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Research Article

Modeling and Control of pH Process Using Various Optimization Algorithms

V. Anusha rani [1], D.Prabhakaran[2], M.Thirumarimurugan[3] Bhuvaneshwaran V[4], Potturi Vishnu Vardhan[5]

Abstract

pH process is extensively applied in waste water treatment, chemical processes, biotechnological industries and pharmaceuticals. The aim of this study is to maintain a pH value within a specified range and to neutralize the liquid under test by regulating base flow rate until the mixture stabilizes at a set point. The present work regulates the pH of the process using PID controller which requires the usage of optimized optimal parameters. It can be obtained by using classical tuning methods such as Ziegler Nichol's, Cohen Coon, Tyreus Luyben and also by using optimization methods such GA (Genetic Algorithm), PSO (Particle Swarm Optimization) for the PID controller. The classical tuning methods and the optimization methods were compared using IAE (Integral Absolute Error), ISE (Integral Square Error), ITAE (Integral Time Absolute Error) and the results imply that GA outperforms other tuning methods.

Keywords: pH Process, waste neutralization, genetic algorithm, particle swarm optimization, IAE, ISE, ITAE

1. INTRODUCTION

Control of pH neutralization processes is a standard problem and has received considerable attention because of its importance in the chemical process industry (Jayachitra et.al. 2014). These processes are difficult to control because of their inborn nonlinearity, high sensitivity at or near the neutralization point and time-varying gains when uncertainties are present rate in flow and concentrations of neutralization agents. Thus for testing the nonlinear controllers, pH neutralization process is considered. In this work, the identification and control in pH neutralization process is very significant.

$pH = -\log_{10} [H+]$

The majority of the Industrial waste is mainly alkaline (base); this certainly troubles the environment by poisoning life onshore or offshore, including humans either through contaminated food and Water or through breathing. So it is a must to neutralize the industrial waste by neutralizing the pH. It is accomplished by maintaining the pH to around the neutral value of seven. In industry, the pH possibly will vary between 2 and 10. The neutralization process follows the following reaction:

$HCl + NaOH \longrightarrow NaCl + H_2O$

The pH neutralization system basically consists of acid and base. One feed is acidic substance and the other feed is base liquid. The added liquid is controlled by a proportional control valve by the controller while the base liquid is manually operated. To make the mixture homogeneous, a variable speed stirrer is used. pH is measured with the aid of a sensor placed into the mixing vessel and is closed to the outlet.

2. MATERIALS AND METHODS

[1]Research Scholar, Department of Chemical Engineering, Coimbatore Institute of Technology, Coimbatore, India (e-mail: anusharani151@gmail.com)
[2]Professor, Department of Chemical Engineering, Coimbatore Institute of Technology, Coimbatore, India
[3]Professor and Head, Department of Chemical Engineering, Coimbatore Institute of Technology, Coimbatore, India
[4,5]Bachelor's degree in electrical engineering under the School of Electrical Engineering, Vellore institute of technology.

pH process is considered as a continuous stirred tank reactor (CSTR) to neutralize a strong acid with a strong base manipulated by a control valve. The process consists of an acid stream (HCl), base stream (NaOH) to regulate the pH of the outlet stream, and an outlet stream (Ahmmed Saadi Ibrehem, 2011).

2.1 ASSUMPTIONS

A dynamic model of the pH process is developed by performing from the component material balance and the stability relationship under the following assumptions:

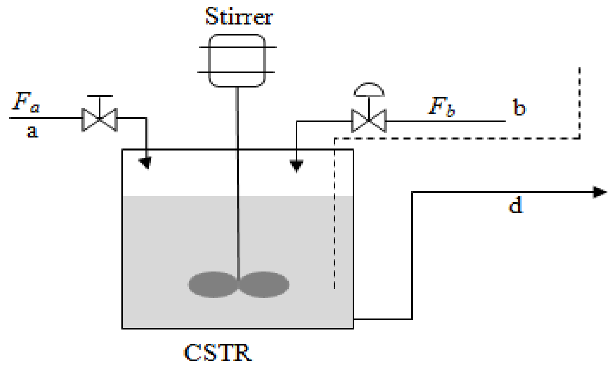
The content inside the reactor is perfectly mixed, so the concentration at outlet stream is the same as the reactor Concentration (Shashank Sultaniya et.al, 2009).

The reactor is in isothermal condition (constant temperature) and it has constant volume (hold up).

Reaction is assumed to be first order and instantaneous.

4. The solution in the reactor is electrically neutral.

2.2 MATHEMATICAL MODELING OF PH PROCESS



Fa= acid flow rate (ml/s)

Fb= base flow rate (ml/s)

Ca= concentration of acid (mol/ml)

Cb= concentration of base (mol/ml)

V= volume of the tank (ml) assumed to be constant

d= outlet flow rate (ml/s)

pH is a negative Logarithm of hydrogen ion concentration(B.Sharmila et.al. 2016) (Diwakar, T.K., et.al. 2014)

$pH = -\log[H^+]$ (1)

The chemical reaction between strong acid and strong base taking place in the CSTR is given by

$H^+ + Cl^- + Na^+ + OH^- \longrightarrow H_2O + Na^+ + Cl^-$ (2)

Thus, the ionic concentration of $[Na^+]$ and $[Cl^-]$ in outlet stream would be related to the flow rate Fa(a), Fb(b) and feed concentration of HCl & NaOH entering the tank. The component material balance is given by (Jayachitra et.al. 2014),

$V\frac{d[Cl-]}{dt} = [Cl^-]\, Fa - [Cl^-]\,(Fa + Fb)$ (3)

$V\frac{d[Na+]}{dt} = [Na^+]\, Fb - [Na+]\,(Fa + Fb)$ (4)

The concentration should also satisfy the electro neutrality equation.

$[Na^+] + [H^+] = [Cl^-] + [OH^-]$ (5)

$[H^+]\,[OH^-] = K_w = 10^{-14}$ (6)

From (3, 4,5) we can write

$[H^+] - [OH^-] = [Cl^-] - [Na^+]$ (7)

Take $X = [H^+] - [OH^-]$ (8)

From eqn (6) and (8), we get [13]

$[H^+] = \frac{X}{2} *[\sqrt{1 + 4\frac{Kw}{X2}} - 1]$ (9)

From equation (3) and (4)

$$V\frac{d[[Cl-]-[Na+]]}{dt} = [Cl^{-}]Fa - [Na^{+}]Fb - XF \qquad (10)$$

Where F =Fa + Fb

From (7) and (8), we get [14]

$$V\frac{dX}{dt} = [Cl^{-}]Fa - [Na^{+}]Fb - XF \qquad (11)$$

The equations (1),(9),(11) corresponds to pH neutralization model. Using above equations to get a first-order plus time delay transfer function for the pH process [9].

$$G(s) = \frac{3.686e{-1.5s}}{7.5s+1}$$

3. EXPERIMENTAL SETUP

The experiment was conducted at Unit Operations Laboratory, Coimbatore Institute of Technology, Coimbatore, Tamil Nadu using bench scale pH process station. An Influent stream (HCl solution) and an alkaline stream (NaOH) with 0.1N are fed to a 4 litres constant volume stirrer tank reactor and the pH is measured using pH sensor which is placed inside the tank. The objective of the process is to maintain the specific pH value by varying base flow rate and keeping the acid flow rate at a constant rate. A step change is given to the base flow rate and pH of the process was measured till it reaches steady state value, the MATLAB system identification toolbox was used to get the first-order plus dead time transfer function model.

$$G(s) = \frac{1.8148e{-0.21s}}{7.9066s+1}$$

4. DESIGN OF CONTROLLERS

4.1 PID CONTROLLER

A PID controller is a control of closed loop feedback mechanism mostly used in industrial control systems (Durgadevi, et.al. 2017) (Elena Roxana, et.al,2019). It calculates an error value as the difference between a measured variable and set point. It attempts to reduce the error by adjusting the flow rate of base process through use of a input variable. The PID controller algorithm involves three constant parameters like the proportional, the integral and derivative time constants values and it is denoted Kp, T_I, T_D.

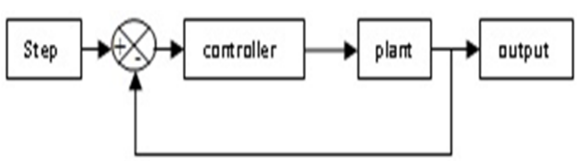


Fig-3: Block diagram of PID controller

A closed loop PID Controller

A closed loop PID Controller The controller possibly will have different structures. Different design methodologies are available for designing the controller in order to attain desired performance level.

$$Mv(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt}$$

Above Equation describes the most basic form of continuous PID algorithm in the time domain. The PID algorithm is basically a simple single equation with three control terms: proportional gain, integral gain and derivative gain. The variable mv (t) denotes the controller output while the variable e(t) is the error, which is the difference between the system output and the set point. The most commonly used simple feedback control approach applied to pH control involves the PID algorithm. PID tuning is a complex problem, even though only three constant parameters and the principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control.

4.1.1 ZIEGLER NICHOLS METHOD

Ziegler Nichols closed loop tuning technique was possibly the first accurate method to tune PID Controllers. The technique is not Widely used today because the closed loop behaviour tends to be oscillatory and responsive to uncertainty (Snehal D. Kambale , et.al. 2015).

Ziegler Nichols also proposed tuning parameter for the process that has been recognized as first-order plus time delay process have a Maximum slope of $K = Kp/\tau$ at $t = td$ for a unit step input changes.

Controller	K_P	Ti	Td
PID	$\frac{Ku}{1.7}$	$\frac{Pu}{2}$	$\frac{Pu}{8}$

Tab-1: Ziegler Nichols Tuning Rules

The obtained gain values of PID controller based on Ziegler Nichols Closed loop Oscillation method is

K_p	1.0675
K_I	0.2529
K_D	0.9883
Rise time	6.45 sec
Settling time	10.5 Sec

Tab-2: Ziegler Nichols parameters

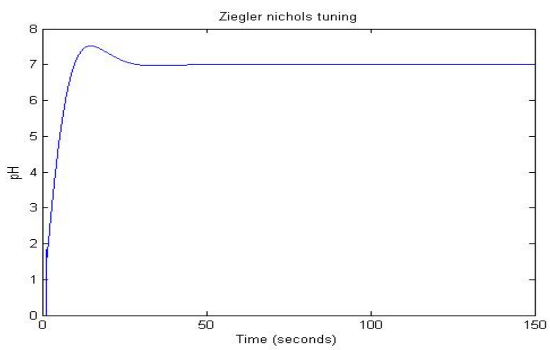


Fig-5: Response of ZN-PID Controller

4.1.2 COHEN COON METHOD

The obtained gain values of PID controller based on Cohen Coon open loop Oscillation method is

K_p	0.2169
K_I	1.8854
K_D	0.3461
Rise time	2.05 sec
Settling time	89.8 sec

Tab-4: Cohen Coon parameters

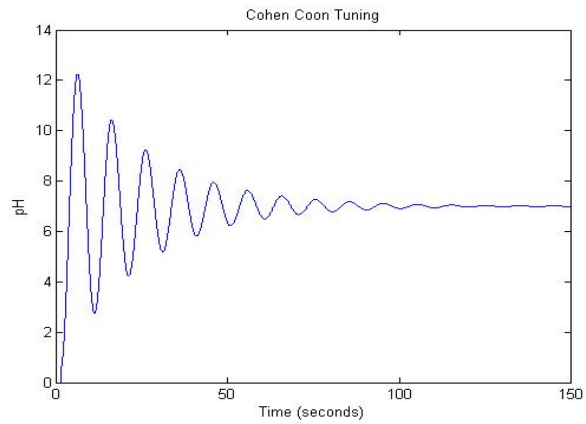


Fig-6: Response of CC-PID Controller.

4.1.3 TYREUS LUYBEN METHOD

It is a more conventional approach than Ziegler-Nicholas method and so it gives improved performance with small values for dead time (Farhad Aslam, et.al 2011). However, when the value of dead time is large it gives a slow performance. The final controller settings are different for the Tyreus-Luyben procedure and the Ziegler–Nichols method.

Tab-5: Tyreus luyben Tuning Rules

Controller	K_P	Ti	Td
PID	$\frac{Ku}{2.2}$	$2.2P_u$	$\frac{Pu}{6.3}$

K_p	0.8249
K_I	0.0575
K_D	1.2250
Rise time	26.3 sec
Settling time	59.2 sec

Tab-6: Tyreus luyben parameters

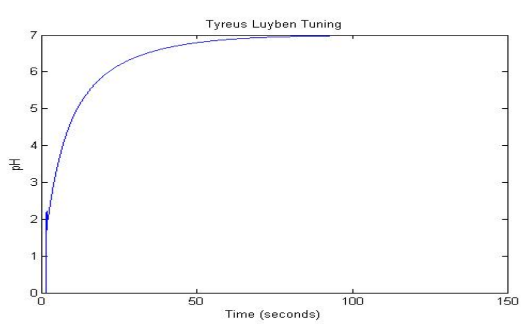


Fig-7: Response of TY-PID Controller.

4.1.4 GENETIC ALGORITHM BASED PID CONTROLLER

Genetic algorithm is an arbitrary search method that can be used to solve nonlinear system of equations and optimize complex problems (Jose T, et.al. 2013). GA uses probabilistic transition rules instead of deterministic rules and handles a population of possible solutions known as individuals or chromosomes that evolve iteratively. All iteration of the algorithm is termed a generation. The evolution of solutions is simulated through a fitness function and inherent operators such as reproduction, crossover, and mutation. Genetic algorithm as illustrated in below diagram is typically initialized with a random population. This population is generally represented by a real-valued number or a binary string called a chromosome. The performance of the individual is measured and assessed by the objective function, which assigns each individual a corresponding number called its fitness. The strength of each chromosome is assessed and a survival of the fittest approach is applied (Jose T, et.al. 2013). In this work, the error value is used to assess the fitness of each chromosome (V.Anusharani , et.al 2020). The following are the main operations in a genetic algorithm Reproduction,crossover and Mutation.

Genetic Algorithm Parameters

Parameter	Value/type
Maximum generations	100
Selection	Uniform
Cross over	Single point cross over
Mutation	uniform
No. of iterations	17
Kp	0-20
Ki	0-15
Kd	0-5

Tab-7: GA parameters

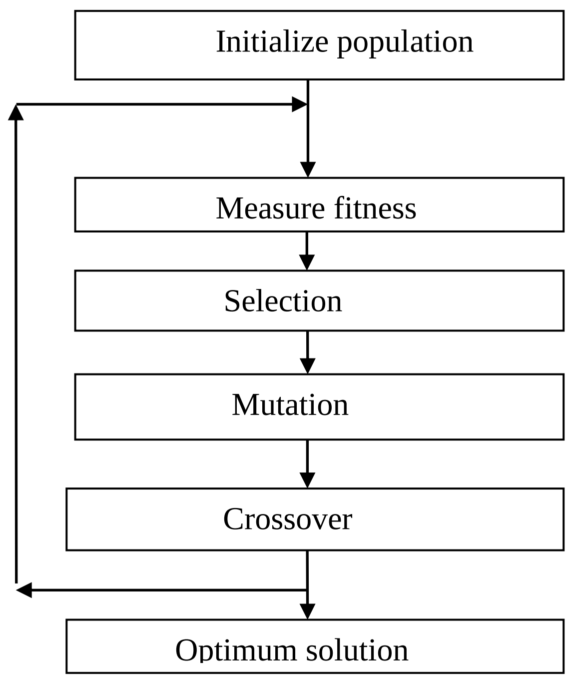


Fig-8: Flow chart of genetic algorithm

Parameters	Values
K_p	13.8315

K_I	12.9518
K_D	0.1056
Rise time	2.05 sec
Settling time	3.85 sec

Tab-8: Time domain Specifications of GA Response

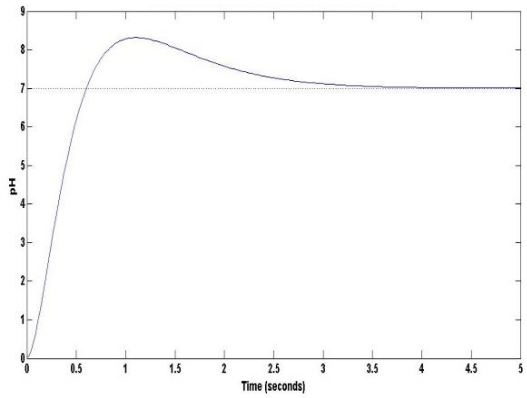


Fig-9: Response of Genetic algorithm.

4.1.5 PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

Particle Swarm Optimization is a population based stochastic optimization technique first introduced by Kennedys and Ebert in 1995, encouraged by social behaviour of bird flocking or fish schooling, it is moreover based on swarm intelligence. The PSO has no analytically calculation method and it has no definite mathematic foundation (Kabila V, et.al 2015). PSO is extensively used in engineering applications due to its high computational efficiency, easy implementation and stable convergence and there are few parameters to adjust and has been successfully useful in many areas such as function optimization, fuzzy gain scheduling, PID Auto tuning and fractional order PID controller design (Teenu Jose, 2013).

Tab-9: PSO parameters

PSO PARAMATERS

PARAMETER	VALUE
Velocity constants(C1)	2
Velocity constants(C2)	2.05
Inertia factor	0.6
No. of particles	50
Searching iterations	50
Fitness	IAE

Tab-10: PSO tuning values

K_p	7.9172
K_I	1.9387
K_D	10.9447
Rise time	6.37 sec
Settling time	19.6 sec

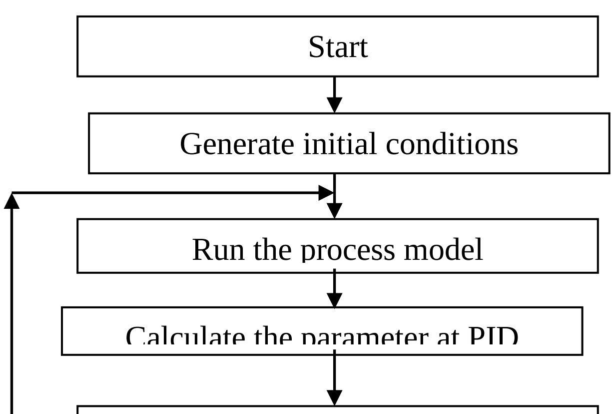


Fig-10: Flow chart of PSO

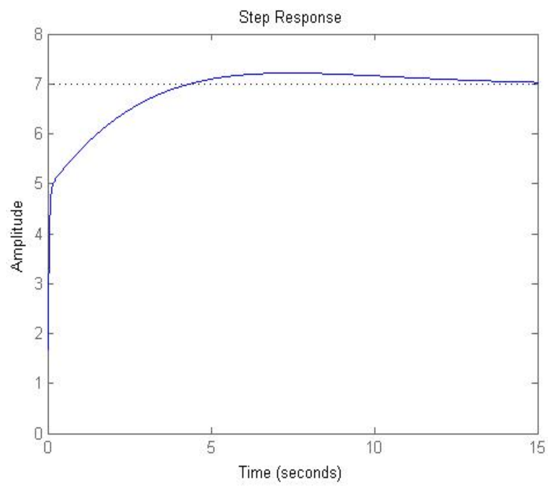


Fig-10: Response of PSO

Tuning methods	**Zieger nichols**	**Cohen coon**	**Tyrees luyben**	**GA**	**PSO**
K_p	1.0675	0.2169	0.8249	13.8315	10.9447
K_i	0.2529	1.8854	0.0545	12.9518	7.9387
K_d	0.9883	0.3461	1.2550	0.1056	1.9387
Rise time(sec)	6.45	2.05	26.3	2.05	6.37
Settling time(sec)	22.9	89.8	56.2	3.85	19.6
IAE	29.48	84.49	64.29	4.243	4.693
ISE	67.93	216.3	138.9	15.96	11.63
ITAE	467.8	1615	1032	2.756	57.64

Tab-11: Comparison of controller

4.2 PERFOR MANCE ANALYSIS OF CONTROLLER

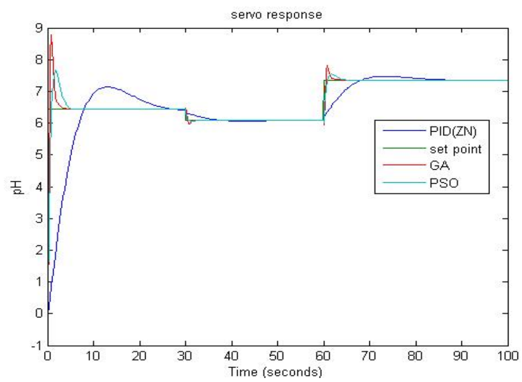


Fig-12: Servo Response of PID Controller

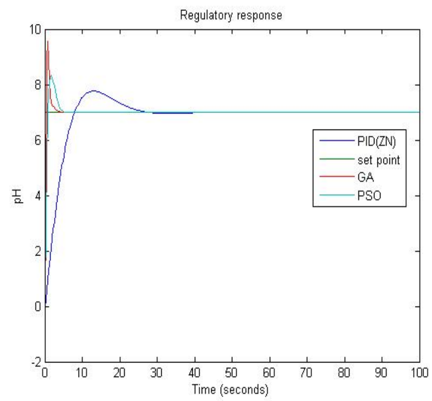


Fig-13: Regulator Response of PID Controller

4.3 DESIGN OF MPC CONTROLLER

Model predictive control (MPC) is a class of computer control algorithms to precise process model to predict the future response of a plant that it allows the current timeslot to be optimized, while keeping future timeslots in account. Future control inputs and the future plant responses are predicted using a system model and they are optimized at regular intervals with respect to a performance (W. Wang, et.al.2014) (Yogesh Chaudhari, 2013). MPC algorithm attempts to optimize future plant performance by computing a sequence of future manipulated variable adjustments at each control interval. If an accurate dynamic model of the process is available, model and current measurements can be used to predict future values of the outputs. Therefore the appropriate changes in the input variables can be calculated based on both predictions and measurements (Zainal Ahmad, et.al, 2007). In MPC applications, the output variables are also referred to as controlled variables, while the input variables are also called manipulated variables. Measured disturbance variables are called feed forward maintaining the Integrity of the Specifications.

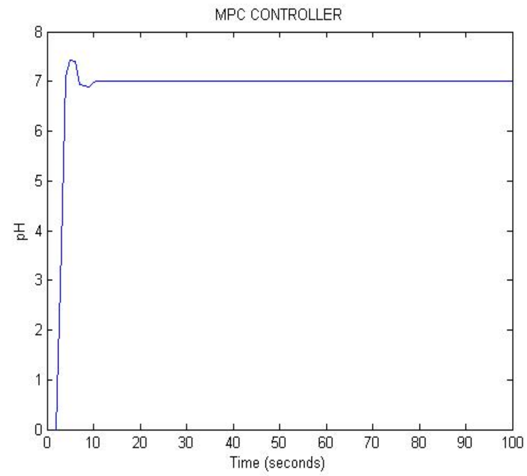


Fig-14: Response of MPC Controller

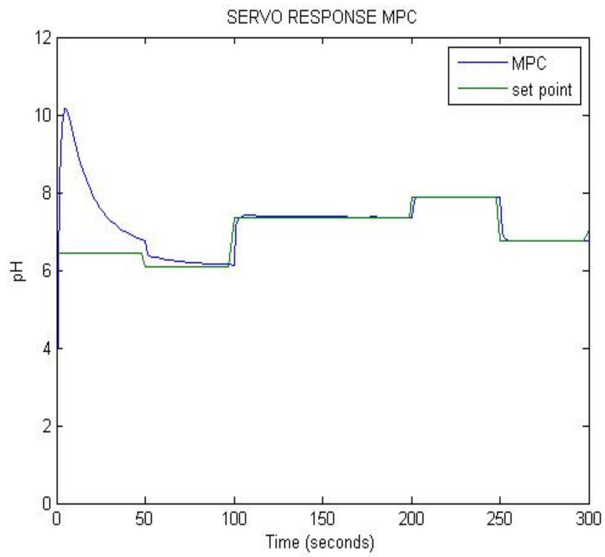


Fig-15: Servo response of MPC controller

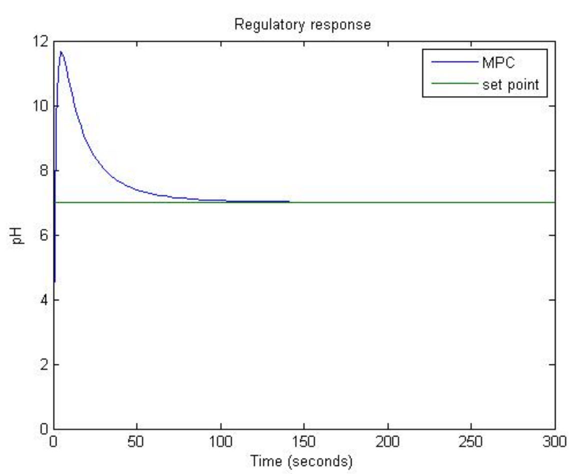


Fig-16: Regulatory Response of MPC Controller

5. CONCLUSION

The controlling of nonlinear system is a very difficult task to perform. Hence, a linear model is obtained for pH process from experimentation. Proper tuning values are obtained for different controllers by using obtained model. The pH value is controlled in simulation using various control schemes such as ZN-PID, Tyreus Luyben-PID and optimization methods such GA (Genetic Algorithm), PSO (Particle Swarm Optimization) for PID controllers, MPC. The tuning methods of PID, optimization methods and MPC were compared in terms of the IAE, ISE, ITAE and the results imply that GA outperforms the other control methods.

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