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Convex Optimization Based Adaptive PID Controller in CSTR Plant

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Abstract— The proposed PSO-PID and HU-PID controller is tested by using Mat-lab Simulink program and their performance is compared. It is clear from Table 5.1 that a HU-PID controller is best implemented. Also, the PID controller parameters obtained from HU algorithm gives better tuning result as compared to PSO-PID rule. The major impact of HU is on integral square error and peak overshooting. Both are minimized by HU-PID controller. HU-PID is a very simple concept and paradigms can be implemented in a few lines of computer code.

Keywords- CSTR, PID, Control, Optimization.

I. INTRODUCTION

Process control has become increasingly important in the process industries as a consequence of global competition, rapidly changing economic conditions, and more stringent environmental and safety regulations. Process control is also a critical concern in the development of more flexible and more flexible and more complex processes for manufacturing high value added products. Any study of process control must begin by investigating the concept of a process. It is generally thought of as a place where materials and most often, energy come together to produce a desired product. From a control viewpoint the meaning is more specific. A process is identified as leaving one or more variables associated with it that are important enough for their values to be known and for them to be controlled. One of the complex and difficult in process control ids control tuning. Control tuning is the major key issue to operate the plant. Process tuning is a key role in ensuring that the plant performance satisfies the operating objectives. Controller tuning inevitably involves a trade-off between performance and robustness. The performance goals of excellent set-point tracking and disturbance rejection should be balanced against the robustness goal of stable operation over a wide range of conditions.

The Process control system is the entity that is charged with the responsibility for monitoring outputs, making decisions about how best to manipulate inputs so as to obtain desired output behavior, and effectively implement such decisions on the process [1]. It is therefore convenient to break down the responsibility of the control system into the following three major tasks:

- Monitoring process output variables by measurements
- Making rational decisions regarding what corrective action is needed on the basis of the information about the past current and desired state of the process
- Effectively implementing these decisions on the process

Control Systems

Control systems are classified into two general categories open loop and closed loop control systems.

Open loop control systems are control systems in which the output has no effect upon the control action. In an open-loop control system, the output is neither measured nor fed back for comparison with the input. For example, in a washing machine, soaking, washing, and rinsing are operated on a time basis. The machine does not measure the output signal namely the cleanliness of clothes. In any open-loop control system the output is not compared with the reference input. Hence, for each reference input,

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there corresponds a fixed operation condition. Thus, the accuracy of the system depends on the calibration. In the presence of disturbance, an open-loop control system will not confirm the desired task. Open-loop control can be used in practice only if the relationship between the input and output is known and if there are neither internal nor external disturbances. Clearly such systems are not feedback control systems. Any control system, which operates on a time basis, is open loop. The block diagram of the open loop control system is shown in Figure 1.

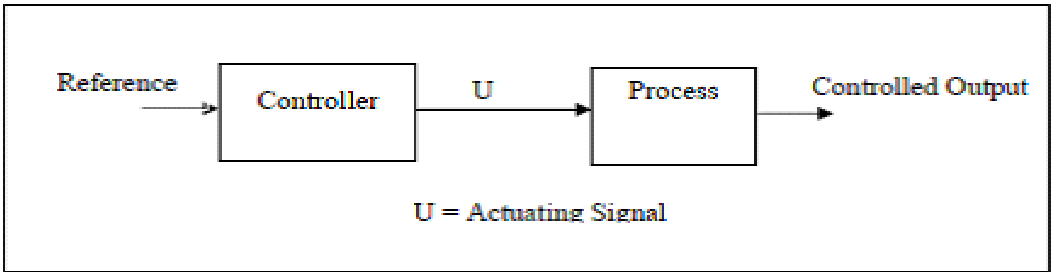

Figure1 Block Diagram of Open Control System

Advantages of open loop control systems are simple construction, very much convenient when output is difficult to measure, and such systems are easy from maintenance point of view. Generally, these are free from the problems of stability. Such systems are simple to design, economical and give inaccurate results if there are variations in the external environment i.e. they cannot sense environmental changes. They are inaccurate and unreliable because accuracy of such system is totally dependent on the accurate pre-calibration of the controller. Similarly they cannot sense internal disturbances in the system, after the controller stage. To maintain the quality and accuracy, recalibration of the controller is necessary from time-to-time. To overcome all the above disadvantages, generally closed loop systems are used in practice.

Closed loop control system is one in which the output signal has a direct effect upon the control action. That is, a closed-loop control system incorporates feedback element. The actuating error signal, which is the difference between the input signal and the feedback signal (which may be the output signal or function of the output signal and its derivatives), is fed to the controller so as to reduce the error. In other words, the term 'closed loop' implies the use of feedback action in order to reduce the system error. The error signal produced in the automatic controller is amplified and the output of the controller is sent to the control value in order to change the valve opening for steam supply so as to correct the actual water temperature. If there is no error, no change in the valve operation is necessary. The block diagram of the closed loop control system is shown in Figure 2.

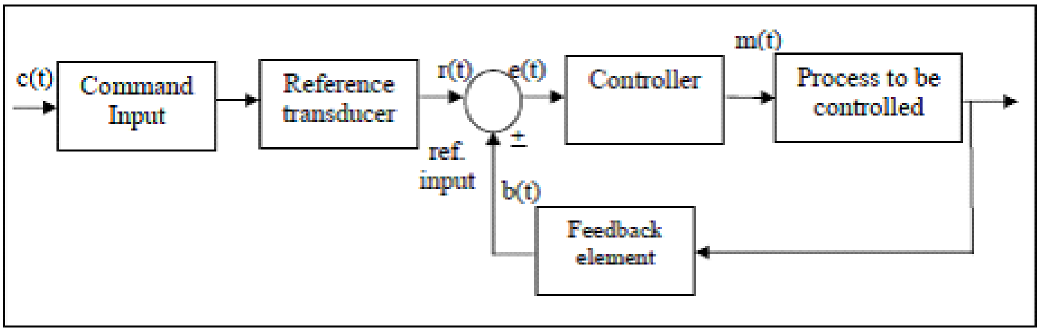

Figure 2 Block diagram of closed loop system

The control of a complex system by a human operation is not effective because of the many interrelations among various variables. Automatic control systems eliminate any human error in operation. If high precision control is necessary, control must be automatic. System in which the controlling action or input is somehow dependent on the output or changes in output are called closed loop system. Feedback is a property of the system by which it permits the output to be compared with the reference input so that appropriate controlling action can be decided. In such a system, output or part of the output fed back to the input for comparison with the reference input applied to it. It is not possible in all the systems that available signal can be applied as input to the system. Depending upon the nature of controller it is required to reduce it or amplify to change its nature. This changed input as per requirement is called reference input, which is to be generated by using reference transducer. The main excitation to make the system called its command input, which is then applied to the reference transducer to generate reference input. The output, which is to be decided by feedback element, is fed back to the reference input. The signal, which is output of feedback element, is called 'feedback signal' b(t). It is then compared with the reference input giving error signal e(t)=r(t)+b(t). When feedback signal is positive it is called positive feedback system and if the signal is negative it is called negative feedback system. This modified error signal then actuates the actual system and produces the controlled output c(t).

An advantage of closed loop control system is that the use of feedback makes the system response relatively insensitive to external disturbances and internal variations in the system parameters. It is thus possible to use relatively inaccurate and inexpensive components to obtain the accurate control of a given plant, whereas this is impossible in the open-loop case. From the point of ability, the open-loop control system is easier to build since stability is not a major problem. On the other hand, stability is always

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a major problem in the closed-loop control system since it may tend to over correct errors, which may cause oscillations of constant or changing amplitude. It should be emphasized that for systems in which the inputs are known ahead of time and in which there are no disturbances, it is advisable to use open-loop control. Closed-loop control systems have advantages only when unpredictable disturbances and/or unpredictable variations in system components are present. A proper combination of open-loop and closed-loop control is usually less expensive and satisfies the overall system performance. The design and implementation of smart structural systems necessitates the integration of mechanical systems with sensors, actuators, and control systems for higher performance and self-diagnosis capabilities. A key element of this combination is the integration of the control system into the structure [2]. Control is important for most industrial processes to the avoid disturbances which degrade the overall process performance, and a great deal of work is being done in this field [3]. The nice thing about tuning a PID controller is that the user need not have a good understanding of formal control theory to do a fairly good job of it. About 90% of the closed-loop control applications in the world do very well indeed with a controller that is only tuned fairly well.

Process Control System

The process control system is the entity that is charged with the responsibility for monitoring outputs, making decisions about how best to manipulate inputs so as to obtain desired output behavior, and effectively implement such decisions on the process [4]. The process has a property called self-regulation. A self- regulating system does not provide regulation of a variable to any particular reference value. In process control, the basic objective is to regulate the value of some quantity. To regulate means to maintain that quantity at some desired value regardless of external influences. The desired value is called the reference value or set point. In many industrial process control systems, the control process is complex in mechanism, and varying with time. So, general PID control is very difficult to obtain satisfactory effects because it is not self-adaptive for many varying factors such as parameter varying.

The process dynamics are concerned with analysing the dynamic (i.e., time dependent) behavior of a process in response to various types of inputs. In other words, it is the behavior of a process as time progresses [5,6]. A process is a progressively continuing operation that concedes of a series of controlled actions or movements systematically directed towards a particular result or end. When the automatic control is applied to system, which is designed to regulate the value of some variable to a set point, it is called process control. Examples are chemical, economic, and biological processes. An automatic regulation system in which the output is a variable such as temperature, pressure, flow, liquid level, or pH is called a process control system. Process control is widely applied in industry. Programmed control such as the temperature control of heating furnaces in which the furnace temperature is controlled according to preset program is often used in such systems. For example, a preset program may be such that the furnace temperature is raised to a given temperature in some given time interval and then lower to another given temperature in some other given time interval. In such program control, the set point is varied according to the present time schedule. The controller then functions to maintain the furnace temperature close to the varying set point. It should be noted that most process control systems include servomechanism as an integral part [7].

Process engineers are often responsible for the operation of chemical processes. As these processes become larger scale and/or more complex, the role of process automation becomes more and more important. The objective of this textbook is to teach process engineers how to design and tune feedback controllers for the automated operation of chemical processes. A conceptual process block diagram for a chemical process is shown in Figure 3. Notice that the inputs are classified as either manipulated or disturbance variables and the outputs are classified as measured or unmeasured in Figure 3a. To automate the operation of a process, it is important to use measurements of process outputs or disturbance inputs to make decisions about the proper values of manipulated inputs. This is the purpose of the controller shown in Figure 3b; the measurement and control signals are shown as dashed lines.

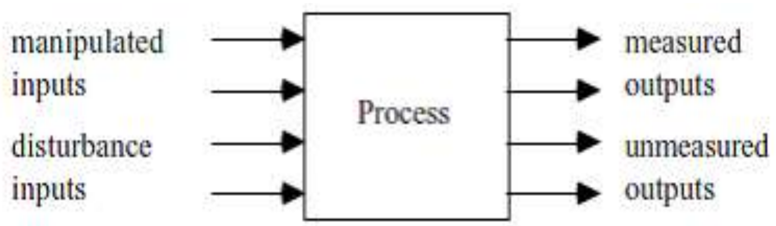

Figure 3a: Input/output Representation

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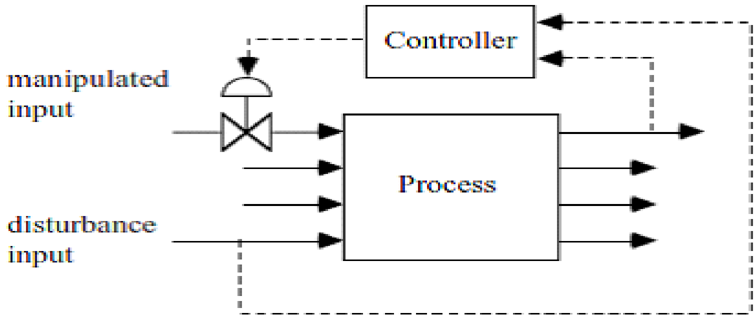

Figure 3b: Control representation

Figure3: Conceptual Process Input/output Block Diagram

The development of a control strategy consists of formulating or identifying the following:

1. Control objective.

2. Input variables—classify these as manipulated or disturbance variables; inputs may change continuously, or at discrete intervals of time.

3. Output variables—classify these as measured or unmeasured variables; measurements may be made continuously or at discrete intervals of time.

4. Constraints—classify these as hard or soft.

5. Operating characteristics—classify these as continuous, batch, or semi continuous (or semi batch).

6. Safety, environmental, and economic considerations.

7. Control structure—the controllers can be feedback or feed forward in nature.

II. LITERATURE REVIEW

This section covers the research findings related to tuning of industrial processes through different tuning algorithm. There are number of control strategies and methods for controlling concentration and temperature of process model which have been implemented by researchers from all over the world. The formulation of variety objective of overcoming the nonlinearity problem by having a robust and effective controller as compared to the conventional techniques.

A.Jayachitra et al.(2014): Genetic algorithm (GA) based PID (proportional integral derivative) controller has been proposed for tuning optimized PID parameters in a continuous stirred tank reactor (CSTR) process using a weighted combination of objective functions, namely, integral square error (ISE), integral absolute error (IAE), and integrated time absolute error (ITAE). Optimization of PID controller parameters is the key goal in chemical and biochemical industries. PID controllers have narrowed down the operating range of processes with dynamic nonlinearity. In this work, globally optimized PID parameters tend to operate the CSTR process in its entire operating range to overcome the limitations of the linear PID controller. The simulation study reveals that the GA based PID controller tuned with fixed PID parameters provides satisfactory performance in terms of set point tracking and disturbance rejection [1].

Ali Zribi et al.(2015): In this paper, a novel adaptive tuning method of PID neural network (PIDNN) controller for nonlinear process is proposed. The method utilizes an improved gradient descent method to adjust PIDNN parameters where the margin stability will be employed to get high tracking performance and robustness with regard to external load disturbance and parameter variation. Simulation results show the effectiveness of the proposed algorithm compared with other well-known learning methods [2].

Meera Viswavandya et al.(2016): This paper proposes the application of fractional order PID controller (FOPID) for reactive power compensation and stability analysis in a stand-alone micro grid. For enhancement of voltage stability and reactive compensation of the isolated system, a SVC based controller has been incorporated. This paper emphasizes the role of fractional PID based SVC controller for reactive power management and improved stability in the stand alone micro grid, as it provides a special advantage of having two more degree of freedom for accurate tuning in comparison with the conventional controller The system performance, particularly the variations in different parameters values are studied properly with different input parameters and loading conditions. Further improvement of stability margin and optimisation of the system parameters have been achieved by the controller, based on Imperialist competitive algorithm [3].

Geetha M et al(2013): Tuning the parameters of a controller is very important in system performance. Ziegler and Nichols tuning method is simple and cannot guarantee to be effective always. In order to overcome the parameter uncertainties, enhance the fast tracking performance of a process system, a brand-new two-dimension PID fuzzy controller, fuzzy PI+ fuzzy ID, is proposed in this paper. The self-tuning fuzzy PI+ fuzzy ID controller is fast; computing on-line easily and can reduce stability error. To

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demonstrate the advantages of the fuzzy PI+ fuzzy ID controller has been applied to an application in the control of Continuous Stirred Tank Reactor (CSTR) level loop. The simulation and real-time implementation were executed and its results show that the proposed control scheme not only enhances the fast tracking performance, but also increases the robustness of the system. From the simulation it is clear that there is substantial improvement in the Self-tuning Fuzzy PID controller in terms of peak overshoot, settling time, peak time, rise time, Integral Square Error (ISE) and Integral Absolute Error (IAE)[4].

Jau-Woei Perng et al.(2016): In this study, the stochastic inertia weight particle swarm optimization (SIWPSO) algorithm and radial basis function neural network (RBFNN) methods were used to identify the optimal controller gain for the fractional order proportional integral derivative (FOPID) controller of time-delay systems; furthermore, a graphic approach was used to plot 3D stability regions in the kp, ki , and kd parameter space. This paper presents an intelligent SIWPSO-RBF algorithm for identifying the optimal solution for a FOPID control system. To explain how to use the SIWPSO-RBFNN method, this paper presents two cases describing how the proposed algorithm can be useful in FOPID-type controllers with two fractional-order time-delay systems. Furthermore, the proposed algorithm can be used in two desired procedures if the system transfer functions are known. The first procedure involves identifying the optimal k p and ki gains while kd varies and the parameters λ and μ are known. The second procedure involves identifying the optimal kp, $k_{i,}k_d$.gains while λ and μ vary. Finally, several simulations of the proposed algorithm verified the effectiveness of a FOPID controller regarding fractional-order with time-delay systems [5].

K. J. Astrom et al.(2004): Author analyzed the Ziegler-Nichols step response method for PID control. The Ziegler-Nichols step response method is based on the idea of tuning controllers based on simple features of the step response. This paper has revisited tuning of PID controllers based on step response experiments in the spirit of Ziegler and Nichols Ziegler and Nichols developed their tuning rules by simulating a large number of different processes, and correlating the controller parameters with features of the step response. Process dynamics was characterized by the parameters obtained from the step response. A nice feature of this design method is that it permits a clear trade-off between robustness and performance. The idea is investigated from the point of view of robust loop shaping. The results are insight into the properties of PI and PID control and simple tuning rules that give robust performance for processes with essentially monotone step responses [6].

Jimisha K et al.(2016):The control of chemical reactor is one of the most challenging problems in control process. A Continuous Stirred Tank Reactor (CSTR) is the heart of many processes, its stable and efficient operation is important to the success of an entire process. The CSTR is one of the optional machineries available to mimic and maintain the deep sea conditions such as pressure, temperature, pH etc in the laboratory to study environmental effects. This paper presents the design of suitable conventional controller and tuning methods to optimize the system performance for a hyperbaric reactor system. In environmental CSTR the control of temperature is an absolute challenge due to strong on-line non linearity. The suitable control strategy was explored here to develop the environmental CSTR system for deep sea applications using real time on-line open loop temperature curve. The First Order plus Dead Time (FOPDT) process model was chosen to derive transfer function from real time on-line system curve at atmospheric pressure and 310C temperature condition. Simulation and result comparison is carried out using MATLAB &SIMULINK. Different conventional controllers are examined to optimize the temperature control for environmental CSTR system. The simulation result on the environmental CSTR system is presented to show efficiency of various controllers [7].

J.C. Basilio et al. (2002) proposed methodologies for tuning PI and PID controllers. Like the well-known Ziegler- Nichols method, they are based on the plant step response. The methodology also encompasses the design of PID controllers for plants with under damped step response and provides the means for a systematic adjustment of the controller gain in order to meet transient performance specifications. Unlike the Ziegler-Nichols step response method, they provide systematic means to adjust the proportional gain in order to have no overshoot on the closed-loop step response. In addition, since all the development of the methodology relies solely on concepts introduced in a frequency-domain-based control course, the paper has also a didactic contribution [8].

Wen Tan (2006), In this paper the author compared the well-known PID tuning rules. Criteria based on disturbance rejection and system robustness are proposed to assess the performance of PID controllers. A simple robustness measure is defined and the integral gains of the PID controllers are shown to be a good measure for disturbance rejection. The integral error is generally accepted as a good measure for system performance. Clearly, if the response is critically damped, IE will be equal to IAE. However, if it is weakly damped, then IE will not be suitable as a performance measure [9].

K. J. Åström et al. (2004), Author analyzed the Ziegler-Nichols step response method for PID control. The Ziegler-Nichols step response method is based on the idea of tuning controllers based simple features of the step response. This paper has revisited tuning of PID controllers based on step response experiments in the spirit of Ziegler and Nichols. Ziegler and Nichols developed their tuning rules by simulating a large number of different processes, and correlating the controller parameters with features of the step response. Process dynamics was characterized by the parameters obtained from the step response. A nice feature of this design method is that it permits a clear trade-off between robustness and performance. The idea is investigated from the point of view of robust loop shaping. The results are insight into the properties of PI and PID control and simple tuning rules that give robust performance for processes with essentially monotone step responses [10]

Mohammad Ali Nekoui (2010), the author presents the optimal design of PID controller based on a particle swarm optimization (PSO) approach for continuous stirred tank reactor (CSTR). The mathematical model of experimental system had been approximate near the operating point for the PSO algorithm to adjust PID parameters for the minimum integral of time multiplied by absolute error (ITAE) condition. This research explains a design of PID controller by using the PSO method to search for optimal parameters converting into the optimal point and the good control response based on the optimal values by the PSO technique.[11]

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S. Palanki et al. Developed software module to run a simulation via the internet. The software module is developed in MATLAB and simulates a regulation problem in a continuous stirred tank reactor (CSTR) in which a series reaction is occurring. The user has the option to input a wide variety of system parameters, initial conditions, final time, and controller parameters. The effect of changing these values on the overall system dynamics can be studied easily. The development of such modules eliminates space, time, and cost constraints. It was found that this software module was a useful teaching supplement to the traditional classroom lecture. Students were able to study the effect of changing various process parameters as well as controller parameters on the regular output. The interactive distance learning concepts include the use of remote computer access to enhance self-paced learning. The internet provides a real-time link that eliminates space time constraints, and gives access from anywhere at any time. Moreover, due to the multiuser-multitasking nature of computer environments, several students can run the software module at the same time. The development of a virtual laboratory has the potential to deliver experiences which are not accessible to students in the real world. Recent technological advances in computer software are bringing virtual laboratories within the reach of educational and student budgets.[12]

J. Kennedy et al.(1995) Introduced particle swarm methodology for the optimization of non-linear functions. Particle swarm optimization is an extremely simple algorithm that seems to be effective for optimizing a wide range of functions. We view it as a biologically derived algorithm, occupying the space in nature between evolutionary searches, which occurs on the order of milliseconds. Particle swarm optimization as developed by authors comprises a very simple concept, and paradigms can be implemented in a few lines of computer code. It requires only primitive mathematical operators, and is computationally inexpensive in terms of both memory requirements and speed. Early testing has found the implementation to be effective with several kind of problems. This paper discusses application of the algorithm to the training of artificial neural network weights. Particle swarm optimization has also been demonstrated to perform well on genetic algorithm test functions. The adjustment toward pbest and gbest by the particle swarm optimizer is conceptually similar to the crossover operation utilized by genetic algorithms.[13]

B. Nagaraj et al. (2011) this paper compared the different soft computing techniques for PID controller. The methodology and efficiency of the proposed method are compared with that of traditional methods. Determination or tuning of the PID parameters continues to be important as these parameters have a great influence on the stability and performance of the control system. Research work has been carried out to get an optimal PID tuning by using GA, EP, PSO and ACO. The results obtained reflect that use of soft computing based controller improves the performance of process in terms of time domain specifications, set point tracking, and regulatory changes and also provides and optimum stability.[14]

III. RESULT AND DISCUSSION

In this work, various spatial domain filters for suppression of Gaussian noise are studied, analysed and implemented those are median filter, bilateral filter and non- local means filter. To evaluate the quality of de-noised images we performed our experiments on 12 standard test images of size 256*256 have been corrupted by Gaussian noise of standard deviation (σ = 10,15,20,25,30). Performance quality metrics are used to measure the quality of an image objectively. Quality metrics which are used for comparison such as PSNR (peak signal-to-noise ratio) and MSE (mean squared error) are represented graphically.

Simulation result of Self-Regulating Process Model

A self-regulating process obtains a steady state level if the controller output and disturbance variables are kept constant for particular time interval. Ziegler-Nichols tuning rule based on two parameters: critical gain and critical period. In the section 2.2.1, we discussed about tuning of self-regulating process model through Ziegler-Nichols method and got parameter values of PID controller for the given plant model. The values are K_p = 18, T_i = 1.405, T_d =0.351. According to figure 5.1, system takes about 10 seconds to achieve steady state.

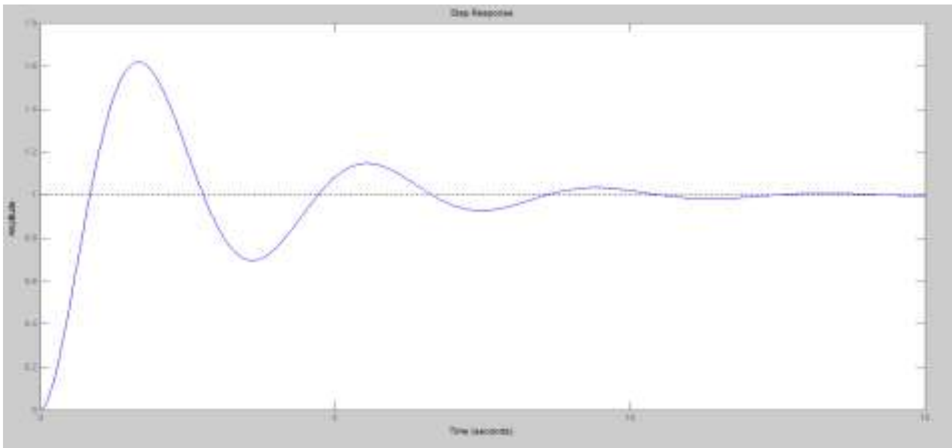

Figure 5.1 Unit step response of the system using Ziegler-Nichols method

Simulation results of CSTR Process Model

A Continuous stirred tank reactor (CSTR) with concentration control transfer system is an interesting dynamic phenomenon. In the section 3.4, we got the mathematical modelling of CSTR process model through state space analysis. This section presents the tuning of PID controller based on different tuning algorithms i.e. Particle Swarm Optimization (PSO) and Human Dynamic opinion Algorithm for concentration control of isothermal CSTR model.

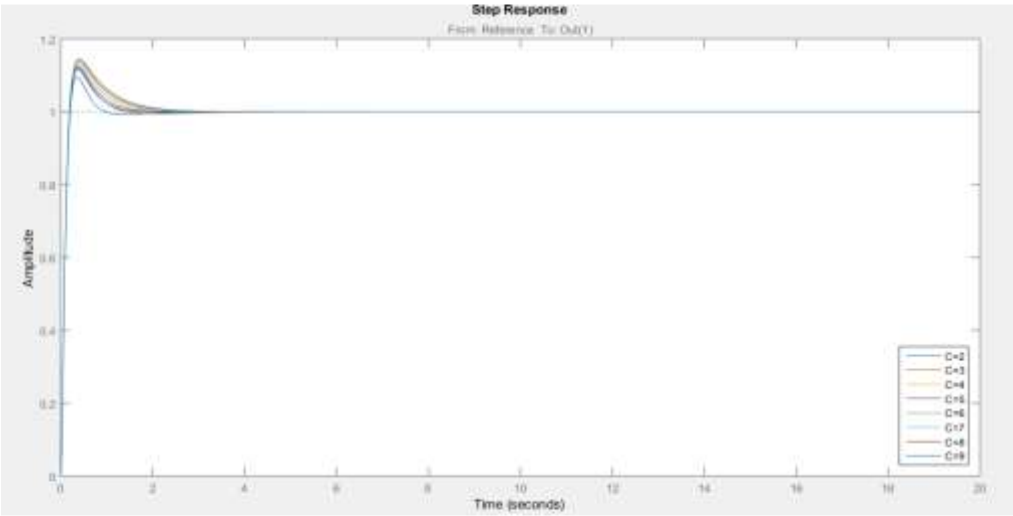

Figure 5.3 Output response of Concentration control of CSTR using PSO-Dependent PID controller

Concentration control of CSTR model by HDOA Technique

This figure 5.5 show how change step response of HDOA in different concentration and different Optimization Step like C=2,3,4,5,6,7,8,9, but amplitude not increase smoothly and highest amplitude is 1.7.

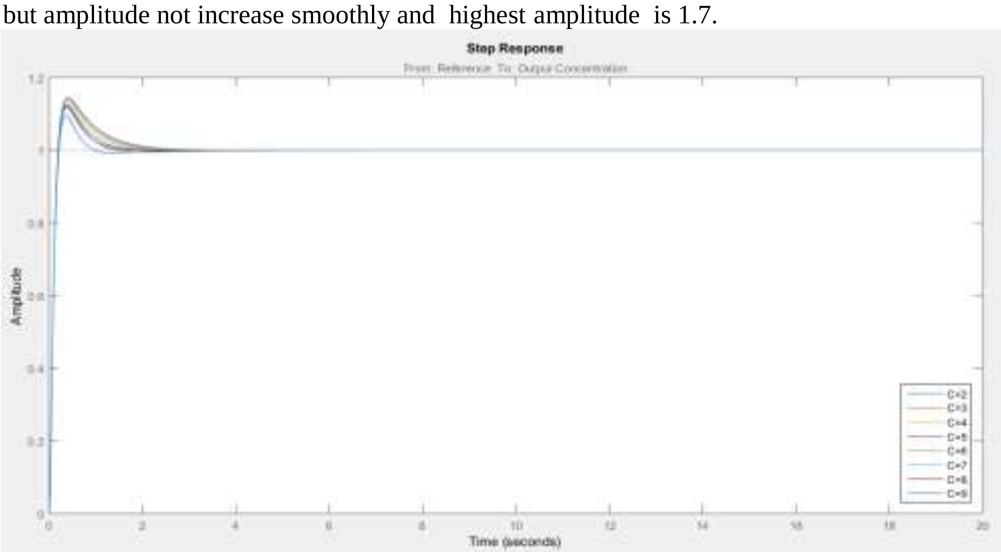

Figure 5.6 Output response of Concentration control of CSTR using HU-Dependent PID controller.

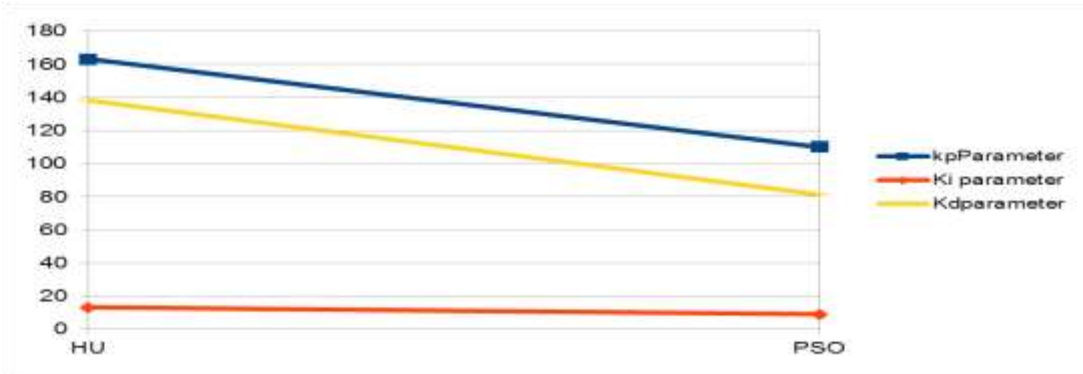

Figure 5.8 Comparison of K_p, K_i & K_d parameters for CSTR process model between PSO and HDOA

HDOA tuned controller (HU-PID) gives best response as compared to other techniques, which we discussed earlier in this section. For good results, system response should have less overshoot and achieves steady state quickly.

RESULT AND DISCUSSION

The proposed PSO-PID and HU-PID controller is tested by using Mat-lab Simulink program and their performance is compared. Also, the PID controller parameters obtained from HU algorithm gives better tuning result as compared to PSO-PID rule. The major impact of HU is on integral square error and peak overshooting. Both are minimized by HU-PID controller. HU-PID is a very simple concept, and paradigms can be implemented in a few lines of computer code.

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