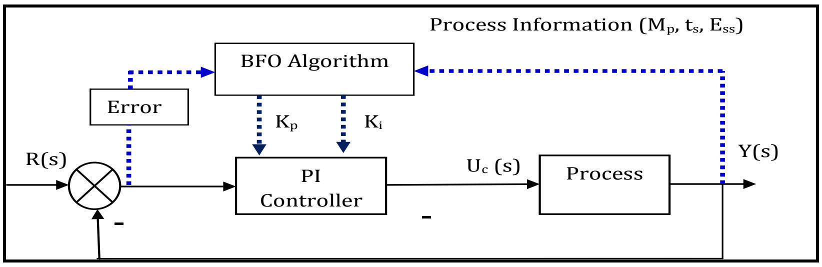

Figure 4. BFO algorithm-based PI controllers tuning

The Figure 4 shows the basic structure of BFO algorithm based PI controller tuning controllers tuning.

The following parameters are assigned to BFO and MOPI as the preliminary process for optimization search. Dimension of the search is assigned as Two (K_p and K_i); number of E. coli bacteria as is ten; number of reproduction steps is assigned as four; length of a swim considered as four; number of chemo tactic steps is selected as five; number of elimination-dispersal events are considered as two; number of bacterial reproduction is set as five, probability for bacteria eliminated /dispersed is considered as '0.25'; d_{att} is assigned as zero ; W_{att} is set as '0.5' h_{rep} is considered as '0.6' and W_{rep} is assigned as '0.6'.

- The limits of the three dimensional search space is as
  - K_p = 0% < K_p < +50%
  - K_i = 0% < K_i < +25%
- The weighting function values are assigned as $w_1 = w_2 = w_3$ =10; $w_4 = w_5$ =6.
- The reference input signal 'R(s)' is unity.
- The "t_r" is chosen as <25% of the maximum simulation time. The settling time 't_s' is selected as <50% of the maximum simulation time.
- The overshoot in the process output 'M_p' is considered as <10% of the reference signal.
- The steady state error (e_{ss}) of process output is assigned as zero.
- Maximum simulation time is 100 sec. The simulation time is selected based on the process time delay.
- Ten trials are carried out for each algorithm and among them best value is considered as suitable optimized controller value.

4 Results And Discussion

PI Controller tuning parameters have been identified for First Order with Dead Time model by Ziegler & Nichols method, Genetic Algorithm and Bacterial Foraging optimization (BFO) Method. The controller parameters such as Proportional gain (K_p) and Integral gain (K_i) values are reported in the Table 3.

Performance study is carried out to indicate effectiveness of the BFO based PI controller. The performance of a controller is tested by mode of servo and regulatory mode of control.

Table 3. PI controllers Parameters at different operating regions

Operating Regions	Z-N		GA		BFO	
	K_p	K_i	K_p	K_i	K_p	K_i
Region - 1	0.7188	0.2178	0.6469	0.1492	0.6746	0.0562
Region - 2	1.3201	0.4125	1.5245	0.2145	1.0117	0.1836
Region- 3	22.7941	6.2450	24.2542	1.3847	19.2547	1.7286

Servo Response

The set point tracking (Servo Response) is the most important requirement for a controller. The controller having faster set point tracking is always preferred in the process industries. In the servo control mode, the objective of controller is to provide accurate tracking of reference signal. The Figure 5 - Figure 7 shows the servo response of the different PI controllers for the three operating regions. It is clearly observed that BFO based PI controller provides better set point tracking compared with the ZN method and Genetic Algorithm method. The Performance Indices of ZN, GA and BFO based PI Controller Tuning for servo response is indicated in the Table 4. The table indicates that the performance indices such as Integral Absolute Error (IAE), Integral Square Error (ISE), Integral Time Absolute Error (ITAE) and Integral Time Square Error (ITSE) comparatively low in BFO based PI controller than the GA and ZN based controller. Also the most important parameter peak overshoot is quite low in the BFO.

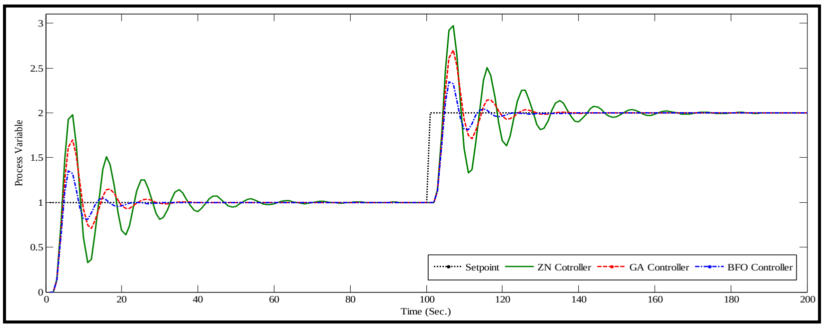

Figure 5. Servo response of PI controller for the Operating Region - 1

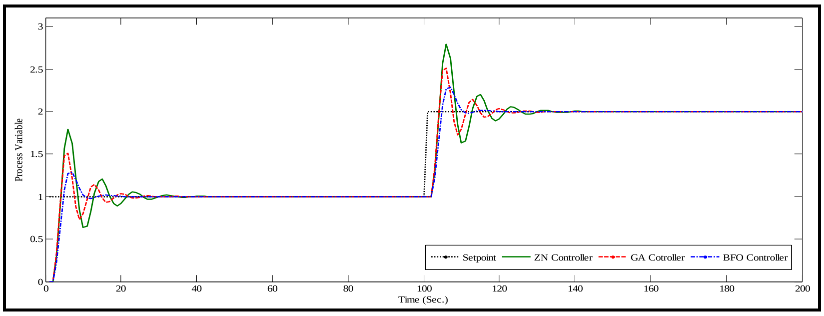

Figure 6. Servo response of PI controller for the Operating Region – 2

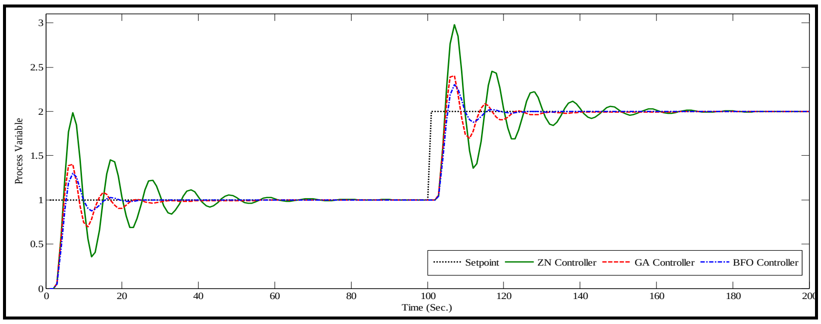

Figure 7. Servo response of PI controller for the Operating Region – 3

Table 4: Performance Indices of different PI controller tuning for servo response.

Operating Region	Tuning Method	% of M_p	t_r (Sec.)	t_s (Sec.)	IAE	ISE	ITAE	ITSE
Region - 1	Z-N	48.85	4.3	54.0	26.59	14.42	1717.0	829.7
	GA	34.95	4.6	26.0	13.54	7.906	767.3	423.1
	BFO	17.45	4.8	23.0	9.288	5.607	511.8	291.5
Region - 2	Z-N	39.6	4.0	27.5	13.67	7.844	777.9	421.0
	GA	25.55	4.0	24.0	9.672	5.55	532.0	290.4
	BFO	14.25	4.8	11.5	7.464	5.002	396.2	258.1
Region - 3	Z-N	49.15	4.6	53.0	26.69	14.57	1722.0	838.7
	GA	20.05	4.85	24.0	11.82	6.404	688.8	337.4
	BFO	15.15	5.28	17.0	9.164	5.951	497.7	308.9

Regulatory Response:

Frequently varying pH values due to different parameter variation is a major problem in the many chemical process and bio chemical industries. The fitness of any controller can be judged by testing the performance of the controller under the load change condition. The performance of the controller is studied by applying load disturbance in all operating regions, which is shown in the Figure 8 - Figure 10. Simultaneously all the three controllers are applied with a disturbance and it can be noted that the BFO algorithm based controller eliminates the effect of disturbance much faster than Z-N method and Genetic Algorithm method. Also from the Table 5, BFO based controller exhibits better performance indices than the ZN and GA based controllers in all regions.

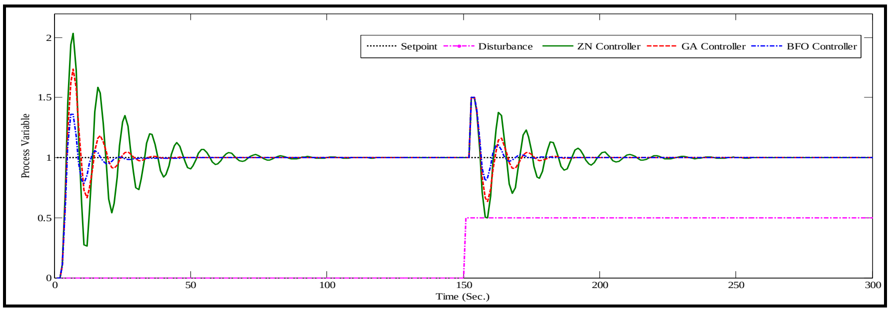

Figure 8. Regulatory response of PI controller for the Operating Region - 1

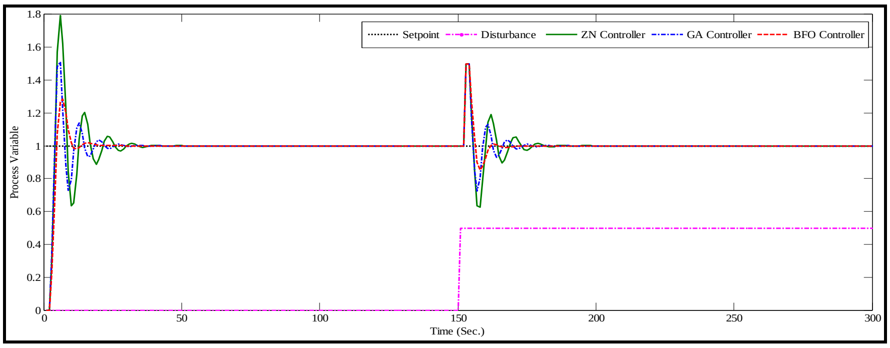

Figure 9. Regulatory response of PI controller for the Operating Region -2

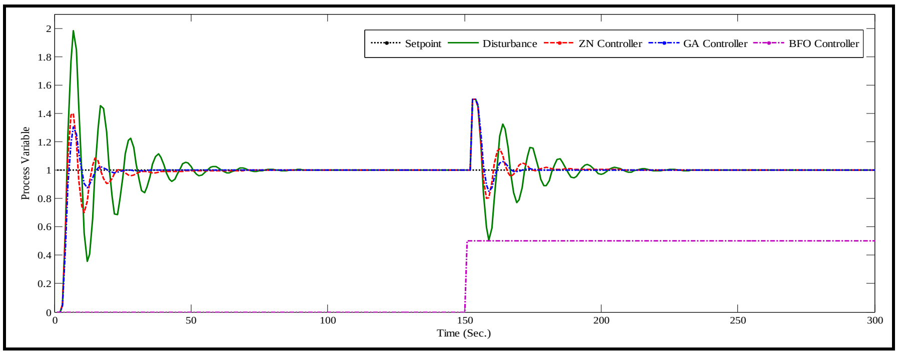

Figure 10. Regulatory response of PI controller for the Operating Region -3

Table 5. Performance Indices of different PI Controller Tuning for Regulatory Response.

Operating Region	Tuning Method	IAE	ISE	ITAE	ITSE
Region - 1	Z-N	24.24	10.8	1667	428.4
	GA	11.05	5.312	641.3	181.9
	BFO	7.339	3.651	410.4	118.6
Region - 2	Z-N	10.25	4.902	417.2	117.5
	GA	7.254	3.469	281.7	78.49
	BFO	5.598	3.126	206.6	68.5
Region - 3	Z-N	20.04	9.106	1307	345.5
	GA	8.872	4.001	523.8	132.2
	BFO	6.873	3.719	377.6	120.1

Real Time Implementation

The performance of Genetic Algorithm and Bacterial Foraging Optimization Algorithm based PI Controller is validated in real time on pH neutralization process system for all operating regions.

The Figure 11 depicts the servo reference of set point tracking of +10 % at the operating point of pH 11 for the GA and BFO based controllers. From the graph it is indicated that the BFO based PI controller has less oscillatory than the GA based controller. Also the over shoot and settling times for BFO based controller is very less compared with the GA based controller. It is observed that the BFO based controller track the given set point comparatively short time over than the GA based controller. The same kinds of analysis are also carried out for set point tracking of +10 % at pH 7 and pH 2.5 belongs to the operating region 2 and region 3 respectively. The servo response of the pH process at region 2 and region 3 are showed in the Figure 12 and Figure 13 for the GA and BFO controllers. Table 6 indicates that the error performance indices of the real time servo response of the pH process and it confirms that error in the BFO Controller is comparatively less than GA controller in all regions.

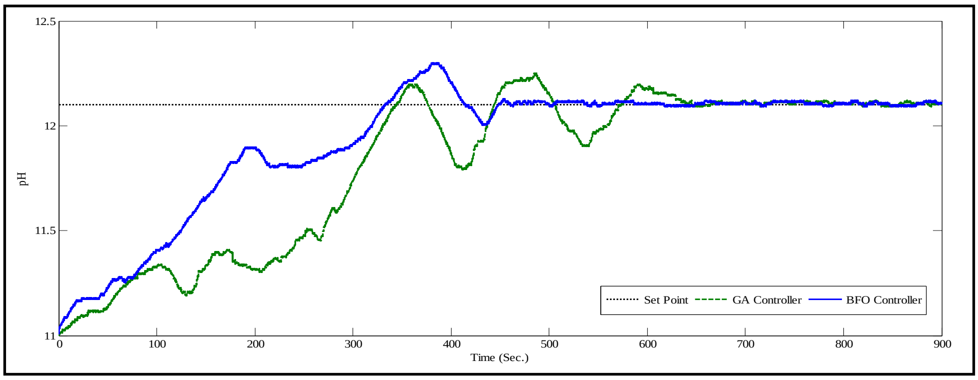

Figure 11. Servo response for set point tracking of +10 % at the operating point of pH 11

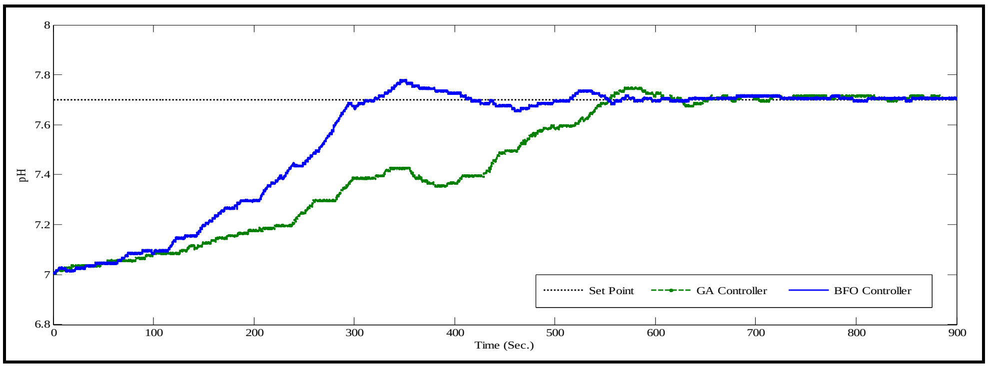

Figure 12. Servo response for set point tracking of +10 % at the operating point of pH 7

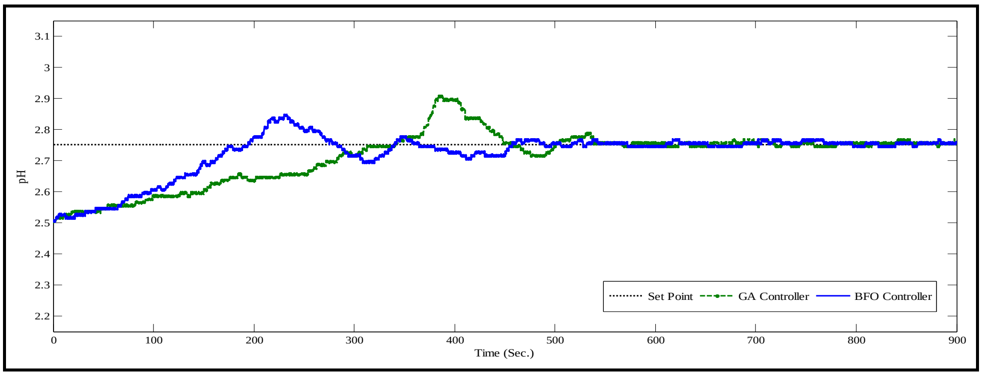

Figure 13. Servo response for set point tracking of +10 % at the operating point of pH 2.5

Table 6: Performance Indices of PI Controllers tuning for Real Time Servo Response

Operating Region	Tuning Method	IAE	ISE
Region-1	GA	274.80	197.00
	BFO	175.48	108.11
Region-2	GA	229.49	112.12
	BFO	147.21	75.01
Region-3	GA	54.82	7.86
	BFO	38.57	5.24

The capability of the controller under a sudden load change condition is studied by applying buffer water in the rate of 1 Lpm to the pH process tank in all selected operating regions. The Figure 14 indicates the performance of the GA controller and BFO controller against the step disturbance of buffer water at the region 2. The graph indicates that BFO controller react fast and again reaches the set point quikly than the GA controller. The Table 7 shows that the error performance indices of the real time regulatory response in all regions. It indicates that BFO controller provides better results than the GA based controller.

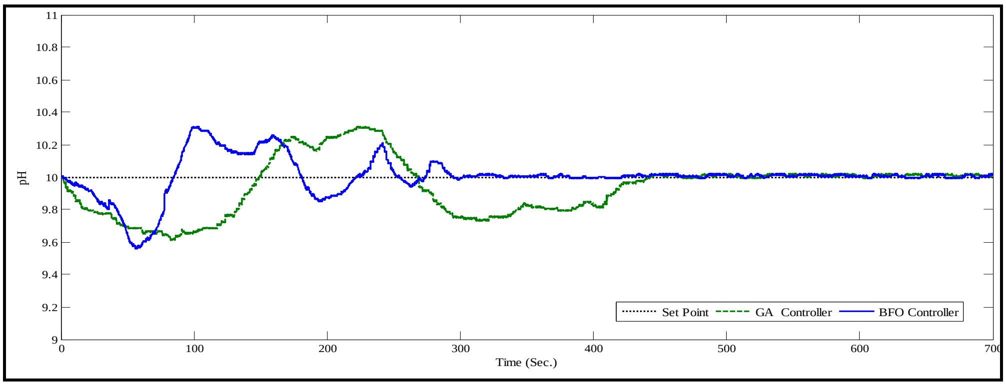

Figure 14. Regulatory response at the operating point of pH 10

Table 7: Performance Indices of PI Controllers tuning for Real Time Regulatory response

Operating Region	Tuning Method	IAE	ISE
Region-1	GA	81.24	17.49
	BFO	50.78	9.88
Region-2	GA	93.67	22.54
	BFO	46.35	9.78
Region-3	GA	111.52	39.45
	BFO	47.97	9.59

5 Conclusion

In this work, the evolutionary algorithms such as GA and BFO based PI controller are designed for a Non- Linear pH neutralization process. For the pH neutralization process , it is tested the performance the ZN, GA and BFO based PI Controller for the developed mathematical model using Servo reference tracking and Regulatory response. From the result it is analyzed that time domain specifications such as peak overshoot and settling time are comparatively less in the BFO based controller than the ZN and GA based controllers. Further the performance indices such as Integral Absolute Error (IAE), Integral Square Error (ISE), Integral Time Absolute Error (ITAE) and Integral Time Square Error (ITSE) are comparatively low in BFO based PI controller than the GA and ZN based controllers. Next, GA and BFO based PI Controller is implemented in real time for pH neutralization process. From the implementation results, it is also found that the set point tracking and disturbance rejection are better in the BFO based PI controller.

References

1. Teenu Jose, Rahul Antony, Samson Isaac, pH Neutralization In CSTR Using Model Reference Neural Network And Fuzzy Logic Adaptive Controlling Schemes ,International journal of advancements in research & technology, 2013, Volume 2, issue1, Issn 2278-7763
2. Norazzizi Nordin, SitiFathritaMohd Amir, Riyanto, and Mohamed Rozali Othman, Textile Industries Wastewater Treatment by Electrochemical Oxidation Technique Using Metal Plate. International Journal of Electrochemical Science, 2013, Vol. 8:11403 – 11415
3. Buchholt, F. and M. Kummel, Self-tuning Control of pH-Neutralization Process, Automatica, 1979, 15: 665-671.
4. McAvoy, T.J., E. Hsu, and S. Lowenthal, Dynamics of pH in Controlled Stirred Tank Reactor. Ind.Engrg. Chem. Process Des. Develop., 1972,11: 68-70.
5. Xiaohui Chen, Jinpeng Chen and Bangjun Lei,. Identification of pH Neutralization Process Based on the T-S Fuzzy Model. Advances in Computer Science, Environment, Eco informatics, and Education Communications in Computer and Information Science, 2011, 215: 579-58.
6. V. Rajinikanth and K. Latha, Controller Parameter Optimization for Nonlinear Systems Using Enhanced Bacteria Foraging Algorithm" Applied Computational Intelligence and Soft Computing, 2012,Volume 2012, Article ID 214264, 12 pages,
7. V. Vijayan and R. C. Panda, Design of a simple setpoint filter for minimizing overshoot for low order processes," ISA Transactions,2012, vol. 51, no. 2, 271–276.
8. Vijayan, V, and Rames C. Panda. "Design of PID controllers in in double feedback loops for SISO systems with set-point filters". ISA Transactions, 2012,Vol. 51, No.4, 514–521.
9. Mitchell, Melanie, An Introduction to Genetic Algorithms. Cambridge, MA: MIT Press. ISBN 9780585030944, 1996.
10. M. Kandasamy and S.Vijayachitra, A Study on Heuristic Algorithm Based Controller Optimization for pH Neutralization Process, International Journal of Applied Engineering Research (IJAER),2014, Volume 9, Number 22.
11. K. M. Passino, Biomimicry of bacterial foraging for distributed optimization and control, IEEE Control Systems Magazine, 2002,vol. 22, no. 3, 52–67.
12. M. Kandasamy and S.Vijayachitra, Performance Testing of Non-Linear pH Neutralization Using Bacterial Foraging Algorithm, Australian Journal of Basic and Applied Sciences, June 2014
13. Gopal M , Control Systems Principles and Design, 2nd Edition, TATA McGraw Hill, New Delhi,2002, 755-761.
14. Meenakshipriya, B., Saravanan, K., Krishnamurthy, K. and Bhaba, P. K. Design and implementation of CDM-PI control strategy in a pH neutralization system. Asian Journal of Scientific Research, 2012,vol. 5, No. 3: 72-92.
15. Swati, D, V.S.R. Rao , R.Pickhardi and M.Chidambaram, Non-Linear PI controller for time delayed pH System, Indian Chem. Eng.,50: 93-105
16. Ziegler, J.G. and Nichols, N.B. 1942. Optimum settings for automatic controllers. Trans. ASME, vol. 64, 759-768
17. Holland, John H., "Adaptation in Natural and Artificial Systems: An introductory analysis with applications to biology, control, and artificial intelligence", U Michigan Press, 1975.
18. Sastry, K., Goldberg, D., and Kendall, G., Genetic Algorithms. Search Methodologies: Introductory Tutorials in Optimization and Decision Support Techniques, (eds. E. Burke and G. Kendall), 2005,pp. 97–125, Springer-verlag New York Inc.,

19. Passino, K. M Biomimicry of bacterial foraging for distributed optimization and control. IEEE Control Systems Magazine, 2002,vol. 22, no. 3: 52–67.
20. Rajinikanth, V. and Latha, K. Set point weighted PID controller tuning for unstable system using heuristic algorithm, Archives of Control Science, 2012,vol. 22, no.4: 481-505.

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