

# Design of IMC Tuned PID Controller for First Order Process with Right Hand Side Zeros



B. Mabu Sarif, D. V. Ashok Kumar, M. Venu Gopala Rao

**Abstract:** *IMC tuned PID controller's present excellent set point tracking but sluggish disturbance elimination, because of introduction of slow process pole introduced by the conventional filter. In many industrial applications set-point is seldom changed thus elimination of disturbance is important. The paper presents an improved IMC filter cascaded with PID tuned using Internal Model Control principle (IMC-PID) for effective elimination of disturbance and healthy operation of non-regular first order process such as processes with right hand side zeros. The suggested filter eliminates the slow dominant pole. The present study shows that the recommended IMC filter produces excellent elimination of disturbance irrespective of where the disturbance enters the process and provides acceptable robust performance to model disparity in provisions of maximum sensitivity in comparison with other methods cited in the literature. The advantages of the suggested technique are shown through the simulation study on process by designing the IMC tuned PID controllers to maintain identical robustness in provisions of maximum sensitivity. The time integral measure has been used to estimate the response. The recommended filter produces excellent response irrespective of nature of the process.*

**Keywords :** *Internal Model Control, filter form, Disturbance elimination, Robustness, Integral criteria, non-regular process.*

## I. INTRODUCTION

The most broadly utilized controller in industries is PID controller, since it can give acceptable execution to a wide scope of processes with a basic calculation. It is fundamental to recollect that it is difficult for different gadgets to achieve the money saving advantage proportion gained through the PID controller [1, 2]. It is discovered that the PID algorithm is used by 97 percent of regulatory controllers [3]. The IMC offers a linear, efficient, generic, natural, distinctive, strong, and easy structure for system efficiency assessment and synthesis [4, 5]. The symptomatically decided IMC-PID tuning strategies have been drawn the thought of industries over the earlier decade as a result of the straightforwardness and improved capability of the IMC-based tuning law [12].

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The trade off among execution and robustness is given by the IMC tuned PID controller, which has just one tuning parameter, is connected to the time constant [1, 4, 6, 7]. The PID controller parameters are acquired in the IMC tuned Direct Synthesis (DS) and PID methods by computing the controller so as to provide the preferred closed loop reaction [6-11].

Rejection of load disruption is one of the most significant control problems in process industries. IMC tuned PID controller provides excellent set-point tracking, but the reaction to disturbance is slow, particularly if  $\theta/\tau \ll 1$  [5, 8].

Dismissal of disturbance is the significant design goal than set-point following for most of the SISO controllers [5, 8, 12]. The goal can be achieved by designing the disturbance elimination controller, instead of designing it for set-point performance. A filter in series with PID controller was recommended in the literature [2, 5-7, 9, 12-14].

The IMC-PID's effectiveness is based on the IMC filter framework. The filter design was chosen in the literature to render the IMC module achievable while meeting the demands for efficiency. IMC controller productivity and IMC controller estimation to perfect controller decide the subsequent PID controller viability. It is accordingly important to choose the proper IMC filter structure not on the exhibition of the IMC controller but rather on the presentation of the subsequent PID controller.

The PID tuning methodologies delineated in the composing used first request not withstanding time delay (FOPTD) and second request not withstanding time delay (SOPTD) structures [10,15-21]. It is seen that the higher-order models approximated by FOPTD as well as SOPTD can likewise agreeably satisfy the control objectives [15, 16, 21]. This inspired the use of model order reduction scheme for plant model. By combining IMC-PID controller with model order reduction, the present work considers the design of an appropriate control strategy for disturbance rejection. This constructed controller is capable of eliminating the disturbances regardless of the place where it enters in the system, and it is capable of managing mismatches of model and uncertainties of variables. The objectives of the present work is to design a IMC tuned PID controller cascaded with filter to enhance the performance of first order process with right hand zeros (FOPRHZ) measured with integral error criteria under uniform maximum sensitivity (Ms).

## II. DESIGN OF IMC-PID CONTROLLER

Garcia and Morari launched internal model control [6], characterizing it as a controller in which the model of the process is clearly an inner controller component.

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IMC's structure system consolidates separating the perceptive plant model as invertible and non-invertible fragments as showed up in (1) through straightforward factorization or all exchange factorization [4, 6, 7, 9, 14, 21]. The IMC (2) is the converse of the invertible part of the plant model [15-21].

$$G_M(s) = G_{M-}(s)G_{M+}(s) \quad (1)$$

The controller of the IMC' is designed as

$$Q(s) = G_{M-}^{-1}(s)G_f(s) \quad (2)$$

The IMC controller of Figure 2 is the perfect feedback controller of Figure 3 by making small modifications to Figure 1, which can be articulated mathematically in provisos of  $G_M(s)$  and  $Q(s)$  in (3).

$$G_C(s) = \frac{Q(s)}{1 - Q(s)G_M(s)} \quad (3)$$

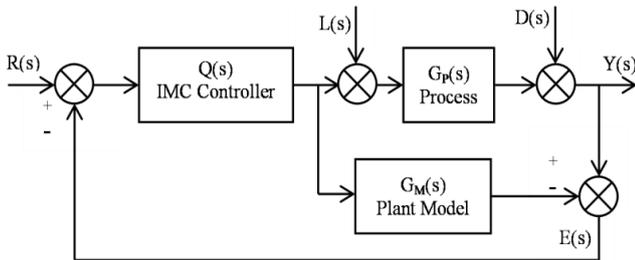


Fig. 1 The structure of fundamental IMC

The controller obtained in (3) does not have the regular form of PID, the PID parameters can be attained by plummeting the Eq. (3) into either the forms of Eq. (4) or Eq. (5) by incorporating suitable approximations of the process dead

$$\text{time. } G_{PID}(s) = K_P \left( 1 + \frac{1}{T_i s} + T_d s \right) \quad (4)$$

$$G_{PID}(s) = K_P \left( 1 + \frac{1}{T_i s} + T_d s \right) \left( \frac{ds^2 + cs + 1}{as^2 + bs + 1} \right) \quad (5)$$

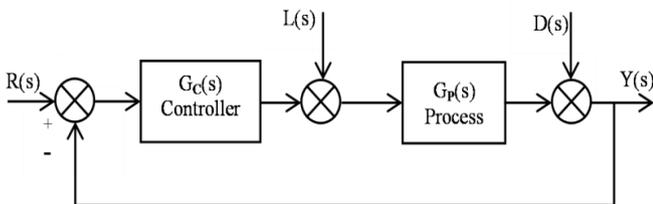


Fig. 2 Feedback control structure

Eq. (6) is the description of process response incorporating the controller for both set-point and the disturbance input.

$$Y(s) = \frac{G_C(s)G_P(s)}{1 + G_C(s)G_P(s)} R(s) + \frac{1}{1 + G_C(s)G_P(s)} D(s) + \frac{G_P(s)}{1 + G_C(s)G_P(s)} L(s) \quad (6)$$

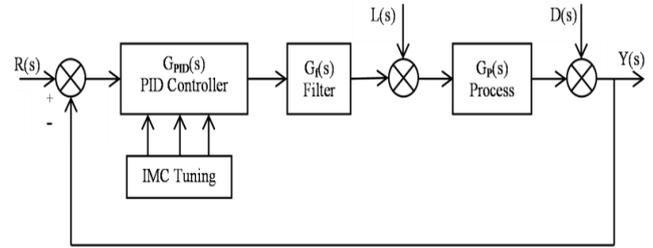


Fig. 3 PID cascaded with filter

(6) (6)

### III. IMC-PID TUNING RULES FOR FOPRHZ MODEL

The predictive model of the process considered here FOPRHZ is given by (7).

$$G_M(s) = \frac{K(-s + Z)}{(\tau s + 1)} \quad (7)$$

As  $(-s + Z)$  becomes the non-invertible portion, the plant model  $G_M(s)$  in the above equation [Eq. (7)], manipulated by performing multiplication and division with  $(s + Z)$  to preserve the implication of the zero.

$$G_M(s) = \frac{K(-s + Z)(s + Z)}{(\tau s + 1)(s + Z)} \quad (8)$$

Division of invertible and non-invertible segments of plant model is completed with required exchange [Eq. (9)].

$$G_{M-}(s) = \frac{K(s + Z)}{(\tau s + 1)}, \quad G_{M+}(s) = \frac{(-s + Z)}{(s + Z)} \quad (9)$$

The PID controller has been designed using the conventional IMC filter of Eq. (10) for step disturbance input produces the output response of Eq. (11).

$$G_f(s) = \frac{1}{(\lambda s + 1)^n} \quad (10)$$

$$\frac{Y(s)}{D(s)} = \frac{K \left( \frac{\theta}{2} \lambda s^2 + (\theta + \lambda) s \right) \left( 1 - \frac{\theta}{2} s \right)}{(1 + \tau s)(1 + \lambda s) \left( 1 + \frac{\theta}{2} s \right)^2} \quad (11)$$

It is observed that a system pole  $s = -1/\tau$  exists in this relation among controllable output  $Y(s)$  and disturbance  $D(s)$ . The effect of this, the response of the controller to disturbances becomes sluggish. To overcome this alternate filter of the structure (12) is recommended. Alternate form of filter is,

$$G_f(s) = \frac{(\alpha s + 1)^n}{(\lambda s + 1)^{n+1}} \quad (12)$$

Where n = 0 to 1.

Using the optimum IMC filter of Eq. (12) with n = 1 to FOP-RHZ system design, the controller of IMC Q(s) is achieved as Eq. (13)

$$Q(s) = \frac{(1 + \tau s)(\alpha s + 1)}{K(s + Z)(\lambda s + 1)^2} \quad (13)$$

Form Eq. (14) is the perfect feedback controller for IMC principle,

$$G_c(s) = \left[ \frac{(\tau \alpha s^2 + (\tau + \alpha)s + 1)(\alpha s + 1)}{Ks(3\lambda Z - 2\alpha Z + 2) \left[ \frac{\lambda^2}{(3\lambda Z - 2\alpha Z + 2)s^2 + \frac{(3\lambda + 2\alpha)}{(3\lambda Z - 2\alpha Z + 2)}s + 1} \right]} \right] \quad (14)$$

The ensuing PID regulation formulas and the lead/lag filter the coefficients of are obtained by comparing Eq. (14) with Eq. (5), which are presented below in Eq. (15) to Eq. (21)

$$K_p = \frac{(\tau + \alpha)}{K(3\lambda Z - 2\alpha Z + 2)} \quad (15)$$

$$T_i = (\tau + \alpha) \quad (16)$$

$$T_d = \frac{\tau \alpha}{(\tau + \alpha)} \quad (17)$$

$$a = \frac{(3\lambda + 3\lambda^2 Z + 2\alpha - Z\alpha^2)}{(3\lambda Z - 2\alpha Z + 2)} \quad (18)$$

$$b = \frac{(3\lambda^2 Z + Z\lambda^3 + \alpha^2)}{(3\lambda Z - 2\alpha Z + 2)} \quad (19)$$

$$\hat{b} = \frac{\lambda^3}{(3\lambda Z - 2\alpha Z + 2)} \quad (20)$$

Of 558.92% and 15.02% and in ITAE by a factor of 1460.85% and 42.7% in comparison to Horn et al. and M. Lee et al. filter structures respectively. The recovery time to disturbance is 9.207 sec in proposed method, 35.63 sec in Horn et al. and 11.61 sec of Rivera et al. The deviation in the performance for 25% mismatch is 1.95% in IAE, 6.39% in ISE and 0.933% in ITAE, demonstrating the robustness of IMC-PID controller. Fig. 6 represents the set-point response

$$c = \alpha \quad (21)$$

The process pole  $s = -1/\tau$  is cancelled by the extra degree of freedom provided by  $\alpha$ , it is obtained by computation of characteristic equation of the controller  $[1 - G_M(s)Q(s)]_{s=-1/\tau} = 0$ .

$$\alpha = \tau - \sqrt{\frac{(\tau Z - 1)(\tau - \lambda)^3}{\tau(\tau Z + 1)}} \quad (22)$$

The integral criteria are generally used for evaluation of the performance the controller on the process, they are described in Eq. (23) – Eq. (25) [8, 21, 22].

$$IAE = \int_0^{\infty} |e(t)| dt \quad (23)$$

$$ISE = \int_0^{\infty} e(t)^2 dt \quad (24)$$

$$ITAE = \int_0^{\infty} t |e(t)| dt \quad (25)$$

The maximum sensitivity  $M_s$  is to be designed to be between 1.2 – 2.0 to provide compromise between performance and robustness [8, 21, 22].

#### IV. SIMULATION RESULTS

The FOPRHZ model for the case study is  $G(s) = \frac{4(-s + 2)}{(6s + 1)}$  [23]. The robustness of  $M_s = 1.95$  is

considered for the design of the controller. The instantaneous load disturbance response of nominal model are represented in Fig. 4, Table 1 and model with 25% variation in all the

parameters  $G(s) = \frac{5(-s + 2.5)}{(7.5s + 1)}$  response is represented

in and Fig. 5, Table 2. The designed IMC tuned PID controller with demonstrate improved disturbance elimination efficiency with improvement in IAE by a factor of 415.64% and 22.02%, in ISE by factor

with set-point filter  $G_{fr}(s) = \frac{4(0.7s + 1)}{(1.41s + 1)}$  and without

set-point filter. Fig. 7 shows the servo response comparison of various design methods considered, for the step input of magnitude 1 at t=0.

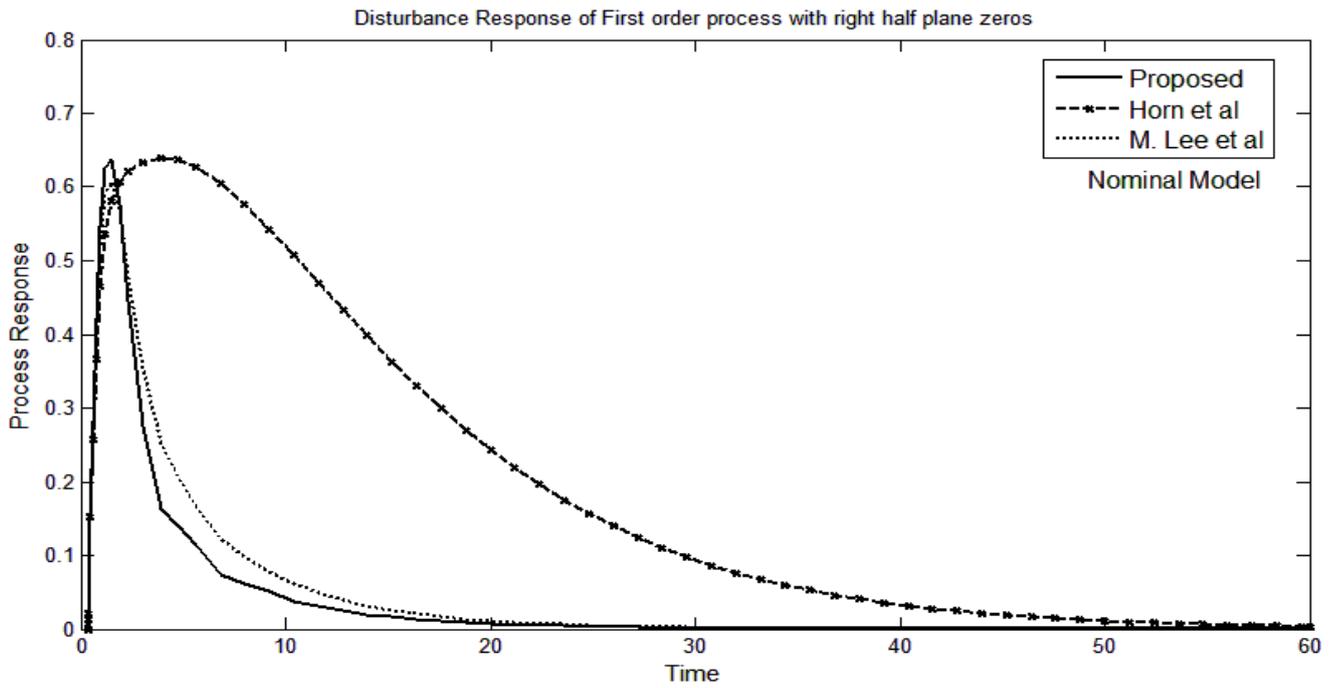


Fig. 4 Nominal model response for instantaneous disturbance of FOP-RHZ

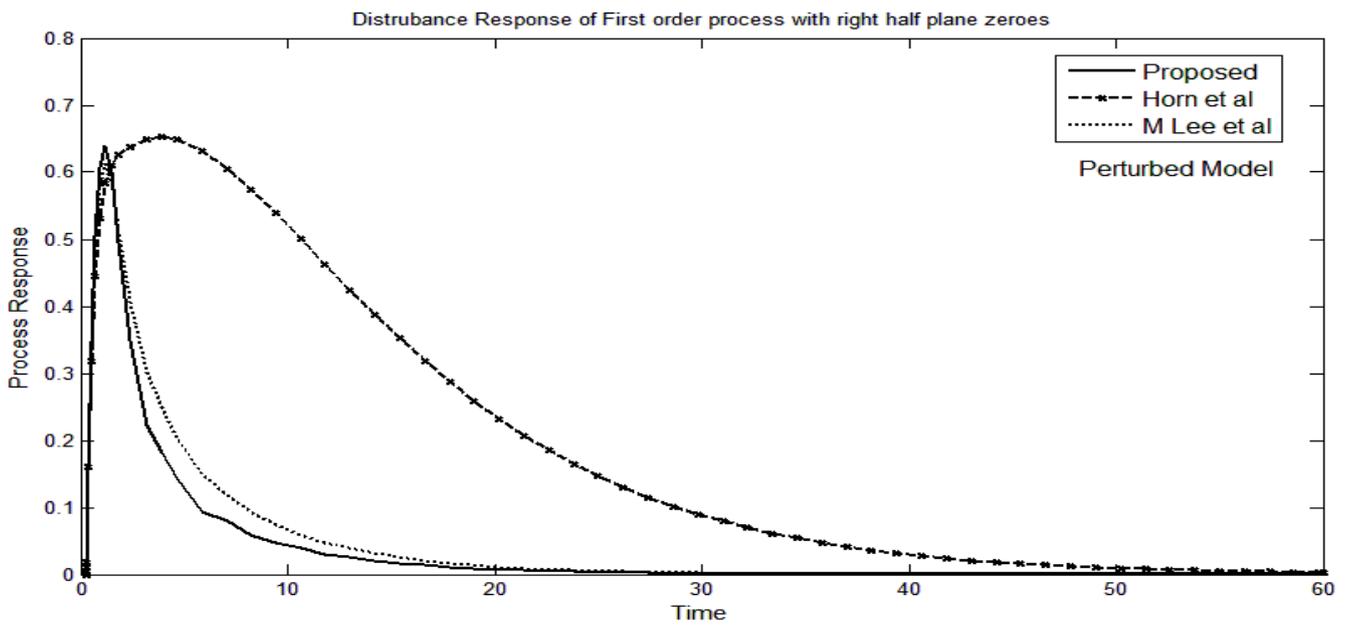


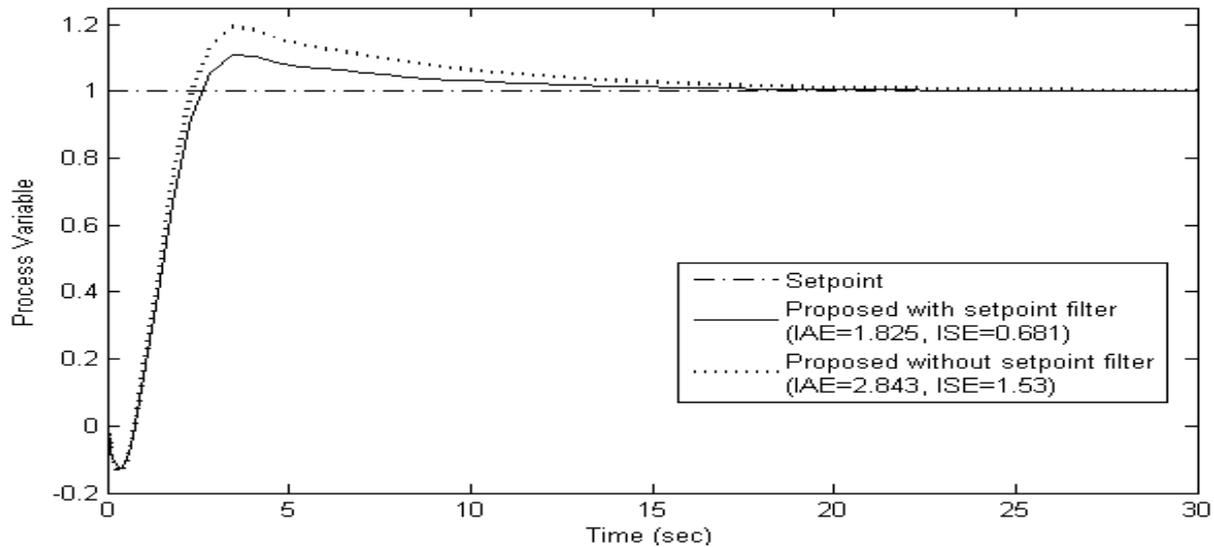
Fig. 5 Perturbed model response for instantaneous disturbance of FOP-RHZ

Table 1: Assessment of FOPRHZ process using IMC tuned PID controller

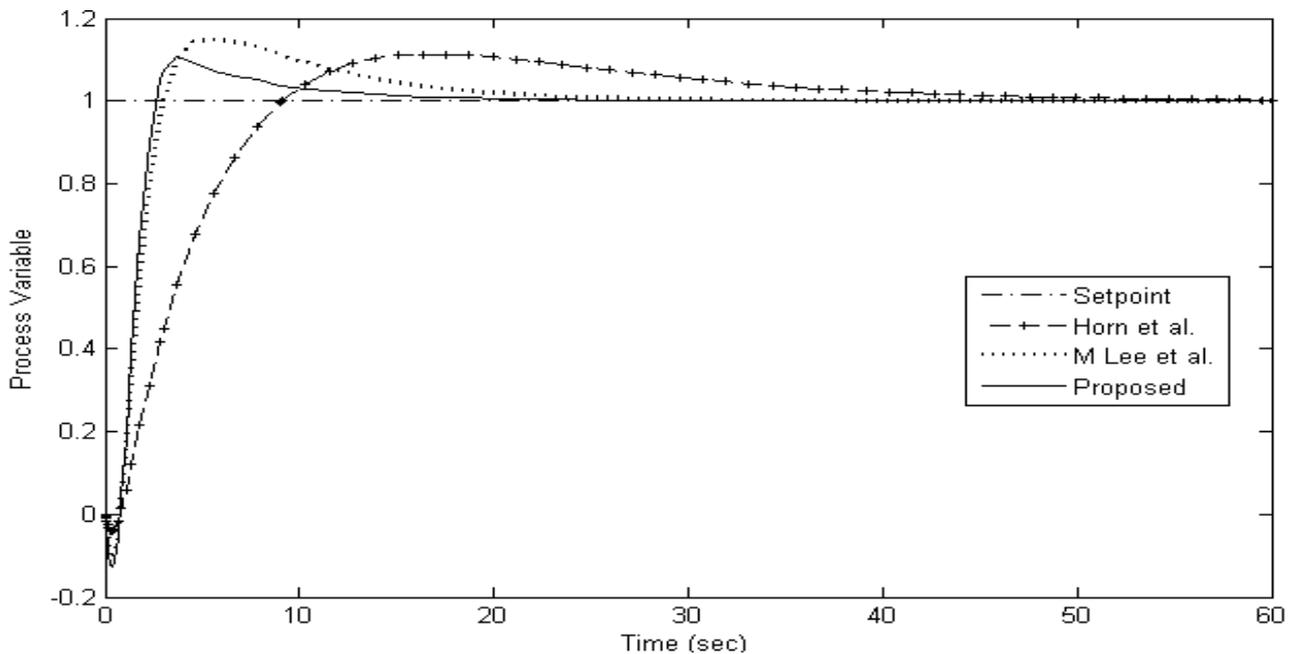
Technique	$\lambda$	$K_p$	$T_i$	$T_d$	$M_s$	Peak	IAE	ISE	ITAE
Proposed	0.7	3.56	7.41	1.14	1.95	0.64	2.3	0.8	9.9
Horn' et al.	9.1	1.25	14.54	3.53	1.95	0.64	12.1	5.2	154.0
M Lee et al.	0.625	3.06	7.93	1.46	1.95	0.61	2.81	0.9	14.0

**Table 2: Robustness Analysis FOPRHZ process using IMC tuned PID controller**

Technique	$\lambda$	Peak	IAE	ISE	ITAE
Proposed	0.7	0.64	2.26	0.73	9.77
Horn' et al.	9.1	0.66	11.83	5.25	149
M Lee et al.	0.63	0.62	2.77	0.86	13.9



**Fig. 6 Set-point responses of PID controller with and without set-point filter**



**Fig. 7 Response of PID controller of FOPRHZ for set-point**

**V. CONCLUSION**

A plan technique for IMC-PID controller fell with lead-lag filter, with improved IMC filter structure was proposed for unsettling influence dismissal. The proposed technique gave a fantastic presentation to unsettling influence dismissal for FOPs. The renewal study was led on various FOPs, with tuning of the PID controller with various IMC filter structures to have a similar vigor as Ms for uniform examination. The robustness test for model zigzag was directed by joining 25% variety in the process model parameters all the while for the dismal outcome imaginable.

The recommended IMC filter has demonstrated to give a great unsettling influence dismissal to relaxed existing procedures contrasted with different techniques. The ideal IMC filter structure got for FOPTD was broadened FOPRHZ frameworks, which furnished better reaction in examination with other filter structures, defending the proposed filter can be utilized for a class of the first-order frameworks It is proposed that for forms with  $\theta/\tau = 1$  or  $\theta/\tau > 1$  the single tuning parameter ought to be  $0.8 \tau < \lambda < \tau$ .

The proposed IMC filter gives an amazing close loop execution which was assessed with basic execution criteria IAE, ISE, and ITAE. The proposed strategy gives palatable reactions to both perturbed and nominal models. A reasonable trade off was accomplished with just one tuning parameter  $\lambda$  in the center of close loop execution and control to demonstrate errors.

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