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Comparison of PID Controller Tuning Methods with Genetic Algorithm for FOPTD System

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ABSTRACT
Measurement of Level, Temperature, Pressure and Flow parameters are very vital in all process industries. A combination of a few transducers with a controller, that forms a closed loop system leads to a stable and effective process. This article deals with control of in the process tank and comparative analysis of various PID control techniques and Genetic Algorithm (GA) technique. The model for such a Real-time process is identified as First Order Plus Dead Time (FOPTD) process and validated. The need for improved performance of the process has led to the development of model based controllers. Well-designed conventional Proportional, Integral and Derivative (PID) controllers are the most widely used controller in the chemical process industries because of their simplicity, robustness and successful practical applications. Many tuning methods have been proposed for PID controllers. Many tuning methods have been proposed for obtaining better PID controller parameter settings. The comparison of various tuning methods for First Order Plus Dead Time (FOPTD) process are analysed using simulation software. Our purpose in this study is comparison of these tuning methods for single input single output (SISO) systems using computer simulation.Also efficiency of various PID controller are investigated for different performance metrics such as Integral Square Error (ISE), Integral Absolute Error (IAE), Integral Time absolute Error (ITAE), and Mean square Error (MSE) is presented and simulation is carried out. Work in this paper explores basic concepts, mathematics, and design aspect of PID controller. Comparison between the PID controller and Genetic Algorithm (GA) will have been carried out to determine the best controller for the temperature system.

Keywords-Transducers, PID controller, GA, FOPTD model, ISE, IAE, ITAE, MSE.

I. INTRODUCTION

During the 1930s three mode controllers with proportional, integral, and derivative (PID) actions became commercially available and gained widespread industrial acceptance. These types of controllers are still the most widely used controllers in process industries[14,18]. This succeed is a result of many good features of this algorithm such as simplicity, robustness and wide applicability [2]. Some of these tuning methods have considered only one of these objectives as a criterion for their tuning algorithm and some of them have developed their algorithm by considering more than one of the mentioned criterion. In this study we have compared the performances of several tuning methods [2]. From the closedloop transfer function, controller transfer function is derived using process transfer function. Later controller transfer function is written as PID controller with a lead lag filter. The proportional-integral-derivative is a particularly useful control approach that was invented over 80 years ago. Here KP, KI, and KD are controller parameters to be selected, often by trial and error or by the use of a lookup table in industry practice. The goal, as in the cruise control example, is to drive the error to zero in a desirable manner.

To design and tune the controller to achieve the better performance it is essential to,

- Obtain the dynamic model of a system to control.
- Specify the desired closed loop performance on the basis of known physical constraints.
- Adopt controller strategies that would achieve the desired performance.
- Implement the resulting controller using suitable platform.
- Validate the controller performance and modify accordingly if required [9,15].

The transfer function of PID controller is:

$$G(S) = Kc\left(1 + \frac{1}{TiS} + Td\right) = Kp + \frac{Ki}{S} + Kd \;..... (1)$$

Where,
$K_P$is the proportional gain
$T_I$is the integral time
$T_D$is the derivative time [14].

The PID controller is the most common form of feedback in use today. The family of PID controllers is rightly known as the building blocks of control theory owing to their simplicity and ease of implementation [9]. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly [19].P-I-D controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system. One of the main advantages of the P-I-D controller is that it can be used with higher order processes including more than single energy storage.

A PID controller provides a control signal that has a component proportional to the tracking error of a system, a component proportional to the accumulation of this error over time and a component proportional to the time rate of change of this error. This module will cover these different components and some of their different combinations that can be used for control purposes.

Designing and tuning a PID controller demands flexible algorithms, if multiple and conflicting objectives are to be achieved. A conventionally tuned PID controller with fixed parameters may usually derive lesser control performance when it comes to system demands. The conventional tuning techniques lack the intelligence and flexibility which would increase the performance rate and also improvise the stability and error criterion [16,17].

GA was first introduced by John Holland. It is an optimization technique inspired by the mechanisms of natural selection.GA starts with an initial population containing a number of chromosomes where each one represents a solution of the problem in which its performance is evaluated based on a fitness function.

Based on the fitness of individual and defined probability, a group of chromosomes is selected to undergo three common stages: selection, crossover and mutation. The application of these three basic operations will allow the creation of new individuals to yield better solutions than the parents, leading to the optimal solution [3].

In the next section, we will discuss about (i) the Experimental Setup of the Heating Tank system. (ii) Determination of Transfer-function of the experimental setup. (iii) Design of basic PID controller method. Section 3 will discuss about the various tuning techniques for designing the PID controllers and determining their proportional band, integral time and derivative time. By those values one can determine the parameters of Proportional constant, Integral constant, Derivative constant.Section 4 will discuss about the Tuning methods for Minimum Error Integral Criteria and determining the error values of ITAE, ISE, IAE, MSE.Section 5 will discuss about the Results and Comparisons of the CHR and GA PID controllers. The curves for those controllers will be plotted and comparisons of Performance index of CHR PID controller and GA controller are presented. Based on the obtained results conclusion is arrived and effective controller is highlighted.

II. EXPERIMENTAL SETUP OF HEATING TANK SYSTEM

The process setup consists of heating tank fitted with SSR controlled heater for on-line heating of the water. The flow of water can be manipulated and measured by Rota meter. Temperature sensor (RTD) is used for temperature sensing. The process parameter (Temperature) is controlled by microprocessor based digital indicating controller whichmanipulates heat input to the process. The controller can be connected to computer through USB port for monitoring the process in SCADA mode. The specifications of the system are:

- Type of Control: SCADA
- Control Unit: Digital indicating controller with RS 485 communication
- Communication: USB port using RS 485-USB converter
- Temperature Sensor: Type RTD, PT 100
- Heating Control: Proportional power controller(SSR), input 4-20mA D.C., Capacity 20 A
- Rota meter: 6-60 LPH
- Process Tank: SS304, Capacity 0.5 lit, insulated
- Overall dimensions: 400w*400D*330H mm

A step input is applied to solid state relay (SSR) and temperature of RTD (PT 100) is recorded in excel format. Stored data is used to plot open loop step response in MATLAB.

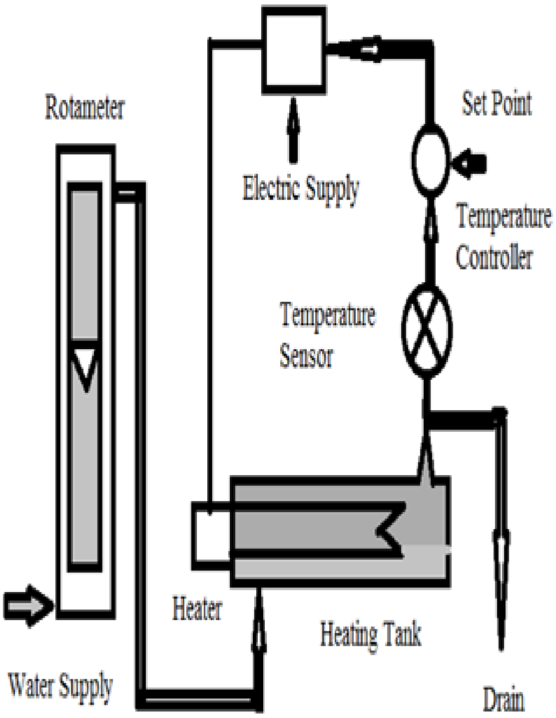


Fig.1 Experimental Setup for Heating Tank [1].

1. DETERMINATION OF SYSTEM MODEL:

In the design of model based controller, system model is an important element. White box model requires complete and correct physical data of the system under consideration. But this data is not available for the system described. Hence, system model id determined through system identification. We used Step signal to the system for the determination of model. We considered FOPTD model.This step response locates the system parameters like steady state gain, time delay and the time constant of the process from which model obtained is of general form as,

$$G(s) = \frac{kpe^{-tdS}}{\bar{i}s + 1}$$

Where,
$k_p$is steady state gain of system,
$\bar{i}$ is time constant of system
$t_d$is dead time of system.

Hence, we get FOPDT model from Figure 1 as,

$$Gp(s) = 2.2 * \frac{e^{-6s}}{40.484s + 1}$$

(Water flow through Rota meter is kept at 40 LPH) [1].

2. CONTROLLER DESIGN FOR FOPTD SYSTEMS:

The single loop controller configuration is shown in Fig.2

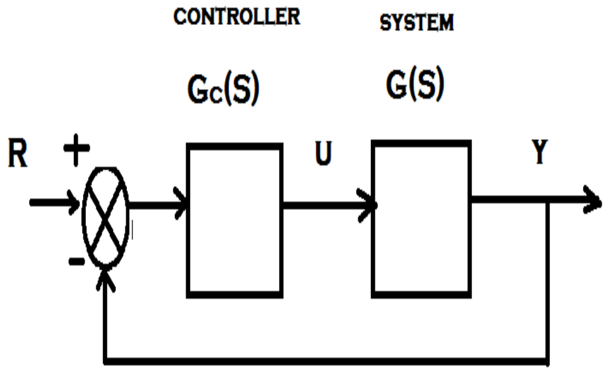


Fig.2A single loop controller configuration

III. TUNING METHODS

The PID controller tuning methods are classified into two main categories
- Closed loop methods
- Open loop methods

Closed loop tuning techniques refer to methods that tune the controller during automatic state in which the plant is operating in closed loop. The open loop techniques refer to methods that tune the controller when it is in manual state and the plant operates in open loop. The closed loop methods considered for simulation are Ziegler-Nichols method [20], Modified Ziegler-Nichols method, Tyreus-Luyben method, Damped oscillation method and IMC method. Open loop methods are C-H-R method Minimum error criteria (IAE, ISE, ITAE, MSE) method. Before proceeding with a brief discussion of these methods it is important to note that the non-interacting PID controller transfer function is:

$$G(S) = Kc\left(1 + \frac{1}{TiS} + Td\right) \ldots. (2)$$

Where
k_c= proportional gain
T_I= Integral time
T_D= derivative time

1. The C-H-R Method:

This method that has proposed by Chien, Hrones and Reswich is a modification of open loop Ziegler and Nichols method. They proposed to use “quickest response without overshoot” or “quickest response with 20% overshoot” as design criterion. They also made the important observation that tuning for set point responses and load disturbance responses are different.

To tune the controller according to the CHR method the parameters of first order plus dead time model are determined in the same manner of the Z-N method [4].

Proportional, integral and derivative constants are **K_C=3.6803 K_I=0.306 K_D=11.04**

2.Genetic Algorithm For PID Tuning:

GA was first introduced by John Holland. It is an optimization technique inspired by the mechanisms of natural selection.GA starts with an initial population containing a number of chromosomeswhere each one represents a solution of the problem in which its performance is evaluated based on a fitness function.

Based on the fitness of individual and defined probability, a group of chromosomes is selected to undergo three common stages: selection, crossover and mutation. The application of these three basic operations will allow the creation of new individuals to yield better solutions than the parents, leading to the optimal solution [3,6,7,8,10].

Proportional, integral and derivative constants are **K_C=4.6379 K_I=0.11357 K_D=9.9406**

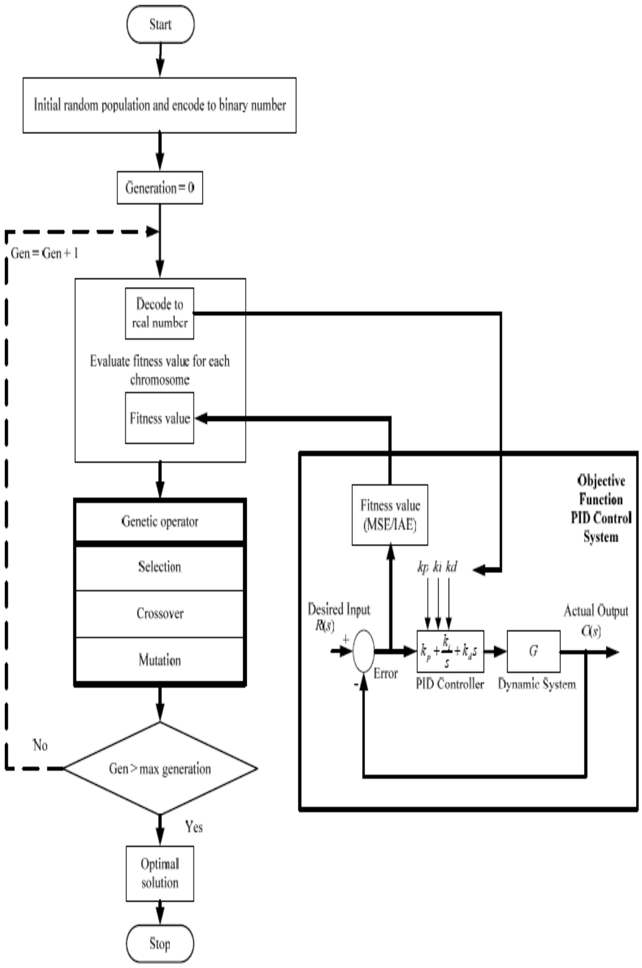


Fig.3Flowchart of Genetic Algorithm

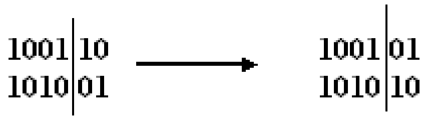
2.1 Reproduction:

During the reproduction phase the fitness value of each chromosome is assessed. This value is used in the selection process to provide bias towards fitter individuals. Just like in natural evolution, a fit chromosome has a higher probability of being selected for reproduction. The probability of an individual being selected is thus related to its fitness, ensuring that fitter individuals are more likely to leave offspring [5].

2.2 Crossover:

Once the selection process is complete, the crossover algorithm is initiated. The crossover operations swap certain parts of the two selected strings in a bid to capture the good parts of old chromosomes and create better new ones. The crossover probability indicates how often crossover is performed. The simplest crossover technique is the Single Point Crossover.

Example: If the strings *100110* and *101001* are selected for crossover and the value of *k* is randomly set to 2 then the newly created strings will be *100110* and *101010* as shown [5].



2.3 Mutation:

Mutation is the occasional random alteration of a value of a string position. It is considered abackground operator in the genetic algorithm. The probability of mutation is normally low because a high mutation rate would destroy fit strings and degenerate the genetic algorithm into a random search. Once a string is selected for mutation, a randomly chosen element of the string is changed or 'mutated'. For example, if the GA chooses bit position 3 for mutation in the binary string *100101*, the resulting string is *100001* as the third bit in the string is flipped [5].

IV. TUNING METHOD FOR MINIMUM ERROR INTEGRAL CRITERIA

As mentioned before tuning for ¼ decay ratio often leads to oscillatory responses and also this criterion considers only two points of the closed loop response (the first two peaks). The alternative approach is to develop controller design relation based on a performance index that considers the entire closed loop response.

Some of such indexes are as below:

Modern complex control systems usually require more sophisticated performance criteria than those presented so far. The error and time are very important factors that must be considered simultaneously. A performance index is a single measure of a system's performance that emphasis those characteristics of the response that are deemed to be important. The notion of a performance index is very important in estimator design using linear-state-variable feedback. A fairly useful performance index is the integral of the absolute magnitude of the error (IAE) criterion.

$$\mathbf{IAE}= {}_0\int^{\infty}| e(t) |.dt$$

By utilizing the magnitude of the error, this integral expression increases for either positive or negative error, and results in a fairly good under-damped system. For a second order system, this error has a minimum for a damping ratio of approximately 0.7. Another useful performance index is the integral of the square of the error (ISE) criterion.

$$\mathbf{ISE}= {}_0\int^{\infty} e^2(t).dt$$

By focusing on the square of the error function, it penalizes both positive and negative values of the error. . For a second order system, this error has a minimum for a damping ratio of approximately 0.5 [14,15,16].A very useful criterion that penalizes long-duration transients is known as the integral of time multiplied by the absolute value of the error (ITAE). This performance index is much more selective than the IAE or the ISE. The minimum value of its integral is much more definable as the system parameters are varied. . For a second order system, this error has a minimum for a damping ratio of approximately 0.7.

$$\mathbf{ITAE}={}_0\int^{\infty} t\ |e(t)|.dt$$

Other figure of merit which has been proposed is the integral of time multiplied by the squared error (ITSE) or mean squared error (MSE) [14,15,16]. The performance index is

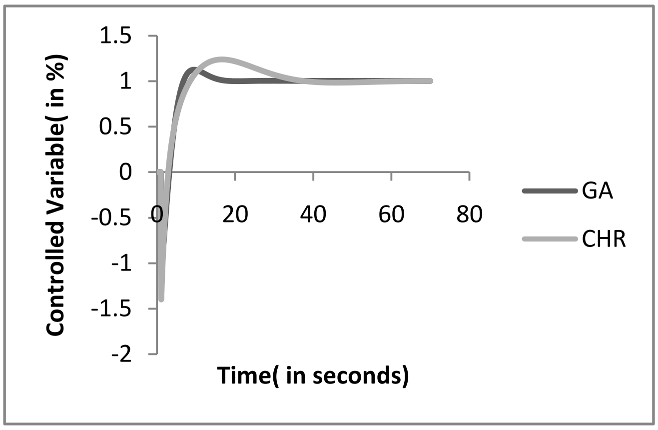
$$\mathbf{MSE}={}_0\int^{\infty} t.e^2(t).dt$$

V. RESULT AND COMPARISON:

The Result can be obtained by comparing the controller time domain specifications and performance index. In this section, the comparisonsof responses of CHR and GA PID controllers that are mentioned above have been plotted. To obtain the result, the comparison of time domain specifications like determination steady state time, peak time, overshoot have been calculated. For the Minimum error integral criteria, the performance index of the PID controllers have been compared. A tabulation of the time domain specificationscomparison and the performance index comparison for the obtained models with the designedcontrollers is presented.

From the curves and controller time domain specifications the proposed controller for this method should be **Genetic Algorithm method(G-A)**. From the performance index, **ISE controller for Genetic Algorithm method(G-A)**should be a suitable choice.

1. Comparison of Curves between CHR and GA:



2. Comparison of time domain specifications for set point:

The Comparison of tuning methods of CHR and GA PID controllers are plotted below.

Controller	CHR controller	GA controller
Rise time (seconds)	4.5	4.6
Peak time (seconds)	17	9
Overshoot (%)	36.5	12.8
Settling time (seconds)	64	17

3. Comparison of performance index:

The Comparison of performance index of ITAE, IAE, ISE, MSE of CHR and GA PID Controllers are given below.

Controller Type	CHR controller	GA controller
ITAE	884.0878	170.5447
IAE	701.5868	73.1886
ISE	0.0032	0.000803
MSE(e-004)	3.7803	2.3240

VI. ROBUSTNESS ANALYSIS

Robustness of the controller is defined as its ability to tolerate a certain amount of change in the process parameters without causing the feedback system to go unstable. Robustness investigation is done by varying the model parameters by twenty percent. In order to investigate the robustness of model in presence of uncertainties, the model parameters are randomly altered. For model obtained, k=2.2, td=6 sec and tp= 40.484 sec. Let, these parameters be deviated as much as 20% from their nominal values due to model uncertainty. Let, there is 20% decrease in dead time and 20% increase in gain and time constant. Therefore, new model is:

$$G(s) = 2.64 * \frac{e^{-4.8s}}{48.581s + 1}$$

VII. CONCLUSION

The temperature control system UT_321 is configured with SCADA system. Proportional band, Derivative time and Integral time are send to local PID controller. Output is recorded into excel file and plotted using MATLAB. The various results presented prove the betterness of Genetic Algorithm (G-A) PID controllermethod than Chien, Hrones and Reswich(CHR) tuned PID controller. The simulation responses for the model validated reflect the effectiveness of GA PID controller in terms of time domain specification. The performance index of Genetic Algorithm (G-A) ISE error criteria is less than the other error criteria of remaining PID controllers. From the real time responses, the CHR method PID controller is suitable for this Heating tank system.

GA is an optimization technique inspired by the mechanisms of natural selection.GA starts with an initial population containing a number of chromosomes where each one represents a solution of the problem in which its performance is evaluated based on a fitness function. Based on the fitness of individual and defined probability, a group of chromosomes is selected to undergo three common stages: selection, crossover and mutation. The application of these three basic operations will allow the creation of new individuals to yield better solutions than the parents, leading to the optimal solution. The features of GA illustrated in the work by considering the problem of designing a control system for a plant of a first order system with time delay and obtaining the possible results. The future scope of this work is aimed at providing a self-tuning PID controller with proposed algorithm (Particle Swarm Optimization - PSO) so as to solve the complex issues for real time problems.

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