Set-point tracking and Disturbance rejection capability analysis of controllers designed for SOPDT model

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ABSTRACT: Disturbance rejection is one of the key performance benchmark for a controller. For an industrial process, disturbance can be internal or external and it is an important that it can be rejected effectively by an optimal controller design. In the present work, set-point tracking and disturbance rejection capability of the controllers have been evaluated by comparing the closed loop responses for a selected second order delayed model.

1 INTRODUCTION

Controller performance is one of the most significant control objectives of a typical control problem. A control system delivers high performance if it exhibits rapid and smooth responses to disturbances and less variation in set-point. PID controller settings specified for excellent disturbance rejection provides large overshoots for set-point tracking whereas controller settings providing excellent set-point tracking produces sluggish disturbance rejection [1, 2].

Many industrial processes, in process control can be analyzed with the help of the model of the process under investigation. The dead time comes naturally in the process model where energy propagates from one place to another [3]. This is the reason that the process industry commonly has FOPDT or SOPDT model. A general SOPDT model transfer function is given as:

$$G(s) = \frac{K e^{-\theta s}}{(1 + \tau_1 s)(1 + \tau_2 s)} \quad (1)$$

Where K is process gain, θ is time delay, τ_1 is slow and τ_2 is fast time constant [4, 5].

Easy implementation and operation of PID controllers makes it extensively applicable in process manufacturing, to control various industrial processes [6]. In the literature, lesser PID tuning techniques are available for Second Order plus Delay Time (SOPDT) model compared to First Order plus Delay Time (FOPDT) model [3, 7]. A typical PID controller transfer function is:

$$G_c(s) = K_c \left[1 + \frac{1}{\tau_I s} + \tau_D s \right] \quad (2)$$

Most of the PID tuning methods existing in literature lay emphasis on improving set-point tracking performance of the controller rather than disturbance. It is the demand of process control that the tuning methods should be simple and easy to implement which require little information and give moderate performance. A tuning method should be widely applicable [8].

TABLE 1: PID controller settings for SOPDT process [1]

Tuning Parameters	Skogestad ($\tau_1 \leq 8\theta$)	Ziegler Nichols	Tyreus Luyben
K_c	$\frac{0.5(\tau_1 + \tau_2)}{K\theta}$	$0.6K_{cu}$	$0.45K_{cu}$
τ_I	$(\tau_1 + \tau_2)$	$\frac{P_u}{2}$	$2.2P_u$
τ_D	$\frac{\tau_1 \tau_2}{(\tau_1 + \tau_2)}$	$\frac{P_u}{8}$	$\frac{P_u}{6.3}$

For PID controllers, there are various tuning formulae existing in literature for PID controllers, viz. Åström and Häglund [9], Ziegler Nichols (ZN) [10], Cohen Coon [11] and Tyreus Luyben (TL) [12]. Internal Model Control [13] and Skogestad [14] tuning techniques are some other important tuning techniques. Three important tuning formulae, applied in this work are shown in Table 1.

2 METHODOLOGY

Fig. 1 shows the flowchart for systematic investigation of the presented analysis. Many distributed parameter systems are often modeled as SOPDT model, where a state variable in a process

plant is a function of two or more independent variables [3].

Figure 1: Flowchart for Systematic Investigation

The selected SOPDT system transfer function for present analysis is [8]:

$$G(s) = \frac{5e^{-4s}}{(1 + 20s)(1 + 8s)} \quad (3)$$

Where, Dead Time (θ) = 4 seconds, Process Gain (K) = 5, Slow time constant (τ_1) = 20 seconds and Fast time constant (τ_2) = 8 seconds [15].

3 RESULTS AND DISCUSSION

PID Controllers tuning parameters for the selected SOPDT process are shown in Table-2. Fig. 2 gives the evaluation of the disturbance rejection capability of the controllers designed using Skogestad and ZN tuning techniques. Response obtained in case of PID controller designed using Skogestad tuning technique has less settling time, one of the important steady-state characteristic but more maximum percentage overshoot in comparison to that in case of ZN tuning technique. Although the disturbance response has more peak amplitude but settles faster, in case of PID controller designed using Skogestad tuning technique based controller.

TABLE 2: PID Controller Settings

Tuning Method	K_c	τ_I	τ_D
Skogestad	0.7	28	5.71
ZN	0.84	16.315	4.09
TL	0.63	71.78	5.18

The comparison of responses for the disturbance rejection capability of the controller designed by Skogestad as well as TL tuning techniques is displayed in Fig. 3. Response exhibited by PID controller designed using Skogestad tuning technique has less settling time and maximum percentage peak overshoot in comparison with the response obtained by PID controller using TL tuning technique. The disturbance settles faster in case of Skogestad tuning technique while comparing with PID controller designed using TL tuning technique.

Fig. 4 displays the comparative analysis of the disturbance rejection capability of the controllers designed using ZN as well as TL tuning techniques. The response obtained in case of controller designed using ZN tuning technique has less settling time and maximum percentage peak overshoot while comparing with PID controller designed using TL tuning technique. The disturbance settles faster in case of PID controller designed using ZN tuning method than PID controller designed using TL tuning technique.

Comparison of the disturbance rejection capability of the controller designed for Skogestad, ZN and TL techniques is displayed in Fig. 5. The response exhibits, settling time is least for PID controller designed with Skogestad technique, maximum percentage peak overshoot is least for PID controller designed with ZN technique. The disturbance settles fastest for PID controller designed with Skogestad technique.

Figure 2: Disturbance rejection capability comparison for Skogestad and ZN techniques

Figure 3: Disturbance rejection capability comparison for Skogestad and TL techniques

Figure 6: Set-point tracking capability comparison for Skogestad & ZN techniques

Figure 4: Disturbance rejection capability comparison for ZN and TL techniques

Figure 7: Set-point tracking capability comparison for Skogestad & TL techniques

Figure 5: Disturbance rejection capability comparison for Skogestad, ZN and TL techniques

Figure 8: Set point tracking capability comparison for ZN and TL techniques

Figure 9: Set point tracking capability comparison for Skogestad, ZN and TL techniques

TABLE 3: Relative analysis of significant characteristics

Characteristics → Tuning Methods ↓	Rise Time	Settling Time	Maximum %age Overshoot
Skogestad	7.6	24.2	4.12
ZN	6.51	54.2	33.5
TL	11.6	216	0

Table 3 shows the relative analysis of significant characteristics. Fig. 6 displays the closed loop step response comparison of PID controllers designed with Skogestad and ZN techniques. The closed loop step response comparison of the controllers designed with Skogestad as well as TL techniques is shown by Fig. 7. Fig. 8 gives the closed loop step response comparison of the PID controllers designed with ZN as well as TL methods. The closed loop step response comparison of the controllers designed with Skogestad, ZN & TL tuning techniques is displayed by Fig. 9.

4 CONCLUSION

In this paper, Skogestad, Ziegler Nichols and Tyreus Luyben tuning methods were employed for PID controller design for selected SOPDT process model. Disturbance response is best in case of PID controller designed using ZN tuning technique among all the three tuning techniques. PID controller designed using Skogestad tuning technique exhibits best set point tracking capability amongst the three tuning techniques.

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