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Set-Point Tracking Analysis of Various Controllers Designed for Orthonormal Basis Filter Process Model

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Abstract

Over the past 50 years PID controllers are used in controlling the linear feedback control system processes. Due to simplicity and reduced number of parameters to be tuned, PID controllers are used in process industries. Time delay models are mostly considered for tuning PID controllers. An Orthonormal Basis Filter (OBF) process model, which can be represented as a Second Order Plus Dead Time (SOPDT) model is selected and delay in the process model is approximated using Taylor series. Controller is design based on different controller tuning techniques. On the basis of the comparison of the set-point tracking capability of the controllers for step response, best controller tuning technique is examined for the selected process.

Keywords- OBF, PID Controller, SOPDT, Set-Point Tracking

Abbreviations.

G(s)	Transfer function of the process
K	Process gain
θ	Time delay
τ	Time constant for first order plus time delay systems
$\tau 1$, $\tau 2$	Time constants for second order plus time delay systems
K_c	Proportional gain
T_i	Integral time
T_d	Derivative time
K_{cu}	Critical gain or Ultimate gain
T_u	Ultimate period
τ_c	Closed-loop time constant

Acronyms

PID	Proportional, integral, derivative
OBF	Orthonormal basis filter
SOPDT	Second order plus delay time

1. Introduction

A procedure or series of operations performed on solid resources or solutions is termed as a process. Main issue that arises in the process industry is to control the process. The main objective of process control is to maintain the process at set-point, ensure safety in the industries and to reduce the process variations by ensuring the quality of the product (Seborg, et al., 2004). The transportation lag in the movement of material or information in a process is termed as time delay. Due to measurement delay most of the industrial processes have the time delay effect and the whole system leads to instability because of this delay. The whole system becomes complicated due to the presence of the delay (O'dwyer, 1999). Whenever two first order processes are connected in series then a second order system arises (Seborg, et al., 2004). The SOPDT model can be represented by the following equations as-

$$G(s) = \frac{Ke^{-\theta s}}{(1+\tau 1s)(1+\tau 2s)} \tag{1}$$

Where K is the gain, θ is the time delay and τ1, τ2 are the time constants (Palani and Jairath, 2013). Using PID controllers most of the control problems are solved in process industry (Koivo and Tanttu, 1991). Various methods have been used for tuning the controllers but every method has certain limitations and therefore for researchers and engineers design of PID controllers is still a challenge. The transfer of PID controller is given as-

$$G(s) = K_c\,(1 + 1 / T_i s + T_d s) \tag{2}$$

In order to meet the closed loop performance, we find PID parameters (Kc, Ti, T_d) (Seborg, et al., 2004). The process selected in this paper is the Orthonormal Basis filter model. In this process model less parameter are used in order to capture the dynamics of the linear systems. The parameters of the model can be easily estimated by using linear least square method. OBF process model can be used for both open-loop and closed-loop identifications and effective modeling is done for systems having uncertain time delays. Further research is going on for the system identification for non-linear systems based on OBF (Tufa et al., 2012).

2. Literature Survey

Antsaklisz and Baillieul (2007) focused on special issues related to networked control system by describing the problems of the real time data mining that are associated with large scale, real time data fission for distributed arrays of sensors and distributed control and the communication to manage device as well as to find how to compensate the output. Cominos, and Munro (2002) commented that a desired control signal can be designed in an open-loop way if the plant is stable. Further, the work is extended by the injection of desired control signal into the model of the process. In this work the controller is limited to a PI controller. Hassaan (2014) presented tuning of PD controller used with second order processes. Tuning technique used in this paper depends on the integral of square of error. By using PD controller higher oscillations in the system were suppressed by reducing the large settling time. Anusha et al. (2014) performed the comparison of tuning methods of PID controller by finding a better solution to non-linear conical tank level process. Various tuning methods are used such as Ziegler-Nicholas method, Modified Ziegler-Nicholas, Internal Model Control, Tyreus-luyben and Chien Hrones Reswich method. Controller is tested for time integral performance criteria like ISE (Integral of the Square Error), IAE (Integral of the Absolute value of the Error), ITAE (Integral of the Time-weighted Absolute Error), and MSE (Mean Square Error). PID controller comparison is done for Single Input Single Output System (SISO) for the considered conical tank model. At last it was concluded that among the five tuning methods used Chien Hrones Reswich is considered as the best controller and also based on the analysis Z-N based PID controller is taken as the best choice. Bansal et al. (2012) presented a review of the recent as well as classical techniques which are used for tuning of PID controllers. For a long time PID tuning has been a field of active research and therefore in industrial processes PID controllers are mostly used. In this work the techniques that are reviewed are classified into classical techniques which are developed for PID tuning and for tuning purposes optimization techniques are used. Comparison between some of the tuning techniques has also been done. Under different conditions, a comprehensive comparative study of all the tuning techniques were tested. According to Hang et al. (1991) for PID auto tuning for excessive overshoot in the set-point response, set-point weighting can reduce the overshoot to a specified value. Further it was also shown that the set-point weighting is superior to the conventional solution of reducing large overshoots. Further for PI controller auto tuning Z-N tuning method is inadequate so refined Z-N formula gives improved performance. For good set-point response as well as load disturbance response PID controller is tuned through set-point weighting. The work presented by Sahu and Sharma (2015) concentrates on the PID control system mostly the time delay systems such as network control systems. Other work which are also done are summarized as gain margin, phase margin methods.

3. Motivation

In most of the process control industries PID controllers are used, due to their simple structure which is easily understood by the engineers who have designed it and also due to the modeling of the error. Whenever a delay is present in a control system, the desired response is always affected. Therefore, set-point tracking is performed in order to obtain a desired response of the control system. The tuning techniques used in this paper are explained below. Table 1 highlights the mathematical formulae of each PID tuning technique as explained below.

(i) Ziegler-Nichols: - This tuning method was first proposed by Ziegler and Nichols. It is known to be the most popular method for tuning P, PI, PID controllers.

(ii) Skogestad: - This tuning technique allows change in integral form for integrating processes in order to improve the disturbance rejection.

(iii) IMC: - This is Internal Model Control. This method is based on the fact that control system consists of some representation of the process to be controlled, then only a perfect process model can be achieved.

4. Research Method

The methodology used in this paper is shown below in Figure 1 in the form of algorithm. In the present analysis a second order plus delay time model is taken. Further the delay in the selected SOPDT process model is approximated using Taylor series expansion. The process model and controller is used in closed-loop system with unity feedback and set-point tracking analysis is performed. The selected SOPDT transfer function (Tufa et al., 2012) is –

$$G(s) = \frac{2e^{-4s}}{(10s+1)(6s+1)} \tag{3}$$

Using Taylor series expansion of the delay term the modified transfer function may be-

$$G(s) = \frac{2\,(1-4s+8\,s\,\hat{}2\,)}{(10\,s+1)(6\,s+1)} \tag{4}$$

By Routh Hurwitz criterion the ultimate gain is $K_{cu} = 2$. By making auxiliary equation from Routh Hurwitz the ultimate period is $T_u = 27.08$. Now using the values of K_{cu} and T_u PID controller parameters are shown in the Table 2. For SOPDT process $\tau_c = 7$.

5. Results and Analysis

In the present work process model and the controller is implemented in a closed-loop with a unity feedback using MATLAB using toolboxes. Simulation is performed for set-point tracking and transient response characteristics i.e. rise-time, settling time, peak time and maximum overshoot. Figure 2 shows the combine simulation response among the values of controller tuning techniques (depicted in Table 3). From the Table 3, it is observed that the controller tuned by various tuning techniques like Ziegler-Nichols, Skogestad and IMC gives different transient response values. In present analysis, Ziegler-Nichols has small rise time followed by Skogestad and IMC. Skogestad settles at rapid rate than IMC and Ziegler-Nichols. IMC has zero overshoots which means it is desirable than Skogestad and Ziegler-Nichols. Among the three controller tuning methods, best response is obtained in case of Skogestad tuning technique for the selected process model.

6. Conclusion

For the OBF process model with dead time, three tuning methods have been defined. Tuning rules are selected and compared for the process model. The performance analysis is based on the transient response characteristics such as rise time, settling time, maximum overshoots. The comparison among the tuning techniques shows that Skogestad tuning method gives the best response than the other selected methods.

Controller tuning methods	**K_c**	**T_i**	**T_d**
Ziegler-Nichols	$0.6\ K_{cu}$	$T_u / 2$	$T_u / 8$
Skogestad	$\frac{0.5\ (\tau_1 + \tau_2)}{K\theta}$	$\tau_1 + \tau_2$	$\frac{\tau_1\ \tau_2}{\tau_1 + \tau_2}$
IMC	$\frac{(\tau_1 + \tau_2)}{K\ (\tau_c + \theta)}$	$\tau_1 + \tau_2$	$\frac{\tau_1\ \tau_2}{\tau_1 + \tau_2}$

Table 1. PID tuning techniques formula

Controller methods	**K_c**	**T_i**	**T_d**
Ziegler-Nichols	1.2	13.54	3.385
Skogestad	1	16	3.75
IMC	0.72	16	3.75

Table 2. PID parameters for SOPDT

Controller methods	**Rise time (sec)**	**Settling time (sec)**	**Peak time (sec)**	**Maximum overshoots (%)**
Ziegler-Nichols	5.86	28.4	1.2	19.7
Skogestad	7.6	24.2	1.04	4.07
IMC	13.8	27.3	1	0

Table 3. Comparison of transient response characteristics

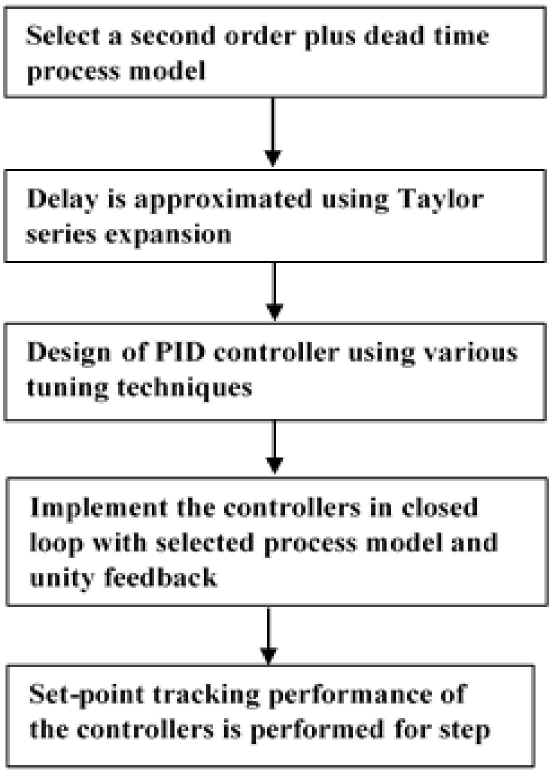

Figure 1. Proposed methodology

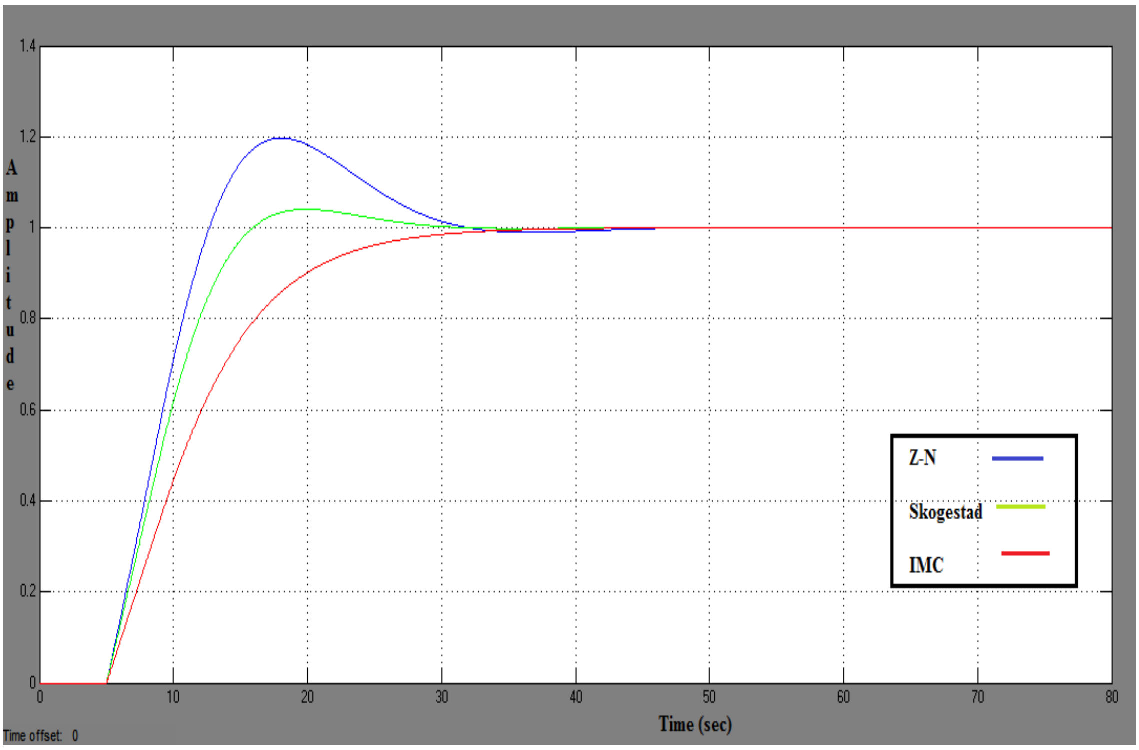

Figure 2 Combine response of Z-N, Skogestad, IMC

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