Fuzzy Logic Based Temperature Control of Continuous Stirred Tank Reactor

Brijendra kr. Maurya¹ Saurabh kr. Bajpai²
School of Engineering & Technology
Shobhit University, Gangoh

Abstract— CSTR (Continuous Stirred Tank Reactor) is an important subject in chemical process and provide a wide range of research in the field of control and instrumentation engineering and chemical engineering. Various controllers have been applied on the process (CSTR) to control the temperature. This paper shows the analysis of response of conventional PID controller and Fuzzy Logic used in Mamdani type of Controller for Temperature control of CSTR in the presence of disturbances acting on it. Mathematical model of CSTR (Continuous Stirred Tank Reactor) is developed by the set of differential equations.

Furthermore, Fuzzy controller gives more accurate behaviour in control action for temperature in CSTR as compare to PID Controller.

Keywords— CSTR, Fuzzy controller, Fuzzy Logic control, Proportional – Integral – Derivative (PID).

1. Introduction

CSTR (Continuous Stirred Tank Reactor) is a non-linear chemical reactor used in chemical industry. A CSTR with one steady state as function of jacket temperature may have multiple steady state behaviour if jacket inlet temperature is considered as the manipulated variable.

Figur2: CSTR (Continuous Stirred Tank Reactor)

Mathematical model of CSTR comes from energy balance and the mass balance inside the reactor. The jacket surrounding the reactor has an inlet stream and outlet stream (coolant).Jacket is supposed to be perfectly mixed and has temperature lower the reactor .Energy flows from the wall of the reactor to the jacket which remove the heat evolved due to reaction. Our aim is to maintain temperature of reacting mixture constant say T at the desired value. The only manipulated variable is coolant temperature (Tj). [1]

The goal of linearization is to find state space model of dynamics

\[ X' = Ax + Bu \] ........................ (1)
\[ y = Cx + Du \] ........................ (2)

Where the states, inputs and output are in deviation variable.

\[ A = \begin{bmatrix} s_f & 1/s_f \\ s_e & 1/s_e \end{bmatrix} \quad B = \begin{bmatrix} s_f \\ s_e \end{bmatrix} \quad C = \begin{bmatrix} 0 & 1 \end{bmatrix} \quad D = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \]

Steady State Solution

The steady state solution is obtained when dCA/dt= 0, dt/dt=0, dTj/dt=0 that is -

\[ f_1 (CA, T, and Tj) = dCA/dt=0 \]
\[ F/V (CAF – CA) – K_0 \exp (-Ea/RT) CA=0 \] .......................... (3)
\[ f_2 (CA, T, Tj) = dTj/dt=0 \]
\[ F/V (Ff– T) + (-ΔH/ρC_P) K_0 \exp (-Ea/RT) CA \]
\[ -UA_0 (T–Tj)/VpC_P=0 \] .......................... (4)

Where

\[ C_{Af} = \text{Concentration of component A in the feed stream} \]
\[ T_f = \text{inlet feed stream temperature} \]
\[ T_j = \text{Jacket temperature} \]
\[ F_f = \text{Coolant flow rate} \]
\[ C_{A,}= \text{Concentration of component A in reactor tank.} \]
\[ T = \text{Reactor temperature} \]
\[ F = \text{flow rate of feed stream} \]
\[ k_0 = \text{the frequency factor}, \]
\[ E_a = \text{the activation energy} \]
\[ \Delta H = \text{The heat of the reaction.} \]
\[ U = \text{heat transfer coefficient.} \]
\[ A = \text{heat transfer area.} \]
\[ \rho = \text{the density of liquid in the reactor.} \]
\[ V = \text{is constant liquid reactor volume.} \]
\[ C_p = \text{constant heat capacity} \]

### Table 1: Reactor Parameter’s values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_0 )</td>
<td>16.96 \times 10^{12} \text{ Hr}^{-1}</td>
</tr>
<tr>
<td>( U )</td>
<td>75 \text{ Btu/hr°F}</td>
</tr>
<tr>
<td>( \rho C_p )</td>
<td>53.25 \text{ Btu/ft}^{-2}°F</td>
</tr>
<tr>
<td>( R )</td>
<td>1.987 \text{ Btu/lbmol °F}</td>
</tr>
<tr>
<td>( F )</td>
<td>340 \text{ Ft/hr}</td>
</tr>
<tr>
<td>( V )</td>
<td>85 \text{ Ft}^3</td>
</tr>
<tr>
<td>( C_{ar} )</td>
<td>0.132 \text{ Lb mol/ft}^3</td>
</tr>
<tr>
<td>( T_f )</td>
<td>60 \text{ °F}</td>
</tr>
</tbody>
</table>

Using all reactor parameter’s value we can find the following State space model system –

\[
A = \begin{bmatrix} -7.9909 & -0.013674 \\ 2922.9 & 4.5564 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 1.4582 \end{bmatrix},
\]
\[
C = \begin{bmatrix} 0 & 1 \end{bmatrix}, \quad D = [0]
\]

By MATLAB command we can find out reactor process transfer function (G)

\[
G(s) = \frac{1.4582s + 11.45}{s^2 + 3.424s + 3.357}
\]

### II. PID Controller

A conventional proportional integral derivative (PID) type controller is mostly used in the industry because of simple control structure easiness in design and less expensive. PID controller cannot yield an efficient control performance if control object is non linear. PID controller is a linear controller. The PID controller is probably the most-used feedback controller. PID is an acronym for Proportional - Integral - Derivative, referring to the three terms operating on the error signal to produce a control signal. If \( u(t) \) is the control signal, \( y(t) \) is the measured output and \( r(t) \) is the desired output, and tracking error \( e(t) = r(t) - y(t) \), a PID controller has the general form.

\[
u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{d}{dt} e(t)\]

Where \( K_p \), \( K_i \), \( K_d \) are proportional gain, Integral gain and Derivative gain. \( e(t) \) is error signal.

**Simulation & Result**

For set point tracking:

- Rise Time (sec) = 1.02
- Settling time (sec) = 5.60
- Overshoot (%) = 16.42
- Undershoot (%) = 2.10
- Steady state error (%) = 0

Mathematical model of CSTR comes from energy balance and the mass balance inside the reactor. The jacket surrounding the reactor has an inlet stream and outlet stream (coolant). Jacket is supposed to be perfectly mixed and has temperature lower the reactor Energy flows from the wall of the reactor to the jacket which removes the heat evolved due to reaction. Our aim is to maintain temperature of reacting mixture constant say \( T \) at the desired value. The only manipulated variable is coolant temperature \( (T_j) \).

### III. Fuzzy Logic Controller

Fuzzy logic is extension of binary logic. It uses partial truth values instead of completely true or completely false. They have a value that shows the degree of truth in the range 0 to 1.0 represents absolute false and 1 represents completely true [2][5]. Fuzzy logic controller converts the intelligent knowledge into an automatic control action. It handles information in systematic way. Fuzzy logic is widely used in very complex and highly nonlinear system. [3]

![Block Diagram of Fuzzy Inference System](image)

Fuzzy logic implemented here is a two-input & single-output. The two inputs are error, and error rate. Both input variables are classified into three fuzzy levels in this implementation based on the resolution and real-time requirements needed.

**Subsets for Inputs and Output:**

**Input 1(Temperature Error):**

- Membership Functions for input1:
  - NB (Negative Big)
  - NM (Negative Medium)
  - NS (Negative Small)

- Where \( K_p = 0.169, K_i = 0.439 \) and \( K_d = 0.025 \)

- Fuzzy logic is widely used in very complex and highly nonlinear system.
Z (Zero)  
PS (Positive Small)  
PM (Positive Medium)  
PB (Positive Big)

**Input 2 (Temperature Error Rate):**

Membership Functions for input 2:

- NB (Negative Big)  
- NM (Negative Medium)  
- NS (Negative Small)  
- Z (Zero)  
- PS (Positive Small)  
- PM (Positive Medium)  
- PB (Positive Big)

**Membership Functions for input 2:**

**Rule Base:**

**SIMULATION TESTING AND RESULT**

![Simulink Block Diagram of FLC](image)

**Output Temperature response:**

![Output Temperature response](image)

**For set point tracking:**

- Rise Time (sec) = 1.4  
- Settling time (sec) = 1.8  
- Overshoot (%) = 0  
- Undershoot (%) = 0  
- Steady state error (%) = 0

**Surface Viewer:** In this paper this plot is generated by the fourteen nine rules that accounted for both error and change in error.

![Surface View](image)

![Figure 12: Surface View](image)
Rule Viewer: This Rule Viewer provides an animation of how the rules are fired during simulation.

Figure 13: Rule Viewer

Figure 14: Comparison of performance of PID and FLC.

Table 2: COMPARISION CHARACTERISTICS OF FLC & PID CONTROLLERS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FLC</th>
<th>PID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise Time (sec)</td>
<td>1.40</td>
<td>1.02</td>
</tr>
<tr>
<td>Settling Time (sec)</td>
<td>1.80</td>
<td>5.60</td>
</tr>
<tr>
<td>Steady state error (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maximum overshoot (%)</td>
<td>0</td>
<td>16.42</td>
</tr>
<tr>
<td>Undershoot (%)</td>
<td>0</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Conclusions: This paper presents a comparative study of performance of PID and FLC. Based on the results and the analysis, a conclusion has been made that FLC provides a better control action.

Acknowledgment

Brijendra Kumar maurya presently working as Assistant Professor in Department of Electronics&Communication Engineering in Shobhit University, Saharanpur. His current area of interest in Control System, Digital Electronics, Signal System, Electromagnetic Field Theory, Analog Integrated Circuits Electronic Circuits.

Saurabh Kumar Bajpai presently working as Assistant Professor in Department of Electrical Engineering in Shobhit University. He published several papers in National & International journal. His current area of interest in control system, power system, Electric Machine, FACTS.

REFERENCES

3) A. Scottedward Hodel, Member, IEEE, and Charles E. Hall, “Variable Structure.
9) Adaptive control systems: techniques and applications By V. V.Chalam:34-98.