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Designing of Controllers for pH Neutralization Process

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Abstract— The primary objective of this paper is to design controllers for the pH neutralization process that is modeled based on the reaction between strong basic solution (NaOH) and strong acidic solution (HCl) in Continuous Stirred Tank Reactor (CSTR). From open loop response pH system is considered as First Oder plus Dead time process. Based on the model Branica et al method, PSO based I-PD controller, MPC are designed in Metrics of Error indices and Time Domain Specifications for acid, neutral and base region. Comparison of Performance analysis are made between PID, PSO based I-PD and MPC in acid, Neutral and base region by keeping set point in 5, 7 and 12.
Key words—pH neutralization, PID controller, PSO based I-PD controller, MPC.

I. INTRODUCTION

Now a days in textile industrial process huge number of useless water comes out as pollutants, in which some of them are costly and difficult to treat. Characteristics of these waste water may change significantly based on industries. The most important scope of waste water treatment plant is to control effectiveness of these harmful waste water. The most important characteristics of these waste water was that the pH value, proper control of pH value is necessary. Waste comes from the textile industries is rarely neutral. Acid is a substance which ionizes in water inorder to give hydroxide ion, while base is the substance which ionize in water and give hydroxyl ion. In this paper strong acid (HCl) made to react with the strong base (NaOH) for maintaining of pH value at neutral, acid and base region. Controlling of pH in neutral region is a important process as small change in input gives the huge change in the output. pH value has to be controlled for minus or plus 1 value of 7 to get the required controlling of pH for the wastage coming out from process industries. pH above 9 and pH below 4 are considered as injurious wastage to the surroundings. The first stage of the work is to define the goal or the needed specification, for the developed system at the end of the modeling process. This is to develop a pH process system which is adequate in terms of the intended application that is to develop an improved form of the controller. It is decided that the simulation model has to be represent the behaviour of the pH neutralization process with sufficient accuracy in terms of steady state and transient performance measures that commonly provide a basis for control system design. The reactor vessel that is used here has a volume of 5L and can be emptied by a drain pipe that is controlled by a valve. The working pressure and temperature, at which the reactor used, will be depend upon the size, design and nature of the material that is been used for manufacturing. Since every material will tend to change its strength according to the variation in temperature, any pressure rating has to be stated in terms of the temperature in which it is applicable. We have selected 350-bar pressure-rated reactor vessel, 140-bar pressure-rated special pH probe, and 400-bar pressure-rated special positive displacement dosing pumps for real-time experiments. Communication among them is established using Delphi 6 software which is installed on a PC. The Multiport Industrial Serial Server SE5008/SE5016 in the system was equipped with popular serial communication ports RS232, RS485, and RS422. It was a gateway between ethernet (TCP/IP) and serial communication ports. It allows most of the serial devices to be joined to a new or existing ethernet network. The simulation model of the system used is shown in Figure 1.

The pressure that is inside the vessel is kept at an elevated value by using pneumatic pressure building technique in the environmental CSTR system by a solenoid valve.

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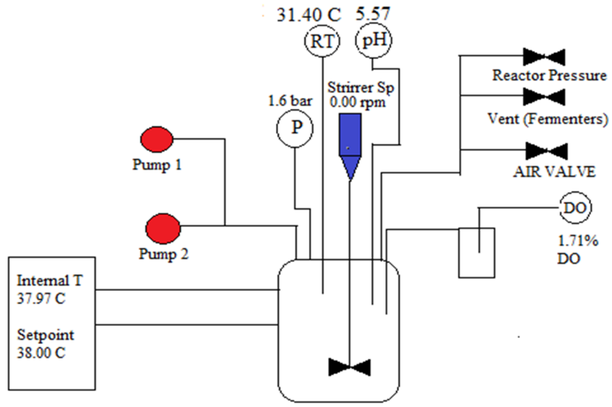

Figure 1. Diagram of simulation model for the system

The CSTR is always kept closed in order to maintain the pressure. Acid/base is send to the vessel by using a special high-pressure pump called 400-bar pressure-rated positive displacement pump at the rate of 1 ml/min. Acid/base that is added is well mixed using a hermetically sealed magnetic stirrer that rotates at a speed of 300 rpm. Special type of pH probe is used inorder to measure the pH inside the setup since it should be able to withstand in the elevated pressure. In this experiment, strong acid (HCl) and strong base (NaOH) of 1 molarity is prepared and used to conduct real-time experiments. The model parameters of the system and pH probe details are given in Tables 1 and 2.

Table 1 Model parameters of the system

Name	Value
Number of fermenter vessel	1
Fermenter vessel volume	5 L
Working pressure	Up to 350 bar
Working temperature	30 C
Reactor material construction	Corrosion 316 atainless steel with PTFE inner coating
Sterilization	There is a steam sterilization all the reactor vessels before and after the process

Table 2 pH probe details

Name	**Value**
Sensitivity of probe in voltage	mV
Resolution of probe	0.001
Range	0-14
Pressure rating	Maximum 140 bar

Considering the delay factors, system is modeled as FOPDT system whose general transfer function model is given below,

$$G(s) = \frac{Ke^{-\tau_d s}}{\tau s + 1}$$

The transfer function model of the system obtained from the open-loop response is

$$G(s) = \frac{0.276e^{-5.005s}}{3.2s + 1}$$

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II. PID CONTROLLER

A proportional integral derivative controller (PID controller) was a generic control loop feedback mechanism (controller) widely used in most of the industrial applications. A PID controller can calculate an "error" value as the difference between a measured process variable and a desired set point value. The aim of controller is to minimize the error by adjusting the process control inputs. The PID controller calculation algorithm is most important that involves three separate constants parameters and is accordingly sometimes called three term control and it denoted as P, I, and D. Simply put, these values can also be interpreted in terms of time: P value depends on the present error, I value is the accumulation of past errors, and D value is a prediction of future errors, based on current rate of change. By tuning these three parameters in the PID controller algorithm, the controller will work to provide control action designed for specific process requirements. Figure 2 shows the block diagram of the PID controller. Table 3 shows the tuning parameter of PID controller using Branica et al method.

Table 3 Tuning parameter of the controller

Controller	Kp	Ki	Kd
Branica et al method	2.66	0.537	2.912

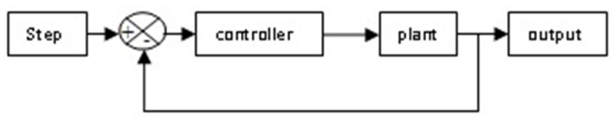

Figure 2 Block diagram for PID controller

III. PSO BASED I-PD CONTROLLER

The I-PD is a another kind of PID structure and is generally most popularly used in industries, wherever a sleek point chase is needed. Particle swarm optimization (PSO) is a method with regard to a given measure of quality optimizes a problem and improves the solution. PSO optimizes a problem by moving the particles around in the search-space according to simple formula over the particle's position and velocity. It gives the local, best, global position and the better positions are updated . PSO moves the swarm towards the best solutions. There are two PID block in first block K_p and K_d are kept as 0. And in second PID block K_i value is kept 0. Now the PSO algorithm is used to run the block. This gives the appropriate values which is entered in the block. Now the system settles smoothly. The block diagram of I-PD controller is shown in Figure 3.

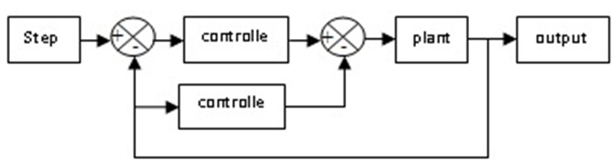

Figure 3 Block diagram for PSO based I-PD controller

Table 4 shows the tuning parameter of PSO based I-PD controller

Table 4 The Tuning Parameter Of The Controller

	I	PD
K_p	0	0.4715
K_i	0.0327	0
K_d	0	0.0388

IV. MODEL PREDICTIVE CONTROLLER

The Model Predictive Control (MPC) Toolbox is a accumulation of functions (commands) developed for the investigation and design of model predictive control (MPC) systems. Control plan schedules in light of the MPC idea have discovered wide acknowledgment in modern applications and have been considered by the educated community. The purpose behind such system is the capacity of MPC outlines to get elite control frameworks equipped for working without master intercession for drawn out stretches of time. MPC methods are then evaluated in the light of these issues so as to bring up their favorable circumstances in configuration and usage. The use of MPC to non-linear system is inspected and it is demonstrated that its principle attractions persist. The block diagram of MPC Controller is shown in Figure 4

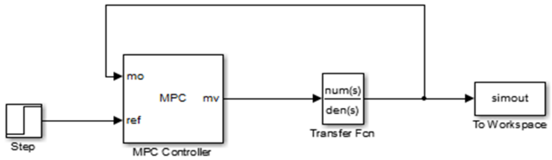

Figure 4 Block diagram of MPC controller

V. RESULT AND DISCUSSION

The response of the controller obtained in MATLAB in Acid, Neutral and Base region is shown in Figure 5,6,7. From these response the time domain specification and error indices are calculated.

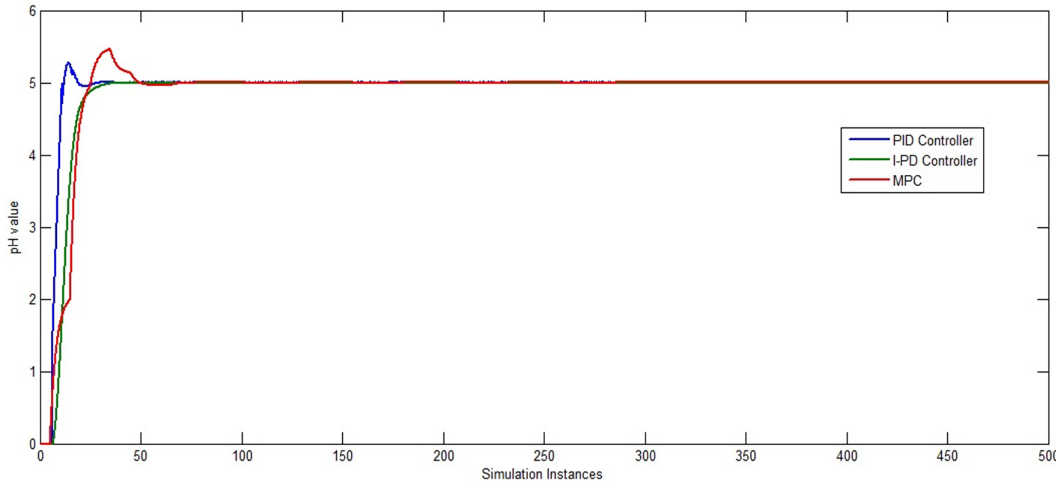

Figure 5 Response of the controllers in Acid region

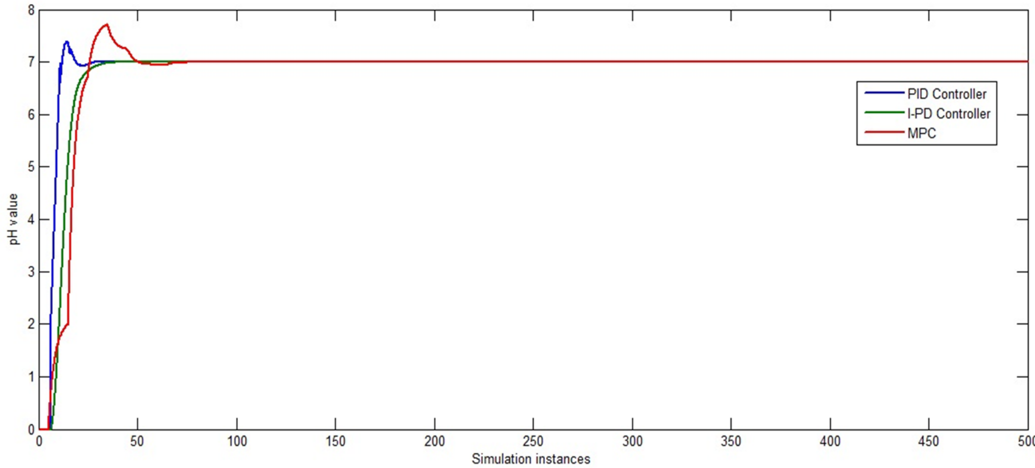

Figure 6 Response of the controllers in Neutral region

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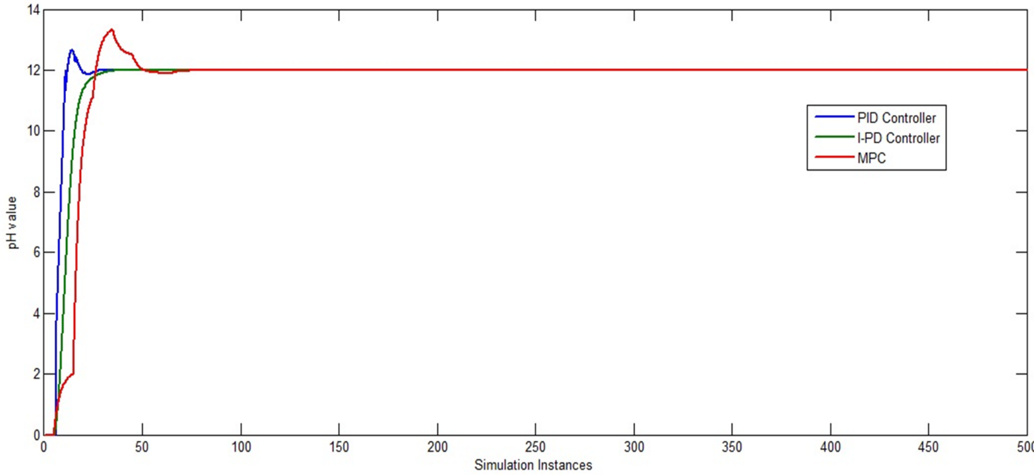

Figure 7 Response of the controllers in Base region

The time domain specification and Error indices are found and are listed in Table 5 . The time domain specifications like settling time, rise time and peak overshoot are identified and listed in Table 5. The error indices like Integral Absolute Error(IAE) and Integral Square Error (ISE) are also calculated and tabulated in Table 5

Table 5 Time domain Specification of controllers

Controllers	Region	Rise time (sec)	Peak overshoot	Settling time (sec)	IAE	ISE
Branica et al method	ACID	6.155	0.28	28.13	2461	1.22e+04
	NEUTRAL	6.155	0.39	28.85	3446	2.41e+04
	BASE	6.155	0.67	29.58	5907	7.08e+04
PSO based I-PD controller	ACID	10.141	0	40.4	2439	1.2e^4
	NEUTRAL	10.141	0	37.1	3414	2.31e^4
	BASE	10.141	0	33.8	5853	6.99e^4
Model predictive controller	ACID	14.899	0.54	66.9	2425	1.21e+4
	NEUTRAL	14.9	0.785	70.5	3390	2.37e+4
	BASE	14.9	1.41	77.4	5804	6.95e+4

VI. CONCLUSION

In this paper work PID, PSO based I-PD, MPC are proposed to handle a unique nonlinear pH neutralization process. Controllers track the response in desired set point at acid, base and Neutral region. The results were compared among different controllers in metrics of Time domain specifications and performance of Error indices. The settling time of PID is less when compared to I-PD and MPC. But it is found that I-PD controller gives smooth response which is the necessary for the process

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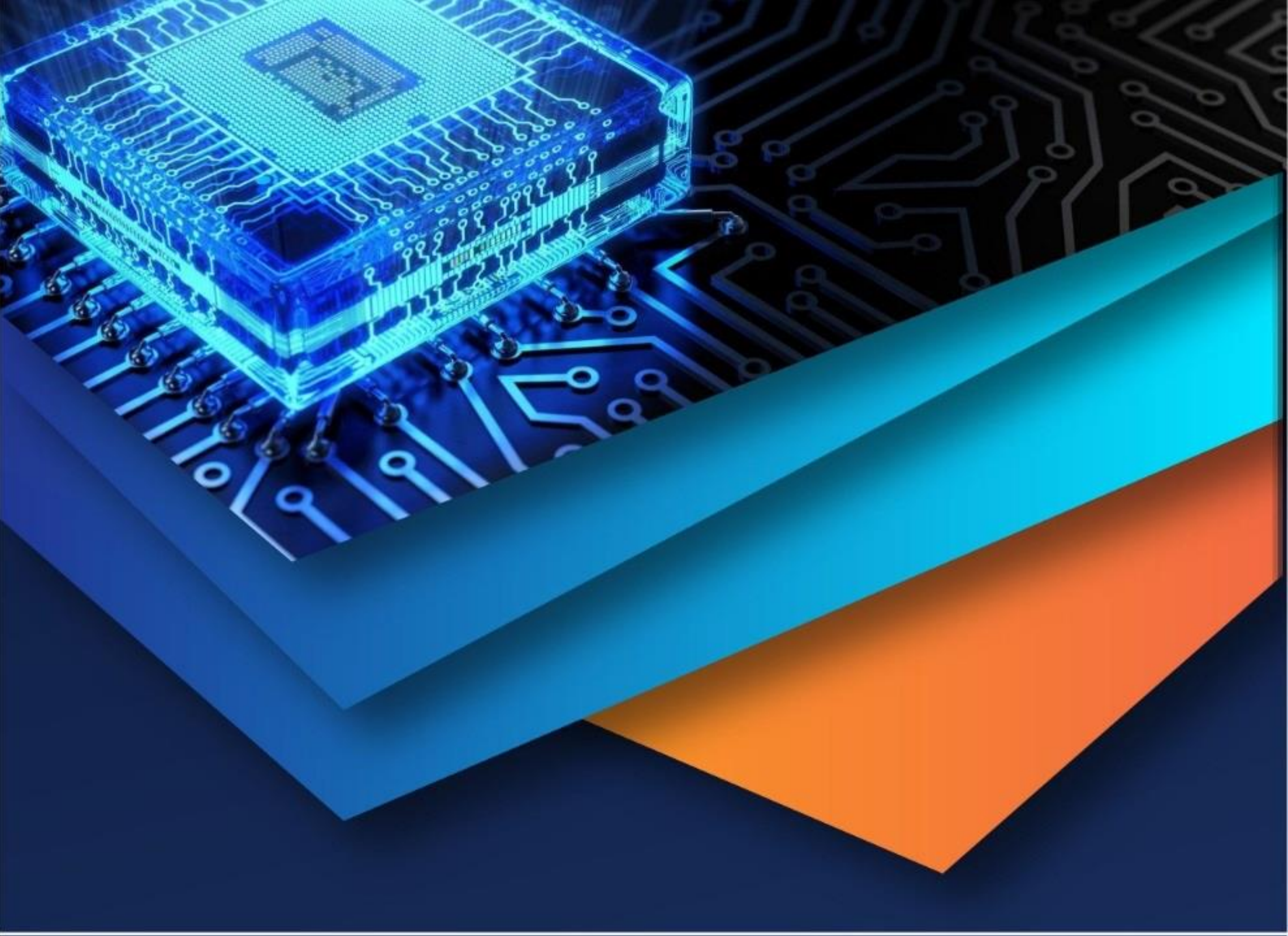

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