International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
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Research Article

Temperature Control of a Non-Linear Process using Genetic Algorithm

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Accepted 16 April 2017, Available online 22 April 2017, **Vol.7, No.2 (April 2017)**

Abstract

Even though traditional controllers are used in chemical industries, automatic soft computing based controllers provides efficient and fine tuning of non-linear process parameters. The main objective of this research work is to control and maintain the temperature of the reacting mixture in CSTR by providing optimum performance indices using GA based PI controller tuning approach. The theoretical case study was mathematically modeled and simulated using MATLAB. The simulated end result proves that GA based controller hand out the best tuning technique in terms of robustness and performance indices when compared to IMC and ZN method.

Keywords: *CSTR, GA, IMC, PI tuning*

1. Introduction

Chemical process control requires intelligent monitoring due to the dynamic nature of the chemical reactions and non-linear functional relationships between the input and output variables. In control engineering, control of nonlinear process is a complex task and it is outbreak to use process models obtained from linearization instead of complete nonlinear models. Increased investigation efforts are now concentrated on the development of nonlinear process models and decision making. In order to guarantee the suitability and stability for proper functioning of a linear model due to linearization, a painstaking justification is required. Therefore, techniques are needed to assess the nonlinearity level of a process to decide whether a process is sufficiently nonlinear to justify a nonlinear controller.

A Continuous Stirred Tank Reactor (CSTR) is one of the most important units in chemical industries which exhibit high nonlinear behavior with wide operating ranges. In CSTR, energy can be either removed or added to maintain a constant temperature. Since the temperature and concentration are identical everywhere inside the reaction vessel, they are same at the exit point in the tank. Accordingly the temperature and concentration at the exit point are modeled as being the same within the reactor. CSTR involves complex reactions with high nonlinearity and it is very hard to control using conventional methods.

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Presently Genetic Algorithm (GA) has been receiving a lot of attention and more research has been done to study its applications.

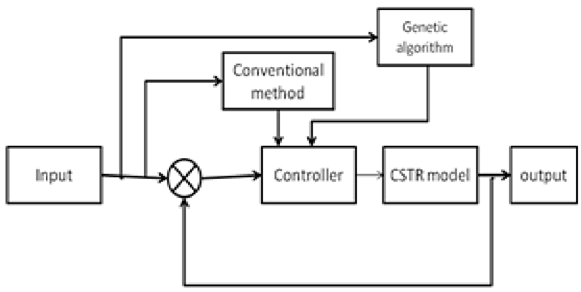

Fig. 1 Block diagram of proposed approach

Genetic algorithm is a random search method used to solve nonlinear system and optimize complex problems which uses probabilistic transition rules instead of deterministic rules and handles a population of potential solutions iteratively known as individuals or chromosomes. Each iteration of the algorithm is termed a generation. The conventional PI controller parameters can be found using GA. In control system design, issues such as performance, system stability, static and dynamic index and system robustness have to be taken into account. For the PI controller design, it is ensured the controller settings estimated results in a stable closed loop system.

In this paper section 2 deals with process sketch, section 3 deals with control approaches briefly, section 4 shares results and discusses about the research work.

2. Process description

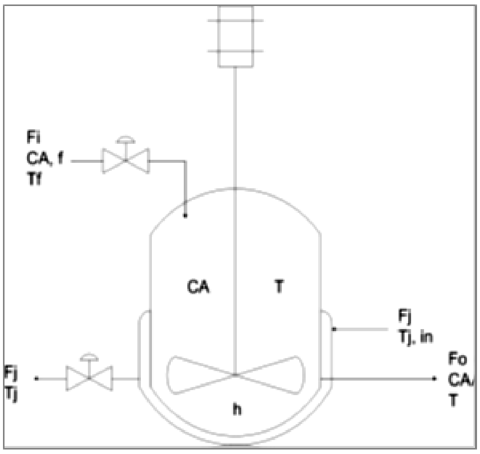

Fig. 2 The Continuous Stirred Tank reactor

The continuous Stirred Tank Reactor (CSTR) is one of the versatile reactor in many chemical industries, exhibit high nonlinear behavior reasonably. The nonlinearity present in the system imposes complication in the design of conventional PID controllers. The linear model for entire operating regions of the CSTR is obtained and controllers are designed for an ideal CSTR. It is assumed that the concentration of chemical mixture inside the CSTR is identical throughout the reactor. The mathematical model of the CSTR is formulated assuming a constant reactor volume and perfect mixing in the reactor. The inputs to the reactor are the feed flow and coolant flow. The states are the effluent concentration and the reactor temperature. The first step in the studying of the dynamic behavior and control of CSTR is to develop a mathematical model depending on mass and energy balances that can be considered as the gate for all works. A first order irreversible exothermic reaction in a Continuous Stirred Tank Reactor is considered as shown in Fig.2. The heat generated by the reaction is removed using a cooling jacket surrounding the reactor. The assumptions ruled in the CSTR are Liquid in the reactor is ideally mixed, Liquid density, liquid level in tank and the physical properties are constant and change in volume due to reaction, shaft work and temperature increase of coolant over the coil are neglected.

The reactor mass and energy equations are:

Overall Mass Balance can be obtained as

$$\frac{dV}{dt} = F_{in} - F_{out} \qquad (1)$$

Since the volume of the reactor is constant, therefore:

$$F_{in} = F_{out} = F \qquad (2)$$

Component (A) Mass Balance is given by

$$\frac{dVC_A}{dt} = F_{in}C_{A0} - F_{out}C_A - VC_AK_0e^{(-E/RT)} \qquad (3)$$

Since, V is constant and from equation (2), equation (3) becomes:

$$\frac{dC_A}{dt} = \frac{F}{V}C_{A0} - \frac{F}{V}C_A - C_AK_0e^{(-E/RT)} \qquad (4)$$

Heat balance on the Jacket is given by

$$\rho_cV_cC_{p_c}\frac{dT_c}{dt} = F_cC_{p_c}\rho_c(T_{cin} - T_c) - \rho C_pF_{out}T + \frac{UA}{\rho C_pV}(T - T_c) \qquad (5)$$

After simplification, equation (5) becomes:

$$\frac{dT_c}{dt} = \frac{F_c}{V_c}(T_{cin} - T_c) + \frac{UA}{\rho_cV_cC_{p_c}}(T - T_c) \qquad (6)$$

The variables and nominal CSTR parameter values are shown in Table 1.

Table 1 CSTR parameter values

Variable	Description	Nominal operating Values
V	Reactor volume (l)	100
F_{in}	Inlet volumetric flow rate to the reactor (l/min)	100
F_{out}	Outlet volumetric flow rate from the reactor (l/min)	100
C_A	Concentration of component A in outlet stream (mole/l)	8.564
C_{A0}	Feed concentration of component A (mole/l)	10
K_0	Pre-exponential factor (l/min)	$3.493*10^7$
E	Activation energy in the Arrhenius equation (cal/mole)	E/R=5960
R	Universal gas constant (cal/mole.K)	
ρ	Density of the inlet and outlet stream (g/l)	1520
C_p	Heat capacity of inlet and outlet stream (cal/g.K)	0.329
T	Temperature of the reactants in the reactor (K)	311.2
T_{in}	Inlet stream temperature (K)	298
H_r	Heat of reaction (cal/mole)	$-5*10^4$
UA	Heat transfer term (cal/min.K)	$5*10^4$
T_c	Temperature of the coolant water in the jacket (K)	-
ρ_c	Density of the coolant water in the jacket (g/l)	1000
C_{p_c}	Heat capacity of the coolant water in the jacket (cal/g.K)	1
F_c	Inlet coolant water volumetric flow rate (l/min)	100
V_c	Jacket volume (l)	100
T_{cin}	Temperature of the inlet coolant water in the jacket (K)	298

The transfer function of CSTR model taken is $G(S) = \frac{6.4 \quad e^{-0.052s}}{(1.7955\ S + 1\ )}$

3. Control approaches

A control system discussed in which the PI controller is tuned using Genetic Algorithm, IMC, Ziegler-Nichols Tuning methods. Traditional methods often do not provide adequate tuning. Genetic Algorithm is an intelligent approach has been widely used to tune the parameters of PID controller. Genetic algorithms are used to create an objective function that can evaluate the optimum PI gains based on the error of controlled systems.

3.1 Ziegler–Nichols tuning method

The Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller. The proportional gain is then increased until it reaches the ultimate gain, at which the output of the control loop has stable and consistent oscillations. Ultimate gain and the oscillation period are used to set the P, I, and D gains depending on the type of controller.
Kp=2.87687, Ki = 1.91217

3.2 Internal model control tuning method

The internal model control technique is one of the recent traditional tuning techniques that yield better values among the techniques available for conventional method. The IMC tuning control parameters are found to be Kp= 3.1623 ,K_i=1.736.

3.3 Genetic algorithm

GA uses a direct analogy of natural evolution to do global optimization in order to solve highly complex problems. It presumes that the potential solution of a problem is an individual and can be represented by a set of parameters. These parameters are regarded as genes of a chromosome and can be structured by a string of concatenated values. The form of variables representation is defined by the encoding scheme and can be represented by binary, real numbers or other forms, depending on the application data. Its range, the search space, is usually defined by the problem. An illustrative flowchart of the GA algorithm implementation is shown in the Fig.3 . In the beginning an initial chromosome is randomly generated. The chromosomes are candidate solutions to the problem. Then, the fitness values of all chromosomes are evaluated by calculating the objective function in decoded form. So, based on the fitness of each individual, a group of the best chromosomes is selected through the selection process. The Genetic operators, crossover and mutation, are applied to this surviving population in order to improve the next generation solution. The process continues until the population converges to the global maximum or another stopping criterion is reached.

During the reproduction phase the fitness value of each chromosome is assessed and it is used in selection process to provide bias towards fitness individuals. Then crossover algorithm is initiated once the selection process is completed. The background operator in genetic algorithm is mutation. The probability of mutation is normally low since high mutation rate will destroy fit strings and degenerate GA into random search. The sequence of evolution is repeated until a termination criterion is reached.

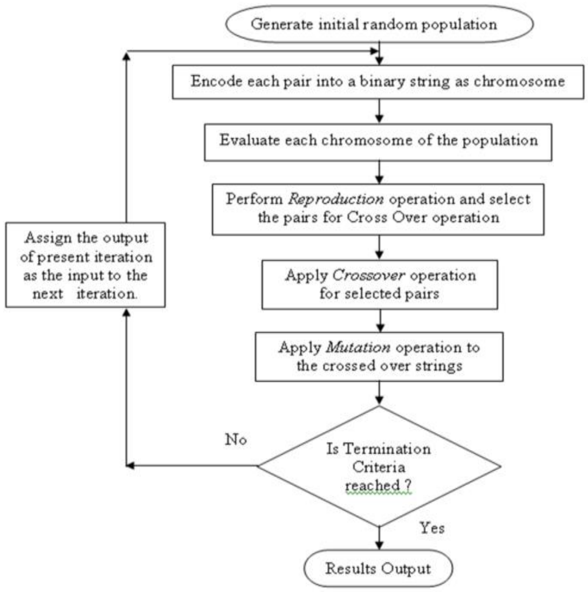

Fig.3 GA algorithm

3.3.1 Objective Function for the Genetic Algorithm

The objective functions considered are based on the error criterion. A number of such criteria are available and in this paper controller's performance is evaluated in terms of Integral time absolute error (ITAE) criteria.

3.3.2 Termination Criteria

Termination of optimization algorithm can take place either when the maximum number of iterations gets over or with the attainment of satisfactory fitness value. Fitness value is the reciprocal of the magnitude of the objective function, since we consider for a minimization of objective function. In this paper the termination criteria is considered to be the attainment of satisfactory fitness value which occurs with the maximum number of iterations as 100. For each iteration the best among the 100 particles is considered as potential solution. Therefore the best values for 100 iterations is sketched with respect to iterations, and are as shown in Fig 4 and 5.

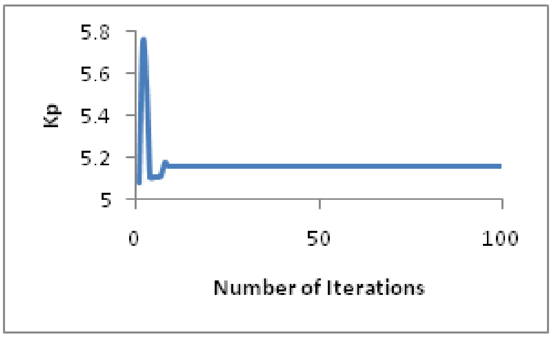

Fig.4 Best solutions of Kp for 100 iterations

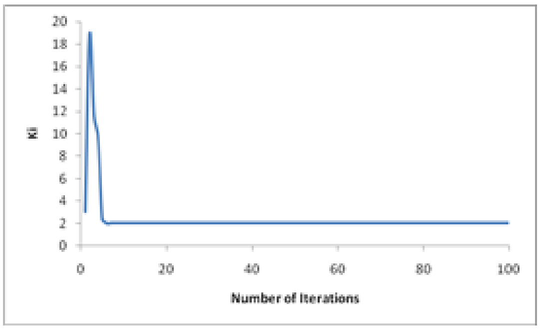

Fig.5 Best solutions of Ki for 100 iterations

The PI controller was formed based upon the respective parameters for 100 iterations, and the global best solution was selected for the set of parameters, which had the minimum error. A sketch of the error based on ITAE criterion for 100 iterations is shown in Fig 6.

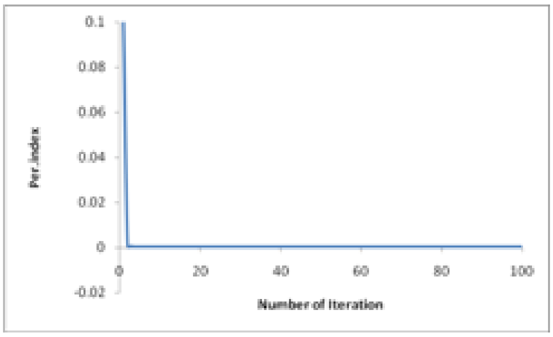

Fig. 6 ITAE values for 100 iterations

It was seen that the error value tends to decrease for a larger number of iterations. As such the algorithm was restricted to 100 iterations for beyond which there was only a negligible improvement.

Based on GA for the application of the PI tuning we get the PI tuning parameters for the model as, Kp=5.164, Ki = 2.006

4. Results and discussion

In this study the simulation results of servo and regulatory responses of ZN, IMC tuned and GA based controllers for reactor temperature at 312K is presented and the PI values obtained by the GA are compared with those of the results derived from IMC and ZN methods in various perspectives, viz. set point changes and regulatory changes in terms of time domain specifications and the performance index are shown in Table 2 and Table3. The servo response of the ZN, IMC tuned controllers and GA based controller of a CSTR for positive set-point change from 311.2K to 312K in reactor temperature and performance for a negative set point change in reactor temperature from set point 311.2K to 308K are shown in fig. 7 and fig. 8 respectively. Performance of controllers for a step change in both set point from 311.2K to 312K and disturbance from 298K to 299K is shown in fig. 9.

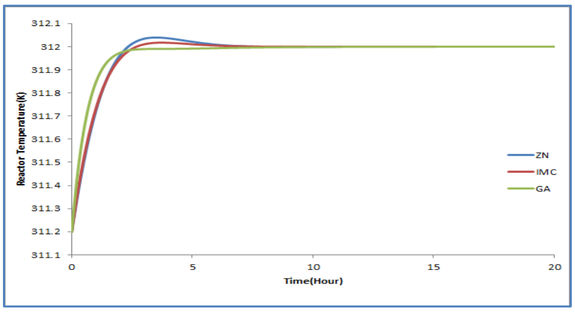

Fig.7 Performance of controllers for a positive set point change in reactor temperature (set point= 311.2k to 312k)

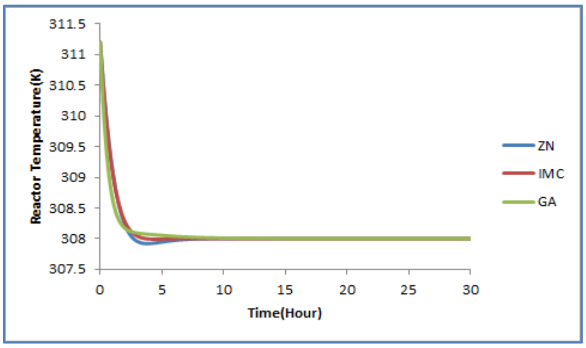

Fig. 8 Performance of controllers for a negative set point change in reactor temperature (set point= 311.2k to 308k)

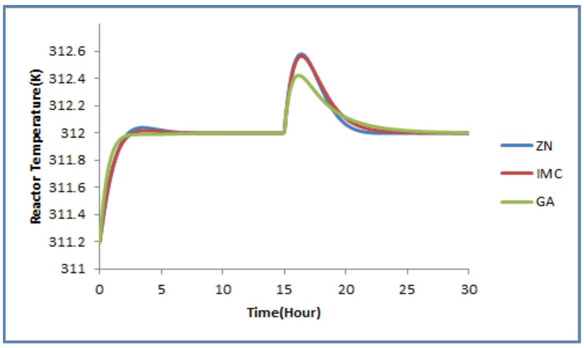

Fig. 9 Performance of controller for a step change in both set point and disturbance (set point= 311.2k to 312k, disturbance = 298k to 299k)

Table 2 Time domain specification

Time domain specification	ZN Tuning	IMC tuning	GA tuning
Rise Time	16.1065	16.7635	12.9442
Settling Time	54.7051	43.0772	24.4831
Peak Time	36	38	201

Table 3 Performance index

Performance Index	ZN Tuning	IMC Tuning	GA Tuning
IAE	1.4592	1.4206	1.2805
ISE	1.2109	1.1628	1.0070
ITAE	0.0459	0.0675	0.6429
MSE	0.00012138	.00011678	.00010192

Conclusions

In the present work the design and implementation of GA based PI controller, IMC tuned PI controller and ZN tuned PI controller for CSTR have been presented. Based on the simulation results it is concluded that the performance of the GA controller is much superior when compared to the ZN and IMC tuned controllers. GA controllers have a faster and more precise control of the process, both for set-point and disturbance step changes. The simulation responses reflect the effectiveness of the GA based controller in terms of time domain specifications. The performance index under the various error criterions of the GA based controller is always less than the IMC tuned controller.

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