Indian Journal of Science and Technology, *Vol 9(34), DOI: 10.17485/ijst/2016/v9i34/100987, September 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Optimal Actuation of Controller using Predictive PI for Nonlinear Level Process

Eadala Sarath Yadav, Thirunavukkarasu Indiran* and Nikita Shankar

DST project, Dept of ICE, MIT, Manipal, India; it.arasu@manipal.edu, sarath.eadala@gmail.com, nsss112@gmail.com

Abstract

Background/Objective: Energy consumption of the actuator illustrates the performance of controller on the process. Objective of this paper is to prove how predictive control approach minimizes the energy utilization of actuator in nonlinear process (conical tank level process). **Method/Statistical Analysis**: Conical tank is divided into three operating regions and model identification using two-point method has been carried out at oneselected operating region. Efficiency of controller is validated by subjecting it with the identified model at all operating regions. Prediction filter which acts as dead time compensation was introduced in cascade with controller. **Findings:** Simulation and experimental results validates the approach. The effectiveness of the design has been compared with the advanced control schemes. **Application and Improvements:** This methodology can be implemented in the nonlinear processes with dead time. It can be applicable for the processes where energy consumption of actuator is considered as key objective.

Keywords: FOPDT, Nonlinear Process, Predictive PI, SIMC

1. Introduction

Controller design for nonlinear process is so frequent in current research and industrial applications. There exist different control strategies for FOPDT models. The conventional compensators tending decent reference tracking, they are lagging in robustness where energy utilization of actuator is high. Hagglund had introduced predictive based control in early 90's, later few researchers extended his work[1,2]. In presented his work on predictive PI, PID for integrating process with long dead time[3,4]. Where the contribution of smith predictor approach comes into consideration. This paper is the extension of modified smith predictor in terms of actuator energy efficient[5]. Conical tank level control is taken as experimental setup and implemented predictive control strategy to it. Torque of Induction motor drives the level in the conical tank which is considered as manipulating variable. Model identification has been done by using two-point method. Controller parameters like K_p and T_i is carried out by using skogestad's approach for dead time process. Saturation is input constraint which is used while operating for higher values of level, as controller output exceeds the actuator input, saturation is used to limit controller output. Prediction filter which is the set of dead time, integrator and predictive gain, is cascaded with controller.

2. Methodology

The crucial section in this paper is the addition of prediction filter along with the controller. It consist of a prediction gain K_{pre}, integrator, and dead time. The difference between controller output and dead time acts as multiplication factor to K_{pre}. Predictive PI on the whole influences process by increasing or decreasing controller output by the factor of prediction filter. The mathematical modeling is carried out by using two-point method by giving step change at selected operating region. For the specific change in input, two points at 23.8% and 62.3% of response has been selected and based on those points model is obtained[6].Therefore mathematical model for conical level process at operating region between (21-28) cm is given by $G_p(s)$ which is shown in the Equation (a).

*Author for correspondence

Figure 1 shows real time experimentation setup for non-linear level control.

$$G_p(s) = \frac{K}{\tau s + 1} e^{-t_d s} \quad G_p(s) = \frac{0.925}{25.05s + 1} e^{-1.09s} \qquad \text{(a)}$$

Figure 1. Conical tank level process.

Figure 2 represents block diagram of predictive PI control algorithm. The control structure of integrating process with long dead time[7] is considered as reference and applied for FOPDT model. The entire structure is cascade of PI controller, prediction filter and process plant (b).

$$R(s) = K_{PI}(s) f(s) e(s) \qquad \text{(b)}$$

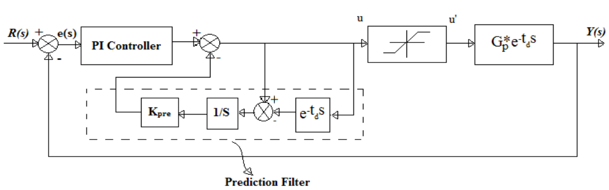

Figure 2. Block diagram of predictive PI control algorithm.

Control Structure of K_{PI} shown in the Equation (c). Prediction filter f(s) has two design parameters, prediction gain K_{pre} and dead time $e^{-t_d s}$ which are obtained by block reduction approach as follows (d).

$$K_{PI}(s) = K_p(1 + \frac{1}{T_i s}) \qquad \text{(c)}$$

$$f(s) = \frac{1}{1 + \frac{1}{s} K_{pre}(1 - e^{-t_d s})}$$

$$f(s) = \frac{s}{s + K_{Pre}(1 - e^{-t_d s})} \qquad \text{(d)}$$

2.1 Controller Design

Design includes tuning the parameters of K_{PI} and f(s), wherein Integrating FOPDT is used in designing K_{PI} and K_{pre}. The controller tuning doesn't includes derivative time filtering, therefore it is suggested to tune derivative gain manually which helps in filtering noise. As this paper deals with only predictive PI, the derivative time is neglected while tuning the controller.

$$K_p = \frac{1}{(KT_{cl})} \qquad \text{(i)}$$

$$T_i = 4T_{cl} \qquad \text{(ii)}$$

$$K_{pre} = \frac{\lambda}{4T_{cl}} \qquad \text{(iii)}$$

T_{cl} is factor of dead time estimate which is suggested as $2*t_d$ and it is recommended to fix λ=1. Table 1 shows controller parameters of PI controller and predictive gain $K_{pre.}$

Table 1. Controller parameters

K_p	2.0165
T_i	8.72
K_{pre}	0.114

3. Result Analysis

The real time experimentation is carried out by classifying different operating regions. The model is identified at operating region between (21-28) cm and control approach is conceded at different regions with the same model. As the tank is nonlinear, the area of tank is low at bottom end and higher at top end. Therefore model mismatch takes place; the control algorithm is optimal if it can drive the process for wide operating region. Predictive PI algorithm is implemented and applied to conical tank in this paper; Figure 3 depicts the simulation response of predictive PI and Figure 4 shows the comparison of predictive PI with modified smith predictor operated [8] at (21-28) cm.

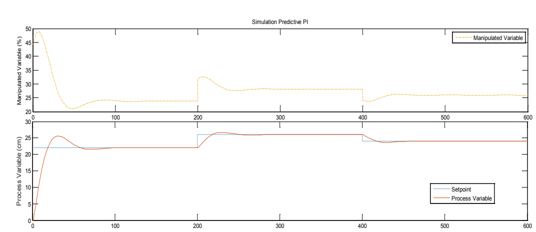

Figure 3. Simulation response predictive PI.

Table 2. Performance characteristics of predictive PI

Setpoint (cm)	Peak Time (Sampling Time)	Rise Time/Fall Time (Sampling Time)	Overshoot/ Undershoot (%)	Settling time (Sampling Time)
16	20	7	10	32
20	20	6	7	38
18	12.5	5	7.9	25
22	33.5	12.6	19	105
26	31	14	6.3	53.5
24	21	8	4.1	38

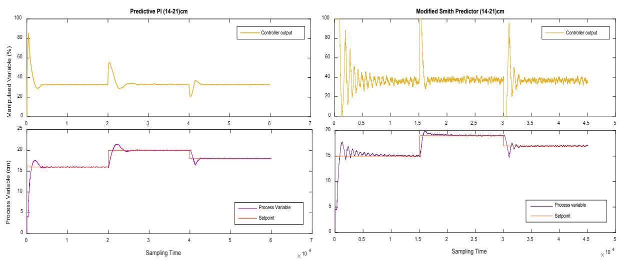

Figure 4. Comparison of Predictive Pi and Modified Smith Predictor operating region (14-21) cm.

Figure 5 illustrations comparison of predictive PI and modified smith predictor at operating region between (21-28) cm. It can be analyzed that as the operating region increases from lower area of cross section to higher of conical tank the necessity of saturation limiter towards actuator comes into picture. Table 2 represents Performance characteristics of Predictive PI for different operating regions.

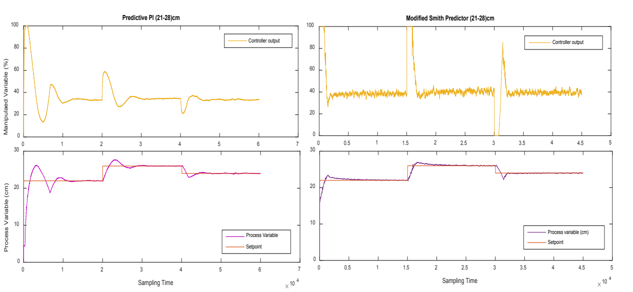

Figure 5. Comparison of predictive pi and modified smith predictor operating region (21-28) cm.

4. Conclusion

Research on energy consumption has been often emerging now and then. It's rather important for control engineer to design controller with optimum energy consumption, similar work is carried out in this paper. An extensive version of actuator energy utilization in our previous work, predictive PI algorithm has been implemented and applied to conical tank level control process. It is observed that Predictive PI control strategy depicts more efficiency in all operating regions with little lag in performance at higher regions. Simulation and real time experiment results validates the inference.

5. Acknowledgement

The authors would like to thank DST, Government of India for the sanction of this project under the wide circular #SB/FTP/ETA-0308/2012 Dated 25th May, 2013. The authors also would like to thank MIT, Manipal University for providing the infrastructure facility for carrying out this Project.

6. Nomenclature

FOPDT	First order plus dead time
K_p	Proportional gain
T_i	Integral time
T_c	Closed loop time constant
τ	Time constant
t_d	Dead time
e(s)	error
Kpre	Predictive gain
K_{PI}	Proportional Integral controller
f(s)	Filter transfer function
T_{CL}	Closed loop time constant

7. References

1. Hagglund T. A predictive PI controller for processes with dead times. IEEE Control Systems. 1992 Aug; 12(1):57-60.

2. Hagglund T. An industrial dead-time compensating PI controller. Control Engineering Practice.1996 Jun; 4(6):749–56.
3. Airikka P. Stability analysis of a predictive pi controller. Proceedings, Mediterranean Conference on Control and Automation; 2013 Jun. p. 1380-5.
4. Airikka P. PID and predictive PID control design for crushing and screening. Proceedings, Nordic Process Control Workshop; 2013 Aug. p. 1-2.
5. Matauiek MR, Micii AD. A modified smith predictor for controlling a process with an integrator and long deadtime. IEEE Transactions on Automatic Control. 1996 Aug; 41(8):1199-203.
6. Yadav ES, Indiran T. Servo mechanism technique based anti-reset windup PI controller for pressure process station. Indian Journal of Science and Technology. 2016 Feb; 9(8):1-4.
7. Pasi A. Predictive PID controller for integrating processes with long dead times. Mediterranean Conference on Control and Automation. 2014 Jun; p. 475–80.
8. Eadal Sabura Banu U, Hemavathy PR, Prabhu L. Real time implementation of enhanced nonlinear PID controller for a conical tank process. International Journal of Computer Applications. 2013: 1-5.