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Model Identification of Temperature Process and Tuning with Advanced Control Techniques

N.Nithyarani[1], **S.M.GirirajKumar**[2]

Assistant professor, Dept of Instrumentation & Control, Saranathan College of Engineering, Trichy, India [1]

Professor & Head, Dept of Instrumentation & Control, Saranathan College of Engineering, Trichy, India [2]

Abstract: In process control industries, automatic controllers are introduced. PID (Proportional-Integral- Derivative) controllers are the workhorses of many industrial controller applications. The commonly used Ziegler Nichols tuning method holds good for a system with small decay ratio and fails when decay ratio is large and tuning is also difficult. IMC tuning rules enhance the control performance by determining one tuning parameter, the filter time constant. The need for improved performance of the process has led to the development of robust and optimal controllers. Genetic (GA) algorithm allows the purpose of the optimized parameters for the controllers. GA performed standard tuning and determine ITAE (Integral Time Absolute Error) performance criterion produces most effective PID controller. In this paper, the objective of the controller design is to maintain the temperature of water in the liquid tank in a desired value. System identification of this nonlinear process is done by empirical method, which is identified to be nonlinear and approximated to be a First Order Plus Dead Time (FOPDT) model. The advanced control algorithm, IMC and GA is designed for this FOPDT process model. GA algorithm is implemented and the performance is compared with the conventional PID and IMC algorithm in terms of performances indices. It is observed that GA for the system provides optimum values of performance indices.

Keywords: PID ZN-II, IMC, GA, System Identification

I. INTRODUCTION

The PID (Proportional-Integral-Derivative) algorithm was invented in the 1940's, and remains significant useful and relevant over a large range of process challenges. PID controllers are used to control the process variables ranging from fluid flow, level, pressure, temperature, consistency, density etc[1]. It is a robust easily understood algorithm that can provide outstanding control performance despite the varied dynamic characteristics of process plant. PID is also the root for many advanced control algorithms and strategies. In order for control loops to work appropriately, the PID loop must be accurately tuned. Designing and tuning a PID controller demands flexible algorithms, if multiple and incompatible objectives are to be achieved [1][2]. 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[2].

In past few decades, intelligent techniques have been used to meet system demands. An intelligent agent is a system that perceives its surroundings and takes actions which maximizes its chances of success. Neural network and fuzzy logic imitate the functioning of the human intelligence process[7]. However their real time implementation is quite difficult. On the other hand optimization algorithms have also established increasing consideration by the research community as well as the industry. The advantage of optimization algorithms over neural controllers is that they can be included in PID tuning with relieve and simplicity. Control design is called "optimal control" when a predefined criterion is optimized [8]. Optimality is just with respect to the criterion at hand and the real performance depends on the suitability of the chosen criterion [11].

The rest of this paper is organized as follows. Section 2, 3 gives an overview of System Identification, the temperature system and the experimental data obtained. Also the details of applying IMC and GA in PID control are discussed in the section 4 and 5. In section 6, simulation results are analysed and comparative studies and results are given. Finally, the paper concludes with the Section 7.

II. TEMPERATURE PROCESS

The aim of the paper is to control or to uphold the temperature of a plant within a desired limit. The temperature controller can be used to control the temperature of any plant. Typically it contains a Temperature input unit, Controller and Control output unit [3]. The ADC (Analog-to-Digital) unit in concert with temperature sensor, that forms the temperature input unit and the SSR (solid state relay) driver forms the control output unit. Electric power to the heating element (heater) is supplied through relay contacts[3]. The switching of the relay controls supply the heat to the tank. Here the process with a liquid tank with a heater, and with two temperature thermocouple sensors[18]. The basic block diagram and the experimental setup of the process is given in the figures, 1 and 2.

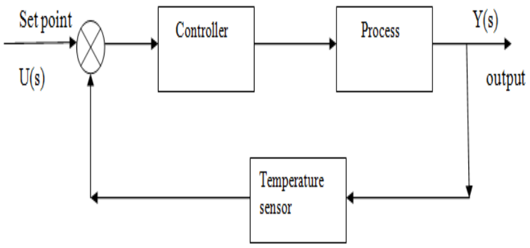

Fig. 1 Block diagram of a temperature process

Fig. 2 Experimental setup of temperature process

The process model on which the simulator is based is a First-Order model based on energy balance under the assumption of homogenous conditions of the liquid in the tank. The system also contains a time delay which represents the time delay which in practice exists between an excitation of the heating element and the response in the temperature sensor[3]. In addition the simulator contains a First-Order transfer function representing a time constant in the heating element. A temperature process system for a water tank with continuous inflow and outflow is simulated. The water is heated by a heater which is controlled by the controller. The process variable is measured by a temperature sensor which is thermocouple sensor[3].

III. SYSTEM IDENTIFICATION

The experimental determination of the dynamic behaviour of the process is called SI (system identification). System identification can be done mainly in two ways one is the mathematical modelling and the other is the empirical modelling. The mathematical modelling equations relating the input and the output are formed. Empirical methods use data gathered from experimental setup to define the mathematical model of a system. In this paper, empirical method is used for the temperature process. The transfer function for the process model is obtained from step response. The liquid tank temperature control system measured here can be assumed as a (FOPDT) first order process with dead time [3]. So for a first order process with dead time the parameters that are to be determined are the process gain (K), Delay time (td) and the time constant (τ).

Most often it has units of minutes or seconds. Step test data implies that the process is in manual mode (open loop) and initially at steady state. The transfer function of the process models are required only for the simulation studies of the controller design. In this paper, we are controlling the outlet temperature[18][19]. The most commonly used model to describe the dynamics of the industrial temperature process is general First Order plus Time Delay Process (FOPTD). And the FOPTD model structure is given in equation 3.1

$$G(s) = \frac{K}{(\tau s+1)}\ e^{-tds} \qquad (3.1)$$

Where, td – Time delay, K – Process gain, τ - Time constant.

Time delay between an excitation in the heating element and the response in the temperature sensor. Here the process of interest is approximated by a First Order plus Time Delay Process. The dead time approximation can be done in several methods; one of the methods are discussed below:

The pade approximation:

$$\text{Pade} = \frac{\left(-\frac{td}{2}\right)s+1}{\left(\frac{td}{2}\right)s+1} \qquad (3.2)$$

$$\text{Pade} = \frac{-0.5s+1}{0.5s+1} \qquad (3.3)$$

Thus by approximating the dead time using above mentioned methods, we can conclude that a First Order plus Time Delay Process can be approximated as a higher order process. The transfer function parameters of the process are obtained by doing the step test. The transfer function parameter for the temperature process is experimentally obtained as $7/(12s+1) * e^{-tds}$

IV. CONTROLLER DESIGN

The basic PID controller parameters are given as, proportional gain Kp, integral gain Ki and derivative gain Kd Over the last fifty years, many methods have been industrial for setting the parameters of a PID controller. In this paper it is measured to proceed with Internal Model Control (IMC) tuning technique proposed by Skogestad for PID tuning [1]. IMC involves a dissimilar structure and controller, a single IMC can be used for multivariable systems and it has zero steady-state offset for step-like inputs[2].

A. Internal Model Controller

Internal Model Controller involve a model based procedure, where the process model is implanted in the controller. IMC involve a single tuning parameter the filter constant. Here we consider a linear transfer function model of the temperature process[1]. Figure 3 shows the general block diagram of the IMC controller structure.

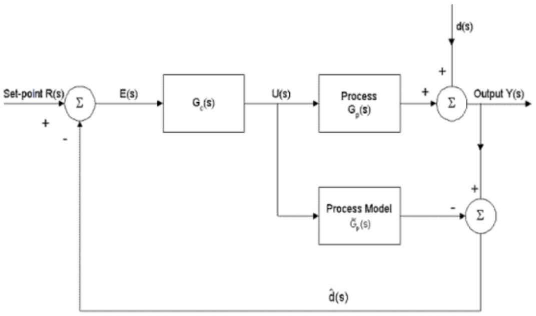

Fig. 3 Schematic of IMC

A controller $G_c(s)$ is used to control the process $G_p(s)$. Suppose $\tilde{G}_p(s)$ is a model of $G_p(s)$. By setting $G_c(s)$ to be inverse of the model of the process, $G_c\ (s) = \widetilde{GP}\ (s)^{-1}$ and if $G_p\ (s\ ) = \widetilde{GP}\ (s)$, (the model is an exact representation of the process) The process output is closely equal to the set point or to the reference. The ideal act of the controller is achieve without any feedback requires [2].

From this closed loop expression, $G_c\ (s) = \widetilde{GP}\ (s)^{-1}$, and if $G_p\ (s\ ) = \widetilde{GP}\ (s)$, then perfect set point tracking and disturbance rejection is achieved. If $G_p\ (s) \neq \widetilde{Gp}(s)$, perfect disturbance rejection can still be realized provided $G_c\ (s) = \widetilde{GP}\ (s)^{-1}$.[18][19]

To get better robustness of the controller, the effects of process model difference should be minimized. This mismatch usually occur at the high frequency range and at the end of the system frequency response, $G_f(s)$ a low-pass filter is usually added to attenuates the effects of process model difference[7]. Thus the IMC is usually designed as the inverse of the process model in series with a low-pass filter, that is $G_{IMC}\ (s) = G_c\ (s)\ G_f\ (s)$.

The most common used industrial controller is still the Proportional Integral and Derivative controller. It gives a transparent framework for a control system designs and tuning. Here IMC PID is implemented in this paper. It is an advanced control technique [2]. By using this controller technique it will gives the faultless control and stable results. IMC is a two degree controller. IMC gives both the set point tracking and disturbance rejection. The purpose of the IMC PID controller is achieved by the IMC block diagram rearrangement to the form of a standard feedback closed loop control. In IMC law, for a number of ordinary process transfer functions, it is equivalent to PID feedback controllers [7]. This use an approximation for time delays in order to find a PID-Type control law.

$$\text{Thus } G_{PID}\ (s) = G_{IMC}\ (s)\ /\ 1\text{-}\ G_{IMC}\ (s)\ \widetilde{Gp}(s) \qquad (4.1)$$

$$G_{PID}\ (s)\ =\ \widetilde{Gp}^{+}\ (s)^{-1}\ G_f\ (s)\ /\ 1\text{-}\ \widetilde{Gp}^{-}(s)\ G_f\ (s) \qquad (4.2)$$

For the (FOPTD) first-order plus time-delay process it is given by

$$\widetilde{GP}\ (s) = \frac{K \exp\ (-tds)}{1+\tau s} \qquad (4.3)$$

This is the temperature process model with first-order plus time-delay. Applying the technique we get the IMC tuning parameters as $K_p = 0.2025$, $K_i = 1.5$, $K_d = 0.3$ for the proposed model.

V. OPTIMIZATION BY GENETIC ALGORITHM

John Holland in 1975 projected an attractive class of computational models, called Genetic Algorithms (GA), that imitate the biological evolution method for solving problems in a wide domain [14]. Genetic Algorithms has three major applications are intelligent search, optimization and machine learning. At present, Genetic Algorithms is used along with neural networks and fuzzy logic for solving more composite problems. Because of their combined practice in more problems, these together are often referred to by a generic first name: “soft computing” [15].

A Genetic Algorithms operates through a simple cycle of stages:

i. String for the Creation of a “population”
ii. Each string Evaluation
iii. Best Strings Selection and
iv. Genetic manipulation to create new population of strings.

Genetic Algorithms produce in an each cycle a new generation of likely solutions for a given dilemma. In the primary stage an initial population describing representatives of the possible solution,. It is created to start the search process. The elements of the population are fixed into bit strings which are called chromosomes and the performance of the strings is often called fitness and it is evaluated with the assist of some functions, representing the constraints of the dilemma [14]. Depending on the fitness of the chromosome they are chosen for a following genetic manipulation development. It should be noted that the selection process is mainly accountable for assuring survival of the best fit individual among all [17].

A.GA Operator:

Population: In GA, group of chromosomes is called population and N is the population size.

Selection: It is performed on the population by keeping the most population individual based on the fitness. The selection rate, Xrate is the population of N that survives for the next step of mating. The number of chromosome is, Nkeep=Xrate*N. In order to replace the deleted chromosome and keep the population size consisting two chromosomes are selected to produces two offspring.

Crossover (Mating): It is used for the creation of one or more offspring from the parents selected in pairing procedure .The most common process involve two parents produces two offspring. The crossover point is randomly selected between the first and last bits of parents chromosomes. The offspring contain portion of binary code of both parents. The parents have produced a total of N, N keep offspring. So the chromosome population is remained constant, N called Single Point Crossover. In Two point crossover, two crossover points are randomly selected between first and last bits of parents.

Mutation: In this, parents are randomly selected from NxN bits. Total number of bits in population matrix. The number of bits that must be change is determined by mutation rate.
(NxN bits) Mutation=μx(N-1)xN bits

B.Initialization of Parameter:

To initiate with GA, definite parameters need to be clear. It includes the size of the population, chromosome bit length, number of iterations, selection, crossover and mutation etc [15]. Assortment of these parameters decide to a great level to the ability of controller designing. The series of the tuning parameters is measured in the series range of 0-10. By initializing the values of the parameters for this paper is as follows:

- Population size – 100
- Bit length of the considered chromosome – 6
- Number of Generations – 100
- Selection method – ‘Maximum Geometric selection’
- Crossover type – ‘Single point crossover’
- Crossover probability – 0.8
- Mutation type –‘Uniform mutation’
- Mutation probability – 0.05

C.Termination Criteria:

Termination of optimization algorithm can be obtain by placing either when the greatest number of iterations gets over or with the ability of suitable fitness value. Fitness value is the reciprocal of the extent of the objective function of the process, since we consider for a minimization of the objective function [12]. And in this paper the termination criteria is measured to be the ability of suitable fitness value which occurs with the maximum number of iterations as 100.

For each iteration the most excellent among the 100 particles measured as potential solution are chosen. consequently the most excellent values for hundred iterations is sketched with respect to the iterations, and are as shown in the following figures 4, 5 and 6.

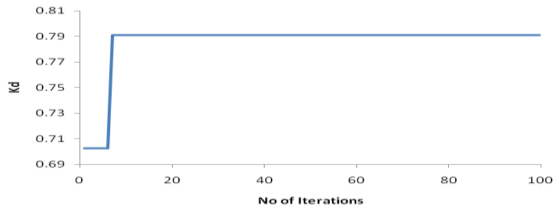

Fig. 4 Best solution of Kd for 100 iterations

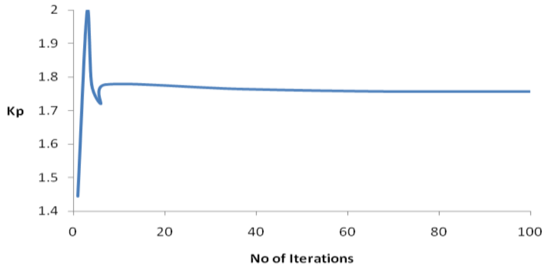

Fig. 5 Best solution of Kp for 100 iterations

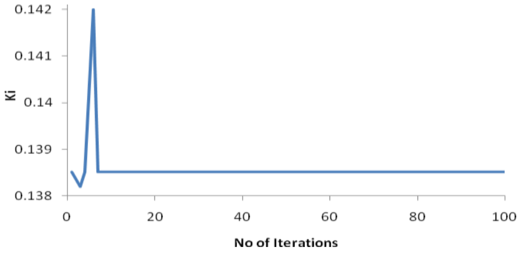

Fig. 6 Best solutions of Ki for 100 iterations

The PI controller was formed based upon the respective parameters for hundred iterations, and the global best solution was selected for the set of parameters, which had the minimum error criteria. A sketch of the error based on ITAE criterion for 100 iterations is as given in figure 7.

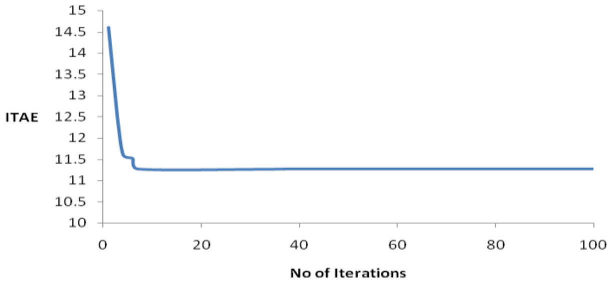

Fig. 7 ITAE values for 100 iterations

It was seen that the error value tends to decrease for a larger no. of iterations. As such the algorithm was limited to hundred iterations for beyond which there was only a insignificant improvement. Based on GA for the application of the PID tuning we get the PID tuning parameters for the model as Kp=1.765, Ki = 0.1385, Kd = 0.7910.

VI. RESULTS AND COMPARISON

In this section the tuned values from side to side the traditional as well as the projected techniques are analyzed for the temperature process. The time domain specifications and the performance index comparison are given in the tabulation. 1 from the obtained models with the designed controllers is presented.

A.Simulated Results of the Temperature Process

It is clear from the responses that the GA based controller has the advantage of a enhanced closed loop time constant, which enable the controller to proceed faster with a overshoot and settling time. The result of IMC controller is more sluggish than the Genetic algorithm controller. The time domain condition comparison is done for the PID ZN-II, IMC and GA based controllers for the results obtained, is tabulated and given in Table 1. For the projected model the comparison of performance index were done and are listed as per the given Table 1.

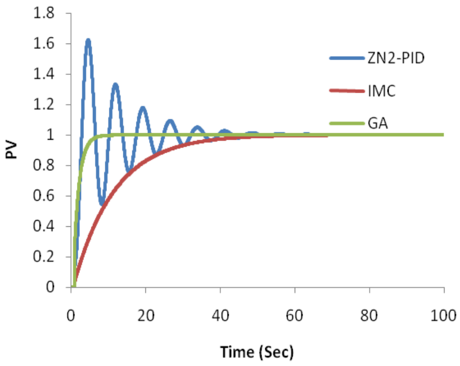

Fig. 8 Simulated result for temperature system

TABLE I
CONTROLLERS COMPARISON OF PERFORMANCE INDEX

Controller	Settling time (sec)	IAE	ISE	ITAE	MSE
PID ZN-II	90	188.23	231.77	0.065	96.53
IMC	65	100.35	99.53	0.01590	95.70
GA	10	11.24	10.76	0.011096	95.63

VII. CONCLUSION

System identification is done and a First Order Plus Dead Time (FOPDT) model is obtained for temperature process. PID ZN-II, IMC algorithm and GA algorithm is proposed for the FOPDT temperature process model. The simulation is done with MATLAB for PID ZN-II tuning, IMC and GA controller and comparison is done in terms of performance indices. It is observed that GA for temperature process provides optimum values of performance indices.

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