Tuning of PID Controller for Cascade Unstable systems Using Genetic Algorithm

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Abstract

Unstable system is difficult to control when compared with stable system. Even though different tuning methods were proposed, because of large dead times in unstable system the desired performance cannot be achieved with simple Proportional Integral Derivative (PID) controllers. The cascade control method is the successful and best method for controlling the unstable system than the single feedback control. It gives the better result than other methods especially in the case of disturbance. In this work we suggest the simple method of tuning the PID controller using Genetic Algorithm (GA) for cascade unstable first order plus time delay process. In this work we give more importance for disturbance rejection than the set point tracking. Because in the process industries disturbance occur often than the set point changing. If there is a change in production rate then only the set point varies. The proposed method gives the improved performance for disturbance rejection when compared to other methods. By giving the disturbance and uncertainty in the model parameters the performance and robustness of the proposed method have been evaluated. The performance of the above mentioned algorithm has been evaluated by comparing the Integral Time Absolute Error (ITAE) with the Lee et al method (2002).

Keywords: CSTR, Cascade control, PID controller, Genetic Algorithm (GA), Integral Time Absolute Error (ITAE).

I. INTRODUCTION

The Continuous Stirred Tank Reactor (CSTR) is used in many process industries. The main characteristic of the CSTR is it maintains constant temperature and concentration throughout the vessel. The constant concentration is achieved by continuous stirring but maintaining constant temperature in CSTR is one of the difficult tasks. The use of GA as a technique for solving control system optimization problem was explained by Krishna kumar et.al [1]. Varsek et.al [2] have discussed about GA in controller design and tuning. A simple method of tuning the cascade systems was proposed by Huang et.al. [3]. Smith predictor with cascade control was proposed by Kaya, I.[4]. In enhanced control with a general cascade control [5] structure, Lee et.al [6] have proposed two IMC based PID controller for both loops. Sree et.al [7] have explained about tuning of PID controllers for stable and unstable First Order Plus Time Delay systems. Telbany et. al [8] presented optimization of PID controller tuning using particle swarm optimizer and genetic algorithms. Optimal H2 IMC-PID controller was detailed by Nasution et.al[9]. Yusoff et.al [10] have discussed about tuning of PID controller using GA. In this work, a simple method of tuning the PID controller using GA for cascade unstable first order plus time delay process is proposed and the paper has been organized as follows: Section 2 describes the CSTR model. Section 3 discusses the cascade control and Section 4 explains the GA. Section 5 shows the simulation results of CSTR and evaluates the performance criteria. Finally section 6 concludes that the GA based PID controller is more robust.

II. MODEL DESCRIPTION

The continuous stirred tank reactor consists of a reactor vessel and it is surrounded by the jacket. The pump is used to supply steam or coolant to the jacket. It is responsible for maintaining the temperature of the fluid inside the reactor. The agitator is present inside the reactor and it is stirred continuously by the motor in order to maintain same concentration throughout the reactor vessel. In CSTR the feed is continuously get into the reactor vessel and the mixed product is taken out from it. The cross section of CSTR is given in the figure..1
Integral mass balance on number of moles $N_i$ of species $i$ in a reactor of volume $V$.

\[
\text{[ACCUMULATION]} = \text{[IN]} - \text{[OUT]} + \text{[GENERATION]}
\]

\[
\frac{dN_i}{dt} = F_{io} - F_i + Vv_i r_i
\]  
(1)

Where $F_{io}$ = Inlet flow rate  
$F_i$ = Outlet flow rate  
$v_i$ = Stoichiometric coefficient.  
$r_i$ = Reaction rate (dependent on the reactant concentration)  

\[
T_A = \frac{1}{1+k\zeta}
\]  
(2)

Where $T_A$ = Temperature of species A  
k = Rate constant  
$\zeta$ = Time constant

### III. CASCADE CONTROL

Two controllers, two sensors, one actuator and two processes in series are the elements of the cascade control system. A primary controller is otherwise called as master controller and its output that serves as the set point for a secondary controller which is called as slave controller. That controller output is used to control the final control element generate the variable which is directly effort the secondary process. Then the secondary process variable produced by the secondary process that effort the primary process. The block diagram of the cascade control is given in the figure 2. The inner loop of the block diagram consists of secondary controller, actuator and secondary process and the outer loop consists of primary controller and primary process. The inner loop functions resembles like a traditional feedback control system with a set point, a process variable, and a controller acting on a process by means of an actuator. The outer loop also does the same except that it uses the entire inner loop act as an actuator.

In the CSTR example, the fluid temperature controller defines the set point that the feed flow rate required to be achieved. The fluid in the reactor vessel, fluid temperature controller and fluid temperature sensor are the elements of primary process. The jacket temperature controller, valve, jacket and jacket temperature sensor are the elements of secondary process. The valve acts as a final control element which is responsible for the flow rate of coolant or steam. And it directly affects the secondary process (jacket) and indirectly the primary process (reactor).
IV. GENETIC ALGORITHM

The genetic algorithm is found by inspiring the biological evolution process. In a genetic algorithm, the concept of natural selection and genetic inheritance has been used. The genetic algorithm is used to find the optimized solution. In genetic algorithm different steps are involved like crossover, mutation etc. Usually the genetic algorithm starts by initializing the population. The GA is an iterative process and the population of each iterations is called generation. The fitness of the population has been evaluated in each generation. Then the fitness is an objective function it may be minimum or maximum function based on the applications it varies. Based on the fitness evaluation the individuals is selected from the population and considered this as a parent. After this process the best from the each individual has been combined and form a new offspring. The new offspring is considered as a individuals and again the new iteration take place in GA. The iteration continues until the maximum number of population has been reached or it reaches the required fitness level. Genetic algorithm is a search algorithm that is based on genetics principles and natural selection. As the number of iteration increases it produce better result. The flow chart of GA is given in the figure 3.

Fig. 2 Block diagram of cascade control system

Fig. 3 Flow chart of Genetic Algorithm
V. RESULTS AND DISCUSSION

To evaluate the performance of the proposed design method, two examples are considered from the paper “Enhanced control with a general cascade control structure (2002)”. By using the MATLAB Simulink the simulation result of the proposed method is analyzed and compared with the Lee et al method (2002).

**Example 1**

\[
G_{p1} = \frac{e^{-4s}}{20s-1}; \quad G_{p2} = \frac{2e^{-2s}}{20s+1} \tag{3}
\]

By using the GA based PID tuning method, the controllers value obtained are \(k_{cs} = 4.46, \tau_i = 3, \tau_d = 0.28\) and other for primary loop \(k_{cp} = 2.48, \tau_i = 27.41, \tau_d = 2.516\) and two filters are \(\alpha = 3.66, \beta = 32.91\) are used. This is compared with Lee et al. method (2002) where two PID controllers have been used, one for secondary \(k_{cs} = 6.92, \tau_i = 4.6, \tau_d = 0.79\) and other for primary loop \(k_{cp} = 3.31, \tau_i = 36.22, \tau_d = 3.08\) along with two filters \(\alpha = 3.66, \beta = 32.91\). With these controller settings the methods are simulated by giving a unit step change in set point and disturbance in the process.

The figure 4 shows the behavior of the process when the step input is given. The figures 5 and 6 shows that if the disturbance is given in primary or secondary loop, the Lee et al method gives oscillatory response but the GA method gives stable response within minimum period. And the figures 7 and 8 shows that if the uncertainty given in the process parameter, the Lee et al method gives unstable response but the GA method gives stable response within minimum period. Hence the proposed method is superior to the method suggested by Lee et.al. (2002).

![Fig. 4 Simulation result for the step input.](image1)

![Fig. 5 Simulation result for the disturbance in secondary loop](image2)
The table I shows the performance criteria with respect to ITAE, under perfect and uncertainty in process parameter conditions.
C. Example 2

\[ G_{p1} = \frac{e^{-4s}}{20s-1}, \quad G_{p2} = \frac{2e^{-2s}}{s} \quad (4) \]

By using the GA based PID tuning method, the controllers value obtained are \( k_{cs} = 0.10, \ z_i = 1.87, \ z_d = 1.63 \) and other for primary loop \( k_{cp} = 2.18, \ z_p = 38.56, \ z_i = 0.806 \) and two filters \( \alpha = 4.07, \ \beta = 32.91 \) are used. This is compared with Lee et al. method (2002) where two PID controllers have been used, one for secondary \( k_{cs} = 0.35, \ z_i = 5.02, \ z_d = 0.82 \) and other for primary loop \( k_{cp} = 3.31, \ z_i = 36.22, \ z_i = 3.08 \) along with two filters \( \alpha = 4.07, \ \beta = 32.91 \). With these controller settings the methods are simulated by giving a unit step change in set point and disturbance in the process. The figure 9 shows the behavior of the process when the step input is given. The figures 10 and 11 shows if the disturbance is given in primary or secondary loop the Lee et al method gives oscillatory response but the GA method gives stable response within minimum period. And the figure 12 shows that if the uncertainty given in the process parameter the Lee et al method gives unstable response but the GA method gives stable response within minimum period. Hence the proposed method is superior to the method suggested by Lee et al (2002).

<table>
<thead>
<tr>
<th>Uncertainty in process parameters</th>
<th>Criteria</th>
<th>Lee et al method</th>
<th>GA method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step input</td>
<td>ITAE</td>
<td>811.3</td>
<td>789.9</td>
</tr>
<tr>
<td>Disturbance in secondary loop</td>
<td>ITAE</td>
<td>2056</td>
<td>2192</td>
</tr>
<tr>
<td>Disturbance in primary loop</td>
<td>ITAE</td>
<td>1273</td>
<td>831</td>
</tr>
<tr>
<td>10% increase in ( z_i )</td>
<td>ITAE</td>
<td>4970</td>
<td>958.8</td>
</tr>
<tr>
<td>20% decrease in ( z_d )</td>
<td>ITAE</td>
<td>1271</td>
<td>754.6</td>
</tr>
<tr>
<td>40% decrease in ( K_{p2} )</td>
<td>ITAE</td>
<td>831</td>
<td>754.6</td>
</tr>
</tbody>
</table>

Fig. 9 Simulation result for the step input.

Fig. 10 Simulation result for the disturbance in primary loop.
Fig. 11 Simulation result-2 for the change in tau value (10% increase in \( \tau_1 \), 20% decrease in \( \tau_2 \)).

Fig. 12 Simulation result-2 for the change in gain value (40% decrease in \( k_p \)).

The table II shows the performance criteria with respect to ITAE, under perfect and uncertainty in process parameter conditions.

<table>
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<th>GA method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step input</td>
<td>ITAE</td>
<td>812.5</td>
<td>1313</td>
</tr>
<tr>
<td>Disturbance in primary loop</td>
<td>ITAE</td>
<td>3525</td>
<td>3279</td>
</tr>
<tr>
<td>10% increase in ( \tau_1 ) 20% decrease in ( \tau_2 )</td>
<td>ITAE</td>
<td>273787</td>
<td>1437.62</td>
</tr>
<tr>
<td>40% decrease in ( k_p )</td>
<td>ITAE</td>
<td>199879</td>
<td>7660</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

In this work the CSTR model is taken and it is divided into two parts. One part consists of integrating unstable process which is taken as a primary loop and the other part consists of stable process which is taken as a secondary loop. For CSTR, cascade control system is used. The idea of cascade structure is that the disturbances introduced in the inner loop are reduced in the inner loop itself before they extend into the outer loop. By the proper selection of PID controller values the desired temperature has been reached. For finding the PID values, the GA has been used. The results generated from this method were compared with the

2017
Lee et al method. The robustness of the system is also analyzed by giving disturbance in both primary and secondary loop and varying the system parameters (uncertainty in system parameters). Then from the above simulation results of two examples it is clear that the GA based PID tuning method give satisfactory response for a step change in input and disturbance or uncertainty occurred in the given model. For each of the cases, a better robust performance is obtained for the proposed method when parameters are perturbed. The ITAE is used to evaluate the performance of the two discussed methods. Then ITAE is minimum for GA based PID tuning method than the Lee et al method. It reveals that the GA based controller is more robust and superior than the Lee et al method (2002).

REFERENCES
