Comparison Study of PID Controller Tuning using Classical/Analytical Methods

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Abstract

The simplicity, ease of implementation and robustness has attracted the use of Proportional, Integral and Derivative (PID) controllers in the chemical process industries. Numerous tuning techniques are available for tuning of PID controllers, each one has its pros and cons. Most of the tuning techniques are proposed for First Order Process with Time Delay (FOPDT). This paper presents the technique for obtaining the FOPDT model using Sundaresan and Krishnaswamy method and performance comparison of PID controller based on open loop, closed loop tuning techniques and PID controller tuned with Internal Model Control (IMC) technique for set point tracking and disturbance rejection. Analysis has been carried out in terms of, Integral error criteria, such as Integral Absolute Error (IAE) and Integral Squared Error (ISE) and time response information viz. rise time, settling time, % peak overshoot and maximum sensitivity. Superheated steam temperature system of 500MW boiler and Mean arterial blood pressure system are considered for the simulation study. The results indicate that the ratio of time delay and time constant have influence on the performance of the tuning techniques. IMC – PID provides the flexibility of adjusting for desired performance in comparison to other tuning techniques.

Keywords: PID; Tuning methods; setpoint tracking; disturbance rejection; IMC;

INTRODUCTION

The most popular controller used in the process industries for closed loop control is PID controller, as it can assure satisfactory performances with simple algorithm for a wide range of processes. It is important to note that cost benefit ratio obtained through the PID controller is difficult to achieve by other controllers [1–4]. It is found that 97% of the regulatory controllers in industry use PID algorithm [5, 6]. The PID controller is popularly known as three term controller– the Proportional (P), Integral (I) and Derivative (D). The desired closed-loop system performance can be achieved with an appropriate adjustment of controller settings. This procedure is known as controller tuning. Hundreds of tools, methods and theories are available for tuning the PID controller [4, 7]. However, finding an optimal parameters for the PID controller is still a tricky task; in practice still the trial and error method is used for tuning process by the control engineers. The controller can provide optimised control action, and minimised error performance with optimum tuning of the three parameters in the PID controller algorithm. The mathematical form of PID algorithm is represented in Eq. (1).

\[ G_{PID}(s) = G_c(s) = K_p \left( 1 + \frac{1}{T_i s} + T_d s \right) \]  (1)

where, \( G_c(s) = U(s)/E(s) \) is the controller transfer function, \( K_p \) - Proportional gain, \( T_i \) - Integral time and \( T_d \) - Derivative time.

This paper focuses on

1. Identifying the FOPDT process models from step response data.
2. Design of PID controller from the identified model using open loop and closed loop tuning techniques.
3. Performance evaluation of the designed PID controller through simulation for setpoint tracking and disturbance rejection.

The paper is organised as, Section 2 describes the system identification procedure from step response data, Section 3 discusses open loop and closed loop tuning techniques of PID controller, Section 4 describes the application of IMC for tuning of PID controller, Section 5 describes the performance evaluation criteria’s, Section 6 demonstrates the simulation results for evaluation of the controller performance for servo operation (setpoint tracking) and regulator operation (disturbance rejection), and the paper ends with the conclusions. No claim of finding new techniques/ methods is made in the paper, except for performance comparison and conclusion drawn from the comparison.

SYSTEM IDENTIFICATION FROM STEP RESPONSE DATA

Most of the tuning algorithms for PID controller are based on the FOPDT, which has the general form represented by Eq. (2). The process can be approximated as FOPDT by applying unit step input and using Sundaresan and Krishnaswamy method [8-10].

\[ G_m(s) = \frac{Ke^{-\theta_s}}{\tau s + 1} \]  (2)

Sundaresan and Krishnaswamy have proposed a simple and easy method for fitting the dynamic response of systems in
terms of FOPDT transfer functions [8]. The modelling parameters, time delay (θ), time constant (τ) and gain (K) are obtained for Eq. (2) by computing the time instances \( t_1 \) and \( t_2 \) at which the response reaches 35.3% and 85.3% of its final value, represented in Fig. 1 and Eq. (3) [10].

\[
\begin{align*}
\theta &= 1.3t_1 - 0.29t_2 \\
\tau &= 0.67(t_1 - t_2) \\
K &= \frac{\text{output \_at\_steady\_state}}{\text{input \_at\_steady\_state}} 
\end{align*}
\]

(3)

Figure 1. step response of open loop process

TUNING OF PID CONTROLLER

A. Open loop tuning techniques

These are experimental methods on the open-loop systems (i.e., on the process itself, independent of the controller, which may be present or not). The plant/process response is obtained with the disconnection of the feedback controller and application of step change in the input. The information from the response is derived as discussed in Section 2. As the controller is disconnected from the plant is no longer under control. If the control loop is critical, these techniques can be hazardous. Open loop tuning techniques are suitable only for self regulating plants/processes. With Open loop experiments it is possible to get informative results quickly.

Wide varieties of tuning rules are available based on the open – loop response of the plant or process which is usually sigmoid (S shape) in nature. They follow the same principle, but they vary in the way they relate the tuning parameters to the model parameters. The three basic methods of open – loop tuning techniques are the classical Ziegler – Nichols (Z-N OL), Cohen – Coon (C-C) and Chien Hrones Nicholas (CHR) methods.

1) Ziegler-Nichols (Z-N OL) Open Loop Tuning Technique

The Ziegler–Nichols rules for tuning of PID controller have been very influential [11, 12]. Z-N has proposed a tuning method in 1942 called the Ziegler-Nichols open loop tuning method; it is one of the most popular and most widely used classical tuning method. It is also referred as Process Reaction Curve method (PRC). This tuning method often forms the starting point for tuning procedures used by controller manufacturers and process industry. The PID controller parameters are computed from the FOPDT parameters. The PID tuning parameters as a function of the open loop model of Eq. (2) are represented in Table 1.

2) Cohen-Coon (C-C OL) Open Loop Technique

Cohen – Coon in 1953 developed a tuning method based on the FOPDT process model [7, 13]. A set of tuning parameters were developed empirically to obtain one quarter decay ratio to yield closed loop response similar to Z-N OL method. The tuning parameters as a function of FOPDT model of Eq. (2) are represented in Table 1.

3) Chien, Hrones and Reswick (CHR) Technique

Chien, Hrones and Reswick (CHR) method is the modified version of the Ziegler-Nichols method [14]. This method was developed in 1952 by Chien, Hrones and Reswick, provides a better way of selection of a compensator for process control applications. They also made an important observation that tuning of setpoint response or load response is different [7,9]. The controller parameters from CHR set point response method are summarized in Table 1.

B. Closed Loop PID Tuning Techniques

Closed loop tuning techniques depend on frequency response of the process/plant. Two parameters ultimate period (\( P_u \)) and ultimate gain (\( K_u \)) are to be evaluated from the closed loop system response. The \( K_u \) and \( P_u \) are obtained from the closed loop system with P-control alone and making the integral and derivative times zero. The gain of the P-Control is increased until sustained oscillations with constant amplitude and frequency as in Fig. 2 are obtained. The \( P_u \) value is obtained by measuring the time between any two consecutive peaks, and \( K_u \) is the value of gain that caused sustained oscillations.
Table 1: Open loop PID Controller tuning technique formulas

<table>
<thead>
<tr>
<th>Tuning Method</th>
<th>$K_p$</th>
<th>$T_i$</th>
<th>$T_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ziegler-Nichols</td>
<td>$1.2\tau$</td>
<td>$2.2\theta$</td>
<td>$0.5\theta$</td>
</tr>
<tr>
<td>Cohen-Coon</td>
<td>$\frac{\tau (4 + \theta)}{K\theta} (\frac{32 + 6\theta}{13 + 8\theta})$</td>
<td>$\theta \left( \frac{4}{9 + 2\theta} \right)$</td>
<td></td>
</tr>
<tr>
<td>CHR</td>
<td>$0.6\tau$</td>
<td>$\tau$</td>
<td>$0.5\tau$</td>
</tr>
</tbody>
</table>

Figure 2: Closed response with P-Control to find $K_u$ and $P_u$

1) **Ziegler-Nichols (Z-N CL) Closed Loop Technique**
   The Ziegler-Nichols [11], continuous cycling method or ultimate gain method is one of the best known closed loop tuning strategies and was developed in 1942. This tuning method often forms the basis for tuning procedures used by controller manufacturers and process industry and the PID tuning values were developed as function of ultimate gain (critical gain) and ultimate period (critical period). The tuning parameters based on Z-N CL are represented in Table 2.

2) **Modified Ziegler-Nichols Technique**
   For reduction of overshoot in the response Ziegler-Nichols suggested modifications to their basic PID closed loop tuning approach, this is known as modified modified approach of Ziegler-Nichols method. The formulas for modified Ziegler-Nichols tuning method are given in Table 2.

3) **Tyreus - Luyben Technique**
   The Tyreus and Luyben's tuning method was introduced in 1997 [15,16] and is based on ultimate gain and ultimate period as in the Ziegler-Nichols method, but with modifications in the formulas for the controller parameters to obtain better stability in the control loop compared with the Ziegler-Nichols' method. The formulas suggested for PID controller are listed in Table 2.

Table 2: Closed Loop PID controller tuning technique formulas

<table>
<thead>
<tr>
<th>Tuning Method</th>
<th>$K_p$</th>
<th>$T_i$</th>
<th>$T_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ziegler-Nichols</td>
<td>$0.6K_u$</td>
<td>$P_u / 2$</td>
<td>$P_u / 8$</td>
</tr>
<tr>
<td>Modified Z-N</td>
<td>$0.33K_u$</td>
<td>$P_u / 2$</td>
<td>$P_u / 3$</td>
</tr>
<tr>
<td>Tyreus-Luyben</td>
<td>$0.45K_u$</td>
<td>$2.2K_u$</td>
<td>$P_u / 6.3$</td>
</tr>
</tbody>
</table>

**PID TUNING WITH INTERNAL MODEL CONTROL**

Garcia and Morari [17-19] have introduced IMC; it is characterized as a controller where the process model is explicitly an integral part of the controller. The design process of IMC involves factorizing the predictive plant model $G_M(s)$ as invertible $G_{M-}(s)$ and non-invertible $G_{M+}(s)$ parts depicted in Eq. (4) by simple factorization or all pass factorization [8,17,19-21]. The IMC in Eq. (5) is the inverse of the invertible $G_{M-}(s)$ portion of the plant model $G_M(s)$, IMC filter $G_f(s)$ a low pass filter given in Eq. (6) is used for the realization of the controller.

$$G_M(s) = G_{M-}(s)G_{M+}(s)$$  \hspace{1cm} \text{(4)}

The design of the IMC controller is

$$Q(s) = G_{M-}^{-1}(s)G_f(s)$$  \hspace{1cm} \text{(5)}

Where, $G_f(s)$ is the low pass filter

$$G_f(s) = \frac{1}{1 + \lambda s}$$  \hspace{1cm} \text{(6)}

The IMC controller can take the form of ideal feedback controller, expressed mathematically in terms of $Q(s)$ and $G_M(s)$ as Eq. (7)

$$G_c(s) = \frac{Q(s)}{1 - Q(s)G_M(s)}$$  \hspace{1cm} \text{(7)}

Using all pass factorization and first order Padé approximation of delay term and comparing of Eq. (7) with Eq. (1) results in Eq. (8).

$$K_p = \frac{2\tau + \theta}{K(2\lambda + \theta)}, T_i = \tau + \frac{\theta}{2}, T_d = \frac{\theta\tau}{2\tau + \theta}$$  \hspace{1cm} \text{(8)}

Essentially IMC – PID has only one tuning parameter $\lambda$ to achieve the desired performance.

**PERFORMANCE ASSESSMENT**

It is well-known that a well-designed control system should meet the following requirements besides nominal stability, it
should possess disturbance attenuation, set point tracking and robust stability and/or robust performance. The first two requirements are referred to as ‘Performance’ and the third, ‘Robustness’ of a control system [22-25].

C. Performance

The integral error is a good measure for evaluating the set point and disturbance response [26]. The following are generally used criteria based on the integral error for a set step point or disturbance response.

\[ IAE = \int_0^\infty |e(t)| \, dt \]  
\[ ISE = \int_0^\infty e(t)^2 \, dt \]  
\[ ITAE = \int_0^\infty |t|e(t)| \, dt \]

IAE penalizes small errors, ISE large errors and ITAE the errors that persist for a long time.

D. Robustness Analysis

Robustness is the ability of the closed loop system to be insensitive to component variations. It is one of the most useful properties of feedback. Robustness is also what makes it possible to design feedback system based on strongly simplified models. It necessary to have quantitative ways to express how well a feedback system performs. Measures of performance and robustness are closely related. In closed loop system, the robustness performance is computed by the sensitivity function(S) which relates to disturbance rejection properties while the complementary sensitivity function (T) provides a measure of set point tracking performances.

\[ S = \frac{1}{1 + G_c G_p} \]  
\[ T = \frac{G_c G_p}{1 + G_c G_p} \]

where, \( |S(j\omega)|\) and \(|T(j\omega)|\) are the amplitude ratios of S and T respectively [24]. The maximum values of amplitude ratios provide useful measure of robustness and also serve as control system design criteria. The maximum sensitivity \( M_s = \max_{\omega} |S(j\omega)|\) is the inverse of the shortest distance from Nyquist plot to the critical point [22]. As \( M_s \) decreases, the robustness of closed loop system increases [27]. The second robustness measure is \( M_T = \max_{\omega} |T(j\omega)|\), referred as resonant peak. For a satisfactory control system \( M_s \) should be in the range of 1.2 – 2.0 and \( M_T \) should be in the range of 1.0 – 1.5 [22, 28].

II. Simulation Results

Simulation results are presented to illustrate the performance of PID controller tuned with open loop tuning techniques Viz. Ziegler – Nicholas, Cohen – Coon and CHR and closed loop tuning techniques Viz. Ziegler – Nicholas, Modified Ziegler – Nicholas and Tyreus – Luyben and IMC based PID tuning. Super Heated Steam (SHS) temperature control system of 500 MW boiler and Mean Arterial Blood Pressure (MABP) are considered for evaluation and comparison of tuning techniques. The simulations were performed in MATLAB/Simulink for step changes in set-point and in the disturbance. The controller performance is measured by calculating IAE, ISE values and determining the rise time (\( t_r \)), settling time (\( t_s \)), % peak overshoot (\( M_p \)) and maximum sensitivity (\( M_s \)).

Example 1:

Superheated steam temperature system of 500 MW boiler is considered for analysis. Superheated steam temperature is one of the important variables in the boilers to be controlled precisely for efficiency and safety [14]. Steam temperature must be stable to achieve peak turbine efficiency and reduce fatigue in the turbine blades [14]. The control of steam temperature is difficult, as there is a time delay between the control action in the form of additions of spray water and when steam temperature is measured. The gain, delay and time constant of the system response also change significantly with the MW load on the steam turbine due to changes in steam flow rates [29]. The transfer function of SHS temperature system is fifth order model [8,30] represented by Eq. (14), the gain, time delay and time constant are obtained from Sundaresan and Krishnaswamy method as described in Section 2. FOPDT of SHS temperature system is represented by Eq. (15).

\[ G(s) = \frac{0.7732}{(19s + 1)^3} \]  
\[ G_M(s) = \frac{0.7717e^{-56.278s}}{42.934s + 1} \]

The performance of the PID controller for SHS system based on open loop and closed loop tuning techniques and IMC tuning are depicted in Table 3, Fig. 3 and Table 4, Fig. 4 respectively.
Table 3: Performance of the PID based on Open Loop tuning techniques for SHS system

<table>
<thead>
<tr>
<th>Tuning Technique</th>
<th>Kp</th>
<th>Ti</th>
<th>Td</th>
<th>Ms</th>
<th>Rise time</th>
<th>Settling time</th>
<th>% M_p</th>
<th>IAE</th>
<th>ISE</th>
<th>Peak</th>
<th>IAE</th>
<th>ISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z-N</td>
<td>1.1863</td>
<td>112.556</td>
<td>28.139</td>
<td>2.58</td>
<td>210</td>
<td>510</td>
<td>0</td>
<td>122.8</td>
<td>74.63</td>
<td>0.399</td>
<td>94.61</td>
<td>23.54</td>
</tr>
<tr>
<td>C-C</td>
<td>1.6417</td>
<td>95.524</td>
<td>19.370</td>
<td>3.16</td>
<td>60.8</td>
<td>266</td>
<td>6.9</td>
<td>80.84</td>
<td>60.21</td>
<td>0.426</td>
<td>58.18</td>
<td>13.97</td>
</tr>
<tr>
<td>CHR</td>
<td>0.5932</td>
<td>42.934</td>
<td>21.467</td>
<td>1.4</td>
<td>105.3</td>
<td>395</td>
<td>9.3</td>
<td>120.9</td>
<td>84.97</td>
<td>0.513</td>
<td>82.53</td>
<td>29.14</td>
</tr>
<tr>
<td>IMC-PID</td>
<td>1.095</td>
<td>71.073</td>
<td>16.998</td>
<td>1.77</td>
<td>80</td>
<td>239</td>
<td>4</td>
<td>88.68</td>
<td>68.97</td>
<td>0.457</td>
<td>64.91</td>
<td>19.95</td>
</tr>
</tbody>
</table>

Figure 3: Set point and Disturbance response of SHS for open loop tuning techniques

Table 4: Performance of the PID based on Closed Loop tuning techniques for SHS system

<table>
<thead>
<tr>
<th>Tuning Technique</th>
<th>Kp</th>
<th>Ti</th>
<th>Td</th>
<th>Ms</th>
<th>Rise time</th>
<th>Settling time</th>
<th>% M_p</th>
<th>IAE</th>
<th>ISE</th>
<th>Peak</th>
<th>IAE</th>
<th>ISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z-N</td>
<td>1.4803</td>
<td>83.25</td>
<td>20.8125</td>
<td>2.68</td>
<td>65.23</td>
<td>185</td>
<td>7</td>
<td>80.53</td>
<td>62.01</td>
<td>0.408</td>
<td>56.24</td>
<td>14.63</td>
</tr>
<tr>
<td>MZ-N</td>
<td>0.8142</td>
<td>83.25</td>
<td>55.50</td>
<td>5.31</td>
<td>207</td>
<td>354</td>
<td>0.6</td>
<td>135.8</td>
<td>89.92</td>
<td>0.427</td>
<td>102.7</td>
<td>29.24</td>
</tr>
<tr>
<td>T - L</td>
<td>1.1215</td>
<td>366.3</td>
<td>26.4286</td>
<td>2.42</td>
<td>&gt;1000</td>
<td>&gt;1000</td>
<td>NA</td>
<td>325</td>
<td>144.9</td>
<td>0.448</td>
<td>236.8</td>
<td>66.16</td>
</tr>
<tr>
<td>IMC-PID</td>
<td>1.2096</td>
<td>71.073</td>
<td>16.9983</td>
<td>1.93</td>
<td>71</td>
<td>222</td>
<td>8.2</td>
<td>87.14</td>
<td>66.3</td>
<td>0.443</td>
<td>58.76</td>
<td>17.72</td>
</tr>
</tbody>
</table>

Figure 4: Set point and Disturbance response of SHS for closed loop tuning techniques
The results indicate that the maximum sensitivity calculated and obtained for IMC – PID is 1.77 and 1.93 respectively which are in the optimal range on 1.2 – 2.0. Thus provide improved robustness and performance in comparison to the other techniques. The faster response to input and settling at steady state is achieved by IMC-PID, this technique also provides smaller values of error criteria IAE, ISE. Thus, the results indicate that the IMC-PID provides improvement in both the performance and robustness in comparison to the other techniques considered. The other advantage of the IMC-PID technique is it has only one tuning parameter to adjust to provide performance and robustness.

**Example 2:**

The patient blood pressure model used here was developed by Martin et al. \[31,32\]. The transfer function of MABP system is third order model represented by Eq. (16), the gain, time delay and time constant are obtained from Sundaresan and Krishnaswamy method as described in Section 2. FOPDT of MABP is represented by Eq. (17).

\[ G(s) = \frac{(150s + 5)e^{-60s}}{30000s^3 + 4600s^2 + 130s + 1} \]  
\[ G_M(s) = \frac{5e^{-78.6s}}{84.4s + 1} \]

The performance of the PID controller for MABP system based on open loop and closed loop tuning techniques and IMC tuning are depicted in Table 5, Fig. 5 and Table 6, Fig. 6 respectively. The results indicate that the IMC – PID provides the maximum sensitivity of 1.96 and 1.98 respectively which are in the optimal range on 1.2 – 2.0. Thus, provide improved robustness and performance in comparison to the other techniques. The faster response to input and settling at steady state is achieved by IMC-PID, this technique also provides smaller values of error criteria IAE, ISE. Thus the results indicate that the IMC-PID provides improvement in both the performance and robustness in comparison to the other techniques considered.

**Table 5: Performance of the PID based on open Loop tuning techniques for MABP system**

<table>
<thead>
<tr>
<th></th>
<th>Kp</th>
<th>Ti</th>
<th>Td</th>
<th>Ms</th>
<th>Rise time</th>
<th>Settling time</th>
<th>% MP</th>
<th>IAE</th>
<th>ISE</th>
<th>Peak</th>
<th>IAE</th>
<th>ISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z-N</td>
<td>0.2577</td>
<td>157.2</td>
<td>39.3</td>
<td>2.8</td>
<td>92.22</td>
<td>302</td>
<td>0.9</td>
<td>124.7</td>
<td>97.94</td>
<td>2.52</td>
<td>609.5</td>
<td>903.3</td>
</tr>
<tr>
<td>C-C</td>
<td>0.3363</td>
<td>144.47</td>
<td>28.944</td>
<td>3.51</td>
<td>55.23</td>
<td>416</td>
<td>21.8</td>
<td>121.7</td>
<td>92.2</td>
<td>2.49</td>
<td>429.5</td>
<td>631.7</td>
</tr>
<tr>
<td>CHR</td>
<td>0.1289</td>
<td>84.4</td>
<td>42.2</td>
<td>1.48</td>
<td>154.5</td>
<td>643</td>
<td>9.5</td>
<td>178.5</td>
<td>123.2</td>
<td>2.87</td>
<td>734.6</td>
<td>1467</td>
</tr>
<tr>
<td>IMC- PID</td>
<td>0.2372</td>
<td>123.7</td>
<td>26.814</td>
<td>1.96</td>
<td>80.65</td>
<td>367</td>
<td>7.2</td>
<td>126</td>
<td>99.06</td>
<td>2.67</td>
<td>521.5</td>
<td>913</td>
</tr>
</tbody>
</table>

**Figure 5:** Set point and Disturbance response of MABP for open loop tuning techniques
Table 6: Performance of the PID based on closed Loop tuning techniques for MABP system

<table>
<thead>
<tr>
<th></th>
<th>Kp</th>
<th>Ti</th>
<th>Td</th>
<th>Ms</th>
<th>Setpoint Rise time</th>
<th>Settling time</th>
<th>%Mp</th>
<th>IAE</th>
<th>ISE</th>
<th>Peak</th>
<th>IAE</th>
<th>ISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z-N</td>
<td>0.3417</td>
<td>118.864</td>
<td>29.7159</td>
<td>2.34</td>
<td>52</td>
<td>425</td>
<td>31.5</td>
<td>130.2</td>
<td>94.87</td>
<td>2.484</td>
<td>348.8</td>
<td>566.1</td>
</tr>
<tr>
<td>MZ-N</td>
<td>0.1879</td>
<td>118.864</td>
<td>79.2423</td>
<td>2.72</td>
<td>185</td>
<td>775</td>
<td>8.5</td>
<td>174.5</td>
<td>114.1</td>
<td>2.41</td>
<td>681.7</td>
<td>1066</td>
</tr>
<tr>
<td>T - L</td>
<td>0.2589</td>
<td>522.999</td>
<td>37.7344</td>
<td>2.06</td>
<td>1120</td>
<td>&gt;1200</td>
<td>NA</td>
<td>322.5</td>
<td>145.9</td>
<td>2.537</td>
<td>1485</td>
<td>2235</td>
</tr>
<tr>
<td>IMC-PID</td>
<td>0.2395</td>
<td>123.7</td>
<td>26.8142</td>
<td>1.98</td>
<td>80.5</td>
<td>373</td>
<td>7.7</td>
<td>125.9</td>
<td>98.91</td>
<td>2.674</td>
<td>516.5</td>
<td>903.1</td>
</tr>
</tbody>
</table>

Figure 6: Setpoint and Disturbance response of MABP for closed loop tuning techniques

CONCLUSIONS

It is observed that IMC-PID provides better setpoint tracking but sluggish disturbance rejection, where as Z-N, C-C provide better disturbance rejection for both the examples considered. IMC-PID has essentially only one tuning parameter to achieve the desired performance and it provides a trade off between performance and robustness in comparison with other tuning techniques considered, which is evident from IAE, ISE and ITAE values in Tables 3, 4, 5 and 6 respectively. The dominance in the performance of IMC-PID is observed when $\theta/\tau$ of the process is $<1$. It is suggested to use IMC-PID when $\theta/\tau < 1$.

REFERENCES


