DESIGN OF INTERNAL MODEL CONTROLLER-BASED PID CONTROLLER

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ABSTRACT

The Internal Model Control (IMC) is a transparent framework for designing and tuning the controller. The proportional-integral (PI) and proportional-integral derivative (PID) controllers have ability to meet most of the control objectives and this led to their widespread acceptance in the control industry. In this paper the IMC-based PID controller is designed. IMC-based PID tuning method is a trade-off between closed-loop performance and robustness to model inaccuracies achieved with a single tuning parameter λ. The IMC-PID controller shows good set-point tracking property. In this paper, Robust stability synthesis of a class of uncertain parameter varying first-order time-delay systems is presented. The output response characteristics using IMC based PID controller along with characteristics using automatic PID tuner are compared. The performance of IMC based PID for both stable, unstable as well as for the processes with time delay is studied and discussed. Various Order reduction techniques are utilized to reduce higher order polynomial into smaller order transfer function. This paper presents results of the implementation of an Internal Model Control (IMC) based PID controller for the level control application to meet robust performance and to achieve the set point tracking and disturbance rejection.

Keyword :- *PID controller, IMC, Order reduction.*

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1. INTRODUCTION

The proportional, integral, and derivative (PID) controller has been the most popular and widely used controller in process industries due to its simplicity, robustness, and the wide range of applicability with near-optimal performance. Although the PID controller provides the benefits described above, the parameter tuning is difficult especially for a plant with dead time[2-3]. The effectiveness of the internal model control (IMC) design principle has made it attractive to process industries, where many attempts have been made to exploit the IMC principle to design PI/PID controllers for both stable and unstable processes[9-10]. IMC is one of the well- known model-based controls and has found wide acceptance in the process control industry owing to its simplicity, robustness and good control performance. The significant characteristic of the IMC is that the responsiveness and robustness of the system is dependent on the single parameter i.e. low pass filter coefficient. The IMC-PID controller allows good set-point tracking. But it gives silky disturbance response especially for the process with a small time-delay/time-constant ratio. But, for many process control applications, disturbance rejection for the unstable processes is much more important than set-point tracking. In this study, we have taken several transfer functions for the model which may be stable, unstable or with some time delay which incorporates within it the effect of model uncertainties and disturbances entering into the process[8]. Also, the parameters of the physical system vary with operating conditions and time and hence, it is essential to design a control system that shows robust performance in the case of the above-mentioned situations. While designing the IMC-based PID controller we have to reduce order of some process model by using various order reduction techniques to convert the IMC controller in equivalent form as that of standard PID controller. While achieving this motive approximation error usually occurs and it is major in case of time delay processes[6]. For this, we have taken some transfer functions with the significant time delay or with non-invertible portions i.e. containing RHP poles or the zeros. Here we have used different techniques of factorization to remove these error-containing stuff. If we did not remove these errors then IMC filter gives best IMC performance but structurally it causes a major error in conversion to the PID controller, therefore the resulting PID controller may give poor controller performance.

1.1 Problem Statement

There are several classical methods for tuning of PID controllers. IMC is the model based approach for controller designing that yields a desired closed-loop response trajectory. There are number of advantages to the IMC structure, compared with classical feedback control structure. One is that it becomes very clear how process characteristics such as time delays and RHP zeros affect the inherent controllability of process. IMCs are much easier to tune than that of to tune controllers in standard feedback control structure. The purpose of this work is to find that the IMC law for a number of common process transfer functions, equivalent to PID-type feedback controller. To design an IMC, then find equivalent PID controller in standard form. Use an approximations for time delays in order to find PID-type control law; compare the performance of IMC-based PID controller to performance of auto-tuned PID controller. In this paper evaluate the IMC-based PID controller for stable, unstable as well as processes with large time delay and compares the results of IMC-based PID controller performance with auto-tuned PID controller.

2. IMC-BASED PID CONTROLLER DESIGN

2.1 IMC-based PID Controller For FOPDT Model

Example1: FOPDT Process Model

Consider a First-order plus Time Delay System as given below,

$$G_p(s) = \frac{1}{4s+1}e^{-8s} \tag{1}$$

Here there is time delay in the process, so we use first-order Pade -approximation for dead time $\left(e^{-\theta s} = \frac{-0.5\theta s+1}{0.5\theta s+1}\right)$

Thus, by following the procedure to design IMC based PID controller, formulas for PID controller tuning parameters are as follows,

$$K_c = \frac{\tau_p + 0.5\theta}{K_p(\lambda + 0.5\theta)}$$

$$T_i = \tau_p + 0.5\theta$$

$$T_d = \frac{\tau_p \theta}{2\tau_p + \theta} \tag{2}$$

Thus, by using these formula we found PID tuning parameters for λ = 20 as Kc = 0.3333,Ki = 0.04166 and Kd = 0.6666. Thus, by using these PID tuning parameters the simulations for example Eq.(1) results in following simulation results as shown in Figure 1 to 6.Figure 3 and 4 shows the process output response and control signal with disturbance respectively. Figure 5 and 6 gives the set-point tracking response of system.

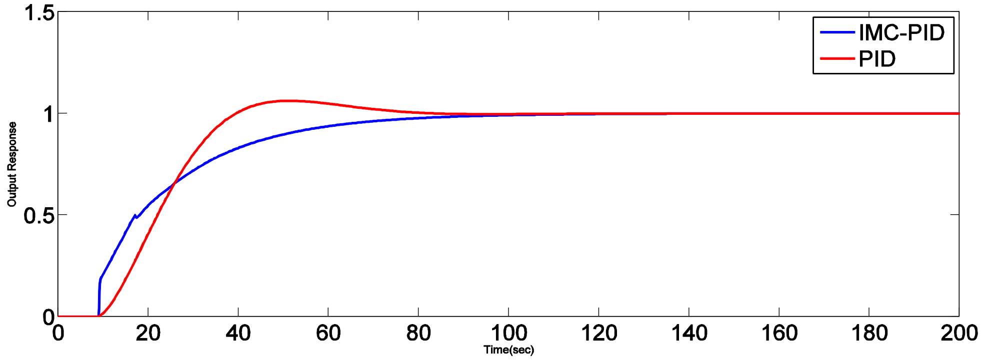

Figure:1 Output response of Example1 For IMC-based PID and auto-tuned PID controller.

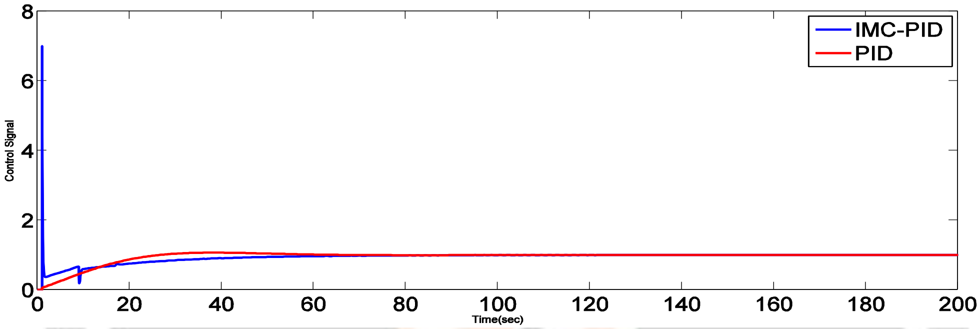

Figure:2 Control Signal of Example1 for IMC-based PID and auto-tuned PID controller with disturbance.

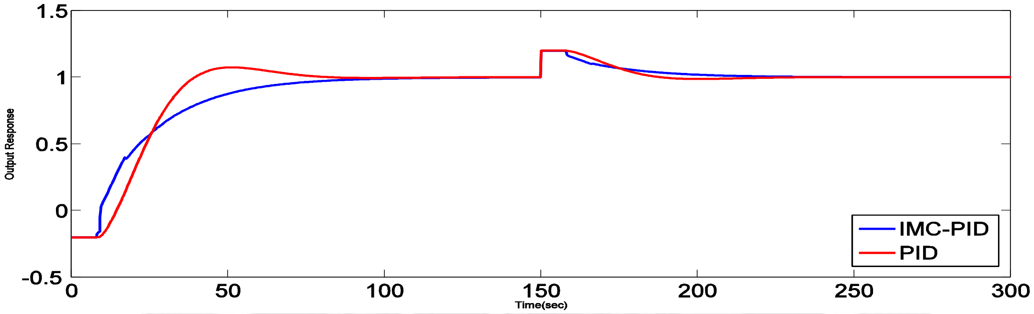

Figure 3: Output response of Example1 for IMC-based PID and auto-tuned PID controller with disturbance.

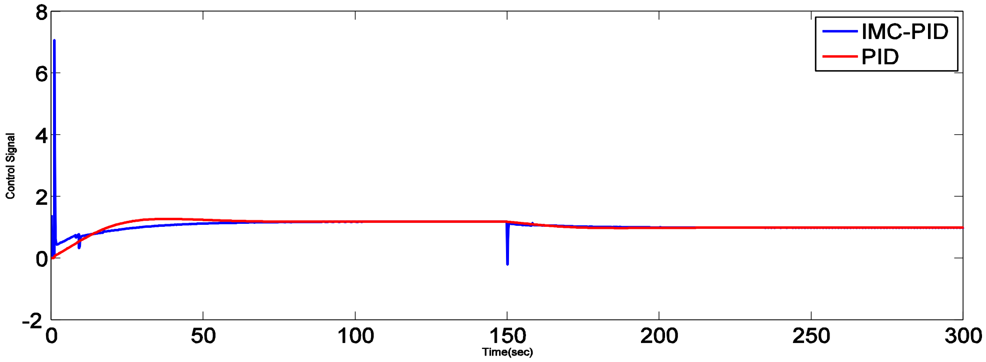

Figure 4: Control signal of Example1 for IMC-based PID and auto-tuned PID controller with disturbance

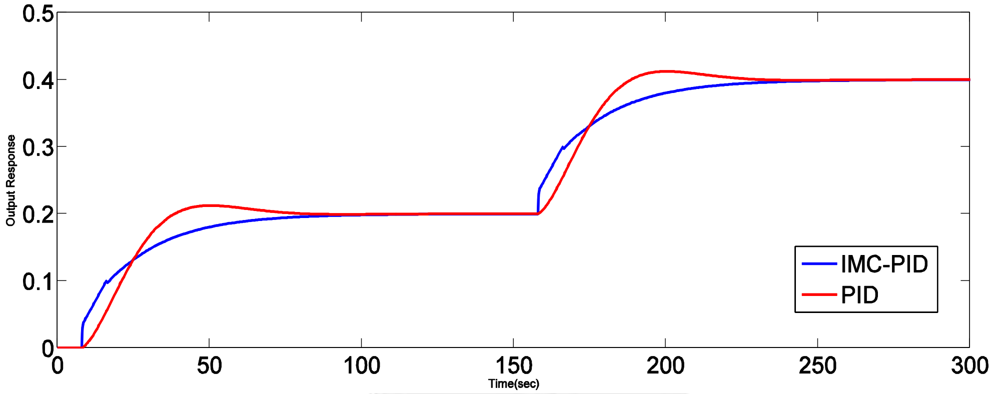

Figure 5: Output response of Example1 for IMC-based PID and autotuned PID controller with set-point tracking

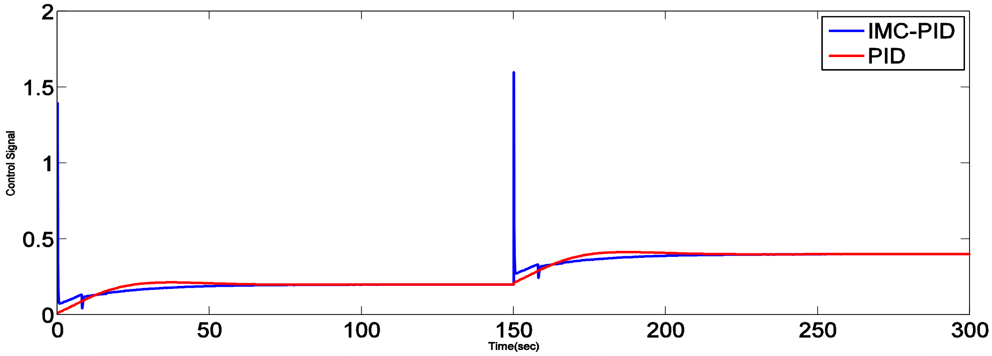

Figure 6: Control signal of Example1 for IMC-based PID and auto-tuned PID controller with set-point tracking

2.2 IMC-based PID Controller For SOPDT Model

Example2: SOPDT Process Model
Consider a process transfer function given below

$$G_p(s) = \frac{9.1785}{s^2 + 10.6375s + 18.2149} e^{-1.2292s} \tag{3}$$

.By applying time delay approximation and Skogestad's half rule we are getting reduced transfer function of the form Eq.(4).

$$G_p(s) = \frac{0.5039}{0.6146s + 1} e^{-1.19859s} \tag{4}$$

Here,for λ = 2 we are getting Kc = 0.9267896,KI = 0.763484 and Kd = 0.2812116. Thus, for these tuning parameters simulation results for output signal, control signal, disturbance rejection and set-point tracking responses are as shown in following figures from 7 to 13 respectively.

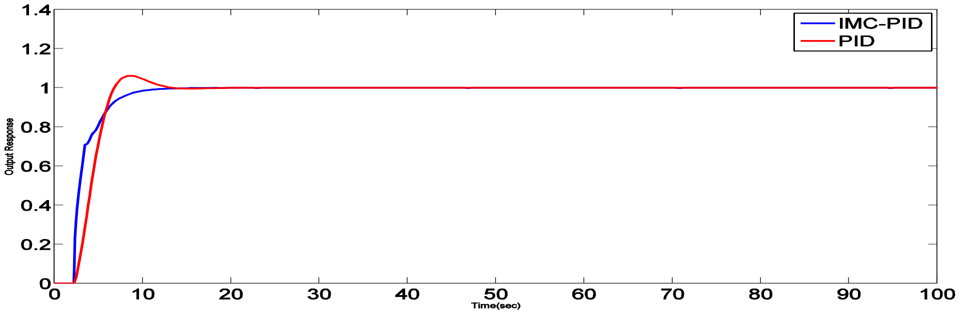

Figure 7: Output response of Example2 for IMC-based PID and auto-tuned PID controller

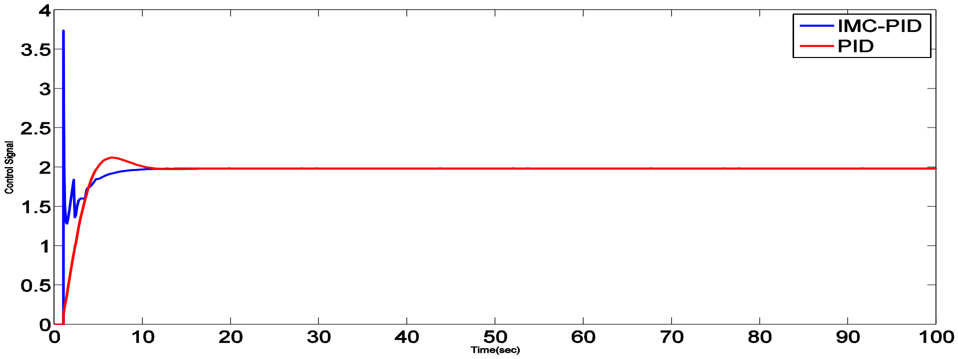

Figure 8: Control signal of Example2 for IMC-based PID and auto-tuned PID controller

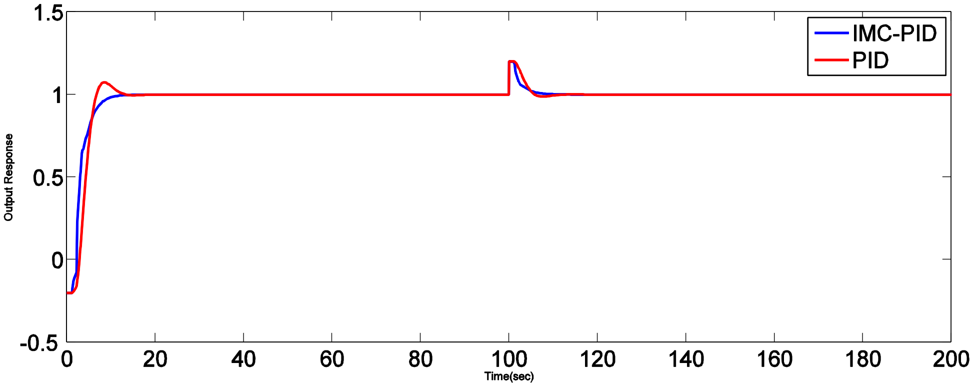

Figure 9: Output response of Example2 for IMC-based PID and auto-tuned PID controller with disturbance

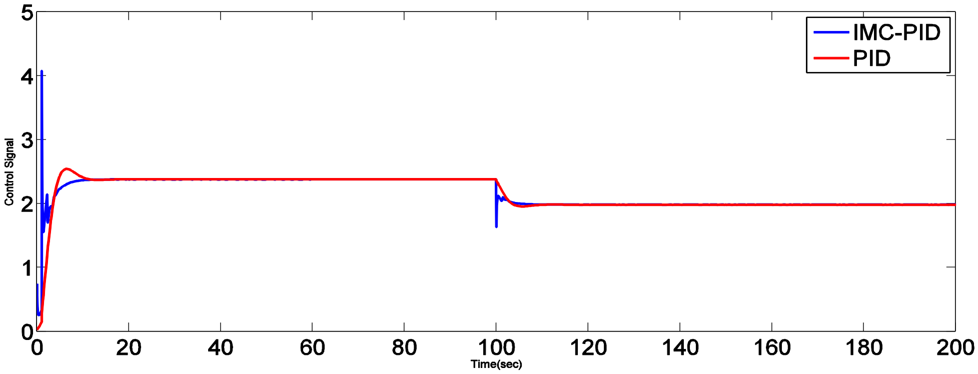

Figure 10: Control signal of Example2 for IMC-based PID and auto-tuned PID controller with disturbance

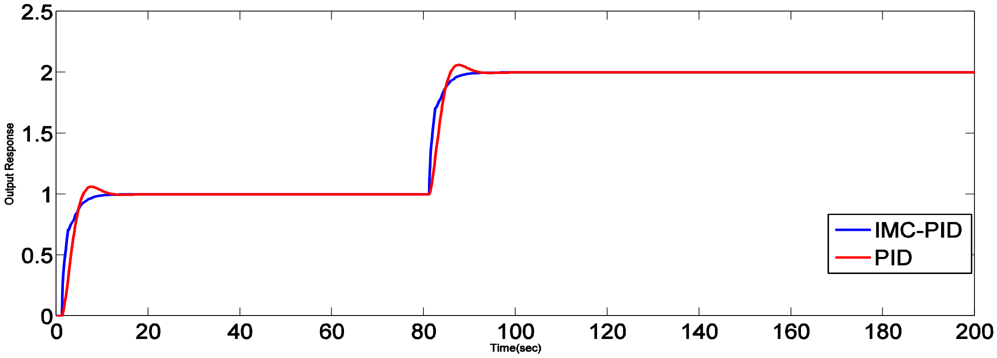

Figure 11: Output response of Example2 for IMC-based PID and autotuned PID controller with set-point tracking

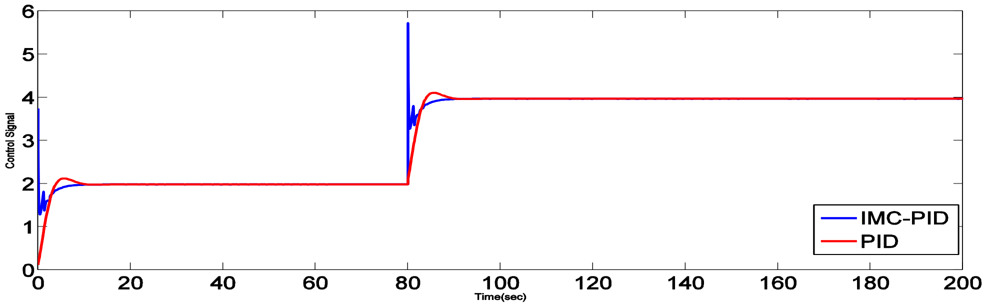

Figure 12: Control signal of Example2 for IMC-based PID and auto-tuned PID controller with set-point tracking

2.3 IMC-based PID Controller For Unstable Process Model

Processes with RHP zeros are unstable. In order to design an IMC-based PID controller for unstable process IMC procedure is modified to some extent. Modifications are done in the filter selection. The slightly more complicated filter transfer function is used in case of such a processes. Following steps are followed to design IMC-based PID controller for unstable processes.

1. Firstly, we have to find IMC-controller transfer function Q(s)which include filter f(s) for making Q(s) improper. Here an additional requirement for designing filter is that the value of f(s) at s = Pu where s = Pu is the unstable pole, must be equal to one .i.e.

   $$f(s = P_u) = 1 \tag{6}$$

   Morari and Zafiriou (1989) recommend a filter transfer function that is having a form as

   $$f(s) = \frac{\gamma s + 1}{(\lambda s + 1)^n} \tag{7}$$

   where n is chosen to make Q(s) proper (usually semi-proper).Value of γ can be found by satisfying the filter requirement f(s = pu) = 1.
2. Equivalent standard feedback controller can be found by using transformation

   $$G_c(s) = \frac{Q(s)}{1 - G_p^*(s)Q(s)} \tag{8}$$

3. Converting the controller into PID equivalent form

   $$G_c(s) = K_c\frac{T_I T_D s^2 + T_I s + 1}{T_I s} \tag{9}$$

   Let us consider the first-order unstable process

   $$G_p^*(s) = \frac{K_p}{-\tau_u s + 1} \tag{10}$$

   where τu is the positive value and Pu is 1 τu which indicates instability of system. Thus by following similar steps to design an IMC controller we can find out,

   $$Q(s) = Q^*(s)f(s) = G_{p-}^{*-1}(s)f(s) = \frac{-\tau_u s + 1}{K_p}\frac{\gamma s + 1}{(\lambda s + 1)^2} \tag{11}$$

   Here in case to design an IMC-based PID controller we have to choose second order filter to make controller, Q(s) semi-proper. As discussed in above mentioned steps solving for γ we get

   $$\gamma = \lambda(\frac{\lambda}{\tau_u} + 2) \tag{12}$$

   And the equivalent standard feedback controller is

   $$G_c(s) = \frac{\gamma}{K_p(2\lambda - \gamma)}\frac{(\gamma s + 1)}{\gamma s} \tag{13}$$

This is the form of PI controller, and tuning parameters can be given as

$$K_c = \frac{\gamma}{K_p(2\lambda-\gamma)} = \frac{-(\lambda+2\tau_u)}{K_p\lambda}$$

$$T_I = \gamma = \lambda(\frac{\lambda}{\tau_u}+2) \qquad (14)$$

Example3: Unstable Process Model

Consider here a reactor process model given by following transfer function with unstable pole as

$$G_p(s) = \frac{-2(3s+1)}{(-4s+1)(5s+1)} \qquad (15)$$

The PID controller parameters can be calculated by using IMC-based PID tuning from Eq.(14). Thus for unstable process given in Eq.(15) PI controller parameters are Kc = 4.5,Ki = 2 for λ = 1.Simulation results of process for process output and control signal with disturbance rejection and set-point tracking are as shown in Figures 13 to 19 obtained by using IMC-based PID controller and auto-tuned PID controller.

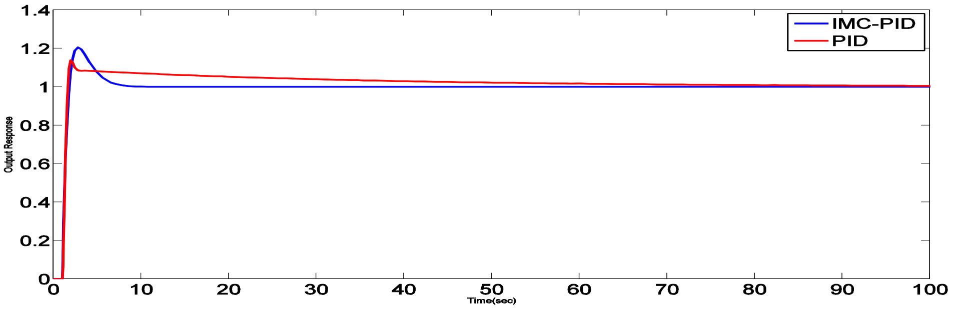

Figure 13: Output response of Example3 for IMC-based PID and auto-tuned PID controller.

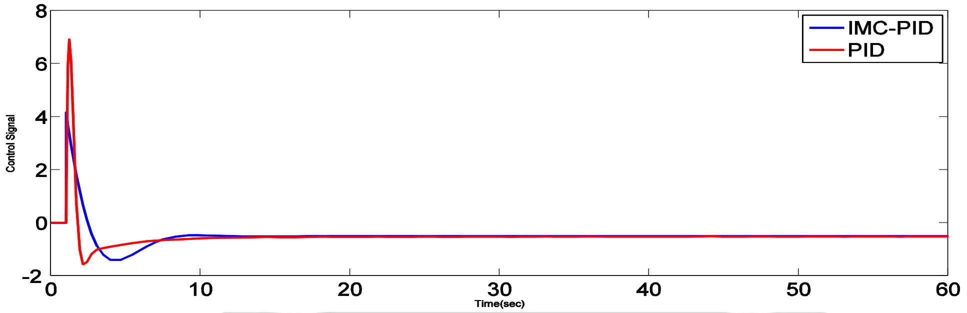

Figure 14: Control signal of Example3 for IMC-based PID and auto-tuned PID controller

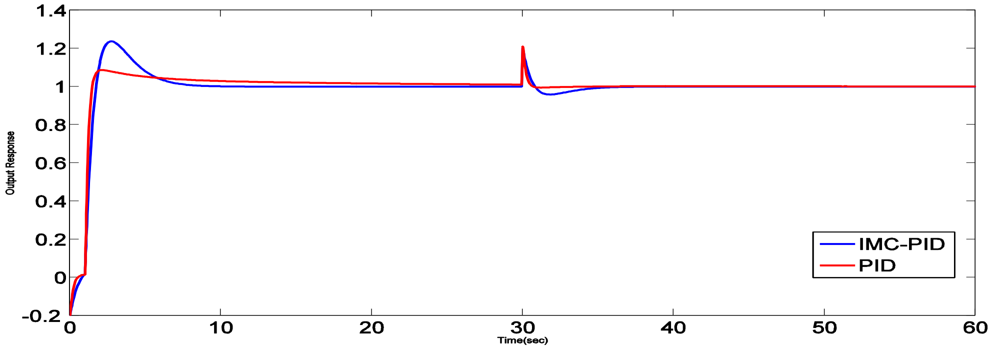

Figure 15: Output response of Example3 for IMC-based PID and auto-tuned PID controller with disturbance

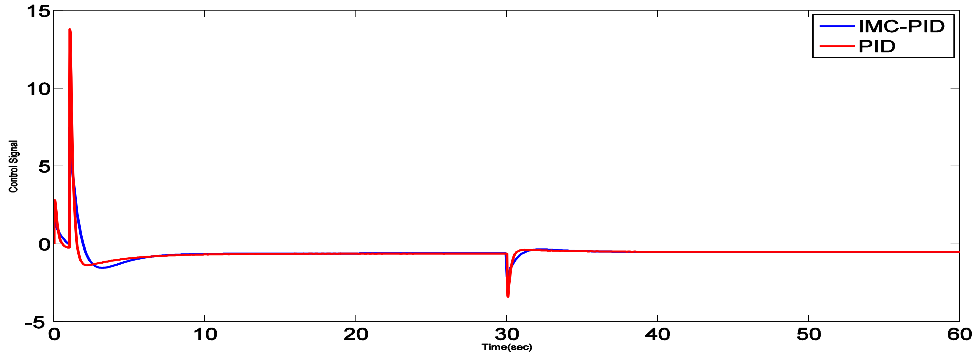

Figure 16: Control signal of Example3 for IMC-based PID and auto-tuned PID controller with disturbance

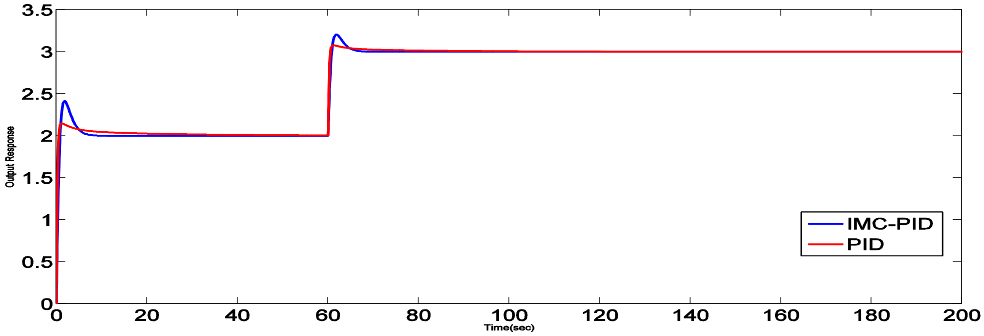

Figure 17: Output response of Example3 for IMC-based PID and auto-tuned PID controller with set-point tracking

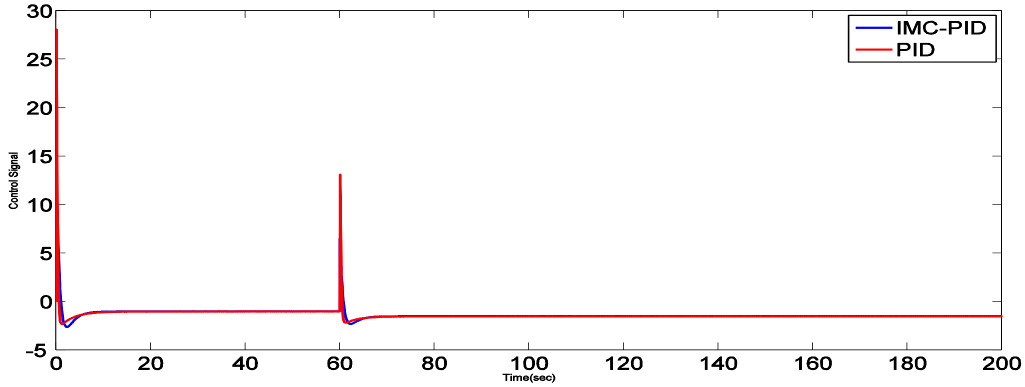

Figure 18: Control signal of Example3 for IMC-based PID and auto-tuned PID controller with set-point tracking

3.EXPERIMENTATION AND RESULTS

The experimentation is performed for level control of a tank, level control trainer is used for this purpose which is designed for studying basic level control principles and advanced study of control engineering. The setup consist of water tank with variable speed positive displacement pump for water circulation, one transparent tank with level transmitter, an inlet and an outlet flow dampers. The signal range for programmable VFD for positive displacement pump is 0 to 5V and signal range from level transmitter is 4 to 20 mA. VFDs pump and bottom tank level transmitter is interfaced to PC through NI6024E PCI DAQ card configured one analogue output and an analogue input in Simulink real time window target.

Thus the model of the process is,

$$G_p(s) = \frac{0.08534}{s^3 + 1.103s^2 + 4.391s + 0.09266} e^{-1s} \tag{16}$$

The reduced order transfer function of this process model is calculated by using order reduction technique. Thus reduced order model is,

$$G_p'(s) = \frac{0.9155}{46.3815s + 1} e^{-2.1394s} \tag{17}$$

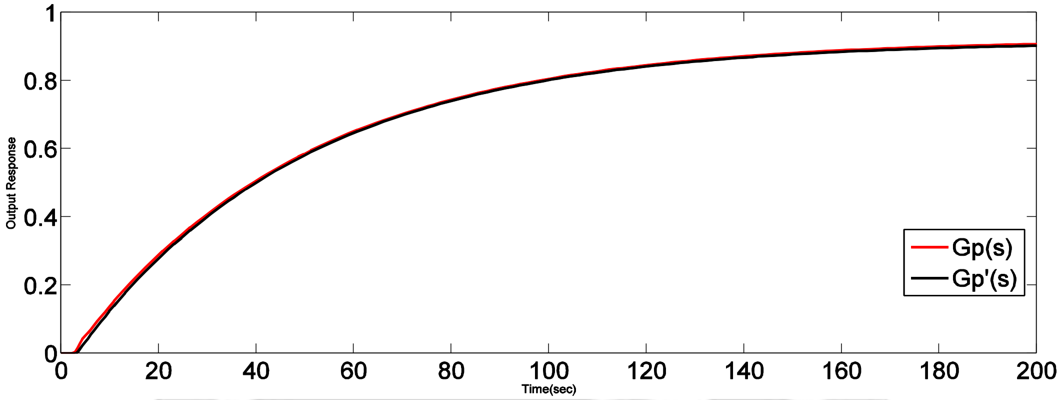

Figure 19.Comparisions of the actual and approximate reduced order process model.

Thus, by following the IMC-based PI controller design procedure we get PID tuning parameters as Kc = 13.2498 and KI = 0.2792. After performing experimentation for this process by using these tuning parameters we get simulation results for output response and control signal as well as process responses using IMC-based PID controller and auto-tuned PID controller with disturbance at t=200 sec. are as shown in bellow Figures 20 and 21.

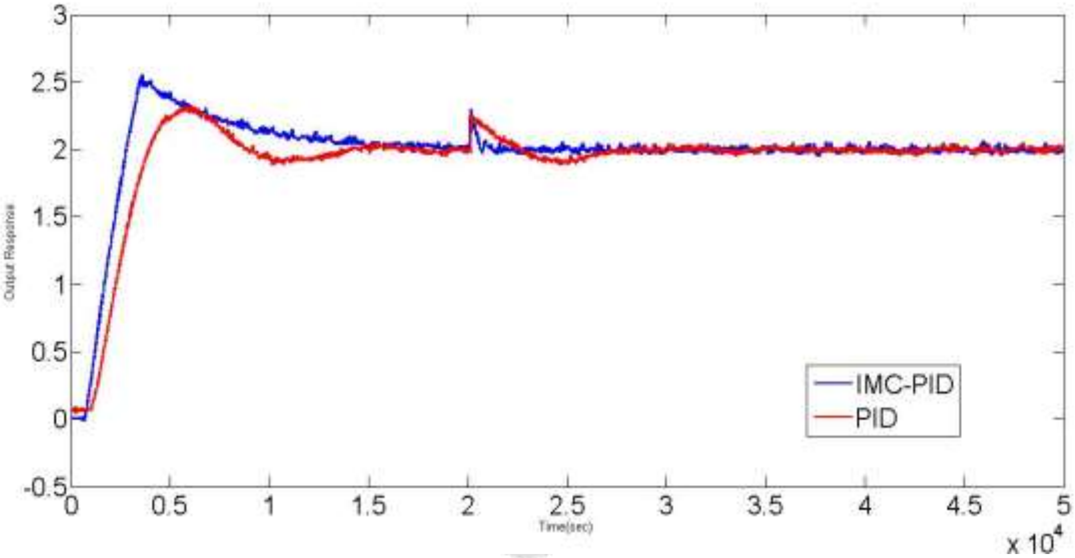

Figure 20: Output response of experimental set-up with disturbance

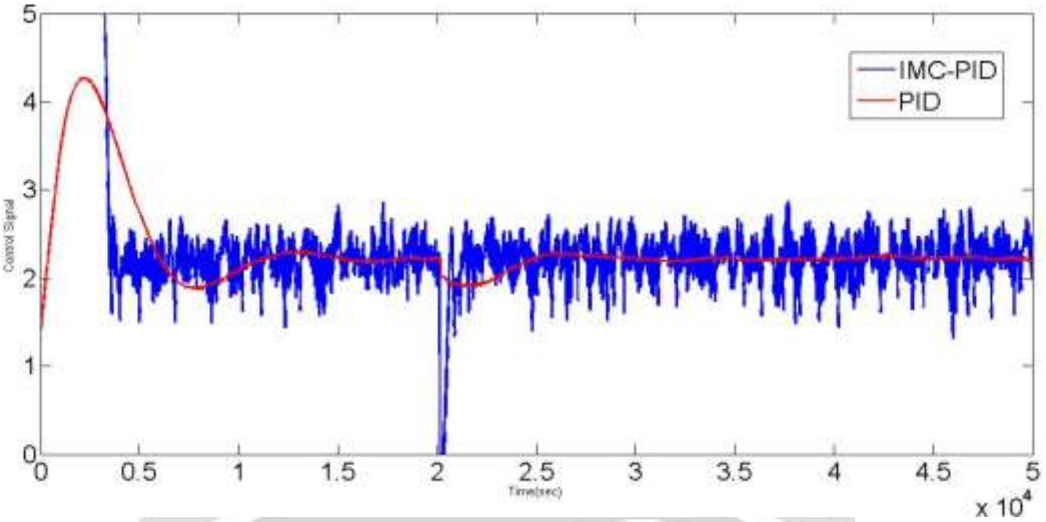

Figure 4.21: Control signal of experimental set-up with disturbance

4. CONCLUSIONS

In this work IMC-based PID controller is designed for FOPDT, SOPDT, and unstable process models. The MATLB-simulation is performed for these models using IMC-based PID controller and auto-tuned PID controller. The simulation results shows that IMC-based PID tuning gives more satisfactory response than auto-tuned PID controller. For experimental analysis the level control process was controlled using a auto-tuned PID controller and IMC-based PID controller, the process gives better response for IMC-based PID controller in-terms of disturbance rejection and set-point tracking. It concludes that IMC-based PID controller has superior performance than auto-tuned PID controller.

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