IMC-PID Controller Designing for FOPDT & SOPDT Systems

Miss. Londhe P.P[1], Prof. Kadu C.B[2], Prof. Parvat B.J[3]

M.E., Instrumentation & Control Engineering, Pravara Rural Engineering College, Loni (M.S), India [1]

Associate Professor & Head, Instrumentation & Control Engg., Pravara Rural Engineering College, Loni (M.S), India [2]

Associate Professor, Dept. of Instrumentation & Control Engg., Pravara Rural Engineering College, Loni (M.S), India [3]

Abstract: In this paper we have designed PID, IMC, IMC-based PID controllers. Proportional-Integral-Derivative Controllers are mostly used in many industries because of its robustness and simplicity. Internal Model Controller is suitable for designing and tuning of many controllers. It has a single tuning filter factor. It is much easier way to tune PID using IMC Controller. The present work is carried out on first order time-delay (FOPDT) and second order time delay (SOPDT) processes. IMC-based PID Controller gives better set-point tracking. Level tank process is designed by using System Identification. The performance of IMC-based PID Controller is better than Ziegler-Nichol and IMC Controller.

Keywords: IMC, Filter factor, PID, System Identification, time-delay.

I. INTRODUCTION

PID Controllers are most probably used in process industries because of its robustness, simplicity n successful practical applications [1]. It withstand consequential useful and applicable in tremendous process challenges. A PID controller steadily calculates an error value as the divergence between a desired set point and a precise process variable. To achieve good stability and fast response the controller tunning is at most important. For any controller a good stability is more important than being fast. There are several prescriptive rules used in PID tuning. We are focusing on Ziegler and Nichols tuning method (1940).

IMC was developed by Morari and Coworkers [2]. For the design and tuning of various types of controller Internal Model Control (IMC) is a commonly used technique. The main advantage is that, the IMC control structure can be contrive in the standard feedback control structure. In this paper this is one of the procedure we are using which is able to compensate for disturbances and model uncertainty. Among the various PID tuning methods, IMC-PID has huge acceptance in process industries. For practical applications PID controller algorithm is simple and robust to handle the model inaccuracies and therefore with IMC-PID tuning method a clear trade-off between closed-loop performance and robustness to model inaccuracies is achieved which is having a single tuning parameter i.e filter factor[3].

In this present work, we have designed PID (Ziegler Nichols), internal model control, IMC-based PID for First order time delay system and second order time delay system which are stable. The first stage in the development of any control and monitoring system, identification and modeling is must. We have used system Identification; with the help of system identification [4] toolbox construction of models from experimental data is achieved. It is a process of acquiring, formatting, processing and identifying Mathematical models . This model is based on raw data from the real-world system. It can be set by adjusting parameters within a given model until its output coincides as well as feasible with the measured output.

Procedure of Internal Model control, PID Control methods as Ziegler-Nichols, IMC based PID system is briefly discussed in section II, III and IV respectively, while Simulation and discussion has been done in section V, and it will be concluded at last in section VI.

II. PID CONTROLLER

The PID controller has three tuning parameters they are kp, ki, kd. The proportional, integral, and derivative terms are compute to measure the output of the PID controller. By tuning the kp, ki, kd parameters of the model, a PID controller can deal with precise process requirements. We have used a Ziegler-Nichols closed loop oscillation based tuning method among the various PID tuning method.

A. Ziegler-Nichols Closed-Loop Method

The frequency domain method is introduced by John G. Ziegler and Nathaniel B. Nichols. They published a paper in 1942 that the description of two methods for tuning parameters of P, PI and PID controllers are given.[5] These methods are the Ziegler-Nichols' closed loop method, and the Ziegler-Nichols' open loop method. It approaches trial and error tuning method which are based on sustained oscillations. Among these methods the closed-loop method is the most useful, which is based on the ultimate gain ku, and the ultimate period Tu, it is described below.

Step 1: Determine the sign of process gain

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Step 2: Implement a proportional control and introducing a new set-point.
Step 3: Increase proportional gain until sustained periodic oscillation.
Step 4: Note ultimate gain and ultimate period: ku and Pu
Step 5: Evaluate control parameters as prearranged by Ziegler and Nichols

Following table shows the tuning parameters rules[5]

TABLE I: ZIEGLER NICHOLS TUNING RULES

Controller type	KC	ƮI	ƮD
P-only	0.5kcu	—	—
PI	0.45kcu	Pu/1.2	—
PID	0.6kcu	Pu/2	Pu/8

The above method does not need the process model, which is the main benefit of this method. On the other hand it having disadvantage also. It is very time consuming due to trial and error procedure, also it is not applicable to the systems like first order n second order without dead time because it do not have ultimate gain. Sometimes dangerous situation should be happened in practice because the system is driven towards instability.

III.IMC CONTROLLER

Internal Model Control system is framed on the Internal Model Principle. It states that if any control system enclose within it, implicitly or explicitly, some illustration of the process to be controlled then a perfect control is readily achieved. IMC have most powerful advantages as, it allows model uncertainty and tradeoffs between performance and robustness which can be contemplated in a more efficient tone. It also provides time-delay compensation. Generally the result of IMC formulation is only one tuning parameter λ. It is general design method, but results in PID controllers for low order process models

A. IMC STRCTURE

In further part we will obtain the feedback equivalence to IMC by using block diagram manipulation. In practice, variance of process model is common. Also it cannot be invertible due to system is often get affected by unknown disturbances. Hence open loop control is unable to maintain output at set-point. Begin with the IMC structure shown in Figure 1.1;

Notice that r(s) - y(s) is simply the error term used by a standard feedback controller. Therefore, it is clearly seen that the IMC structure can be rearranged to the feedback control structure[6].

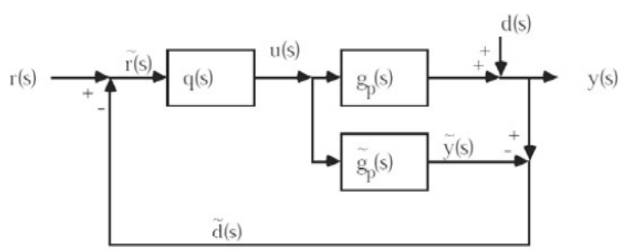

Fig. 1. Example of an image with acceptable resolution

The advantage of reformulation is that when the IMC design procedure is used a PID controller often results. Also, the standard IMC block diagram is not deal with unstable systems, so this feedback form must be used for those cases.

The various parameters used in the IMC basic structure shown above are as follows:
q(s) = disturbance
r(s) = set-point
r̂(s) = modified set-point
u(s) = manipulated output
g(s) = process
ğ(s) = process model
d(s) = disturbance
y(s) = measured process output
ỹ(s) = model output

Unknown disturbance d(s) is affecting to the system. The process and the model are introduced by the manipulated input u(s). y(s) is the process output get compared with the output of the model, as a result signal estimated disturbance .

The obtained feedback signal is

$$\tilde{d}(s) = (g_p(s) - \widetilde{g_p}(s)u(s) + d(s)$$

B. IMC DESIGN PROCEDURE

IMC controller designing is relatively easy. The very first step is factor the process model into “invertible” and “noninvertible” components to make controller stable[7].

$$\breve{g}_p(s) = \breve{g}_{p+}(s)\breve{g}_{p-}(s)$$

To obtain idealized IMC controller we have to make inverse of the invertible part of the model.

$$\tilde{q}(s) = \breve{g}_{p^{-1}}{}^{-1}(s)$$

To make controller proper filter will be added

$$q(s) = \breve{g}_{p^{-1}}{}^{-1}(s)f(s)$$

Where the filter factor f(s) is

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

n should be chosen to make the controller proper or semi-proper. Filter factor λ should be adjusted. System performs fast for small value of λ and if the value is large then closed-loop become more robust.

IV. IMC-BASED PID CONTROLLER

In the majority time-delay procedure, the ideal controller that gives the desired closed-loop response is more complicated than a PID controller. This problem is solved in the IMC-PID tuning method. IMC-PID controller allows good set-point tracking[8]. The IMC-PID control is very effortless to implement as only one parameter need to be tuned to achieve an adequate performance. One of the main advantages is that it has no restriction on the set of process models. Tuning rules mentioned in the generalized

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IMC-PID method for the numerous complex process are applicable.

C. Design Of a IMC-based PID Controller Procedure with Time-delay for 1st Order System

According to the procedure we get the result in PID equivalent form so we have to first make approximations to the dead time. Some control system design techniques require a rational transfer function in such cases padé approximation for dead time is mostly used. The padé approximation frequently gives better approximation of the function.

The design steps should be as follows

If the given process model is

$$\widetilde{g_p}(s) = \frac{k_p e^{-\theta s}}{\tau_p s + 1}$$

We will use first-order padé approximation for dead time

$$e^{-\Theta s} = \frac{-0.5\theta s + 1}{0.5\theta s + 1}$$

By using padé approximation we get

$$\widetilde{g_p}(s) = \frac{k_p e^{-\theta s}}{\tau_p(s) + 1}$$

$$\widetilde{g_p}(s) = \frac{k_p(-0.5s + 1)}{(\tau_p s + 1)(0.5s + 1)}$$

By factoring invertible and noninvertible element we get

$$\widetilde{g_p}(s) = \frac{k_p}{(\tau_p s + 1)(0.5s + 1)}$$

$$\widetilde{g_p}(s)(-0.5s + 1)$$

Form the idealized controller

$$q(s) = \frac{k_p}{(\tau_p s + 1)(0.5s + 1)}$$

Add filter factor

$$q(s) = \frac{k_p}{(\tau_p s + 1)(0.5s + 1)} \frac{1}{\lambda s + 1}$$

The following PID parameters are found by solving above equation

$$k_c = \frac{(\tau_p + 0.5\theta)}{k_p(\lambda + 0.5\theta)}$$

$$\tau_I = \tau_p + 0.5\Theta$$

$$\tau_D = \frac{\tau_p \theta}{2\tau_p + \theta}$$

The IMC-based PID controller design procedure has resulted in a PID controller

V. SIMULATION AND DISCUSSION

Example1: First Order + Time Delay Stable Process

The process having transfer function [9]

$$G(s) = \frac{1.54}{5.93 + 1} e^{-1.07s}$$

We get following calculations by the methodology discussed in the preceding section.

Calculation Ziegler-Nichols Parameters are , $KC = 4.056, TI = 2.028\ TD = 2.2815$.

By using IMC method we obtained following transfer function

$$q(s) = \frac{5.93s + 1}{1.232s + 1.54}$$

, where the filter factor λ is adjusted to 1

IMC-PID Parameters are, $KC = 1.8602, TI = 0.29971$ $TD = 0.4834$

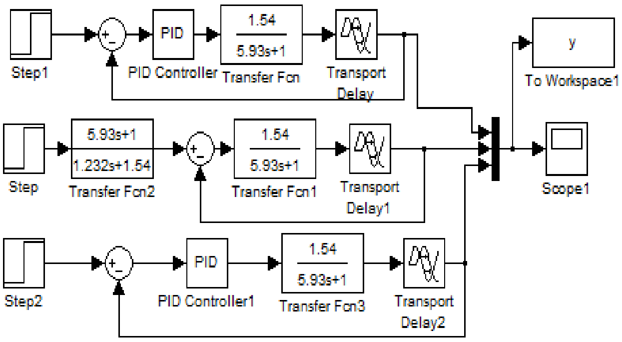

Fig. 2. Step response of FOPDT system block diagram with set point

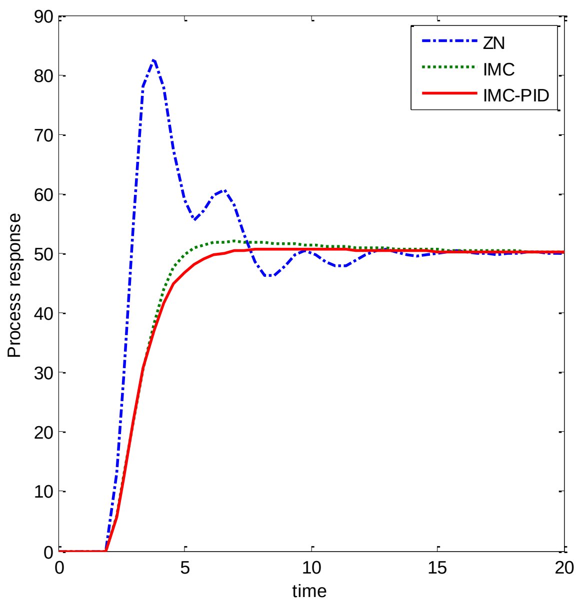

Fig. 3. Step response of FOPDT system for set point tracking

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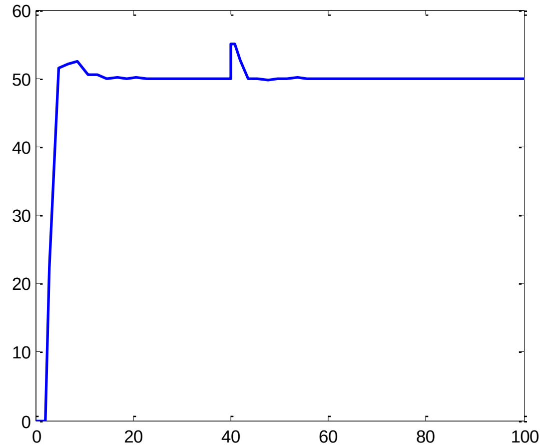

Fig. 4. Disturbance rejection step response of FOPDT system

TABLE II: PERFORMANCE MEASUREMENTS

Time domain Specification	ZN	IMC	IMC-PID
Rise Time	0.7714	2.0942	2.3954
Settling Time	11.9055	10.6676	5.8323
Overshoot	65.4091	3.5631	1.2062

Example2: Second order + Time Delay stable Process

The process having transfer function [10]

$$G(S) = \frac{2}{(10s+1)(5s+1)} e^{-s}$$

Below are the parameters obtained by using ZN closed-loop table, $KC = 1.722, TI = 0.20259, TD = 3.65925$

By using IMC method we obtained following transfer function

$$q(s) = \frac{50s^2 + 15s + 1}{0.6s + 2}$$

Where the filter factor λ is adjusted to 0.3

IMC-PID Parameters are, $KC = 1.9230, TI = 0.039,$ $TD = 19.9192$

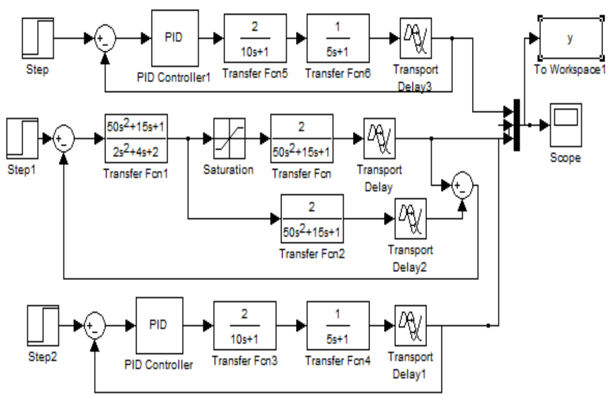

Fig. 5. Step response of FOPDT system block diagram with set point

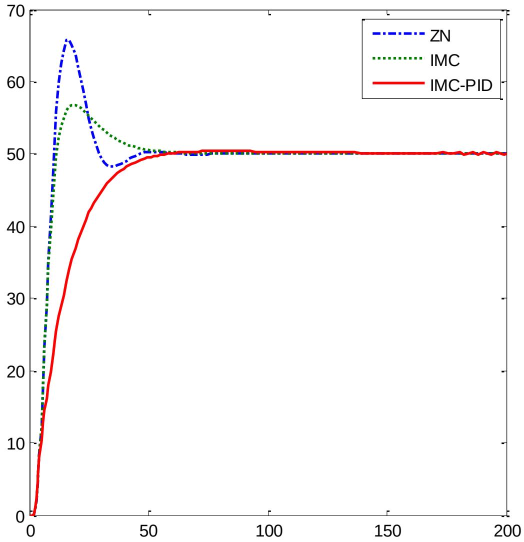

Fig. 6. Step response of SOPDT system for set point tracking

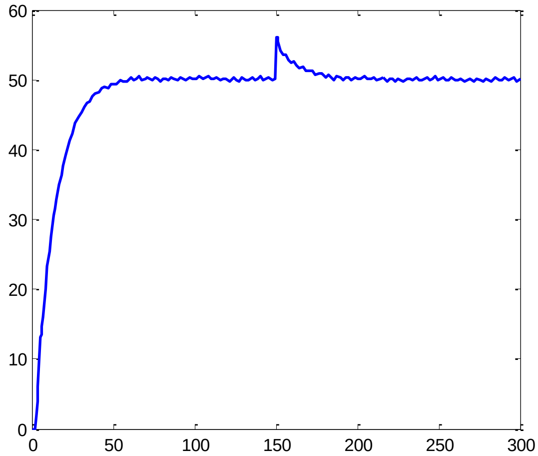

Fig. 7. Disturbance rejection step response of FOPDT system

TABLE III: PERFORMANCE MEASUREMENTS

Time domain Specification	ZN	IMC	IMC-PID
Rise Time	5.5941	6.2650	25.4891
Settling Time	42.2739	44.1697	45.2478
Overshoot	33.7814	13.6484	1.4306

VI. CONCLUSION

In present work we have done two parts, i.e., process modeling and tuning of controllers. For tuning we used Ziegler-Nichols, IMC and IMC-based PID Controller. For model identification we have used System Identification Toolbox by which we have got the process model. We have designed IMC-PID controller for first order time delay and second order time delay process model. The controllers perform well for set-point tracking, the simulation results concluded that Ziegler Nichols method gives oscillations, while IMC method gives overshoot but the proposed IMC based PID method have much faster response time and gives adequate and better result.

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In IMC-PID tuning method a clear trade-off among robustness and closed-loop performance to model inaccuracies is achieved with a single tuning parameter.

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BIOGRAPHIES

Miss. Prajakta Prafulla Londhe received the B.E. degree in Instrumentation & Control Engineering from D.Y.Patil College of Engineering, Pimpri, Savitribai Phule Pune University, India, in the year 2012.She is currently pursuing M.E from Department of Instrumentation Engineering, Loni(M.S), Savitribai Phule Pune University, India

Mr. Chandrakant B. Kadu is working as an Associate Prof. & HEAD, Instrumentation & Control Engineering, Pravara Rural Engineering College, Loni (M.S) Savitribai Phule Pune University , India. He was a Member of Board of Studies Instrumentation, Savitribai Phule Pune University (2011-2015) .He was also Govering Council Member of Instrumentation Society of India (ISOI) Bangalore(2014-2016). He has published more than 20 National &International paper in the field of Process Control. Presently pursuing Ph.D from College of Engineering Pune (COEP), Savitribai Phule Pune University

Mr. Parvat B.J. is working as an Associate professor with Instrumentation and Control Engineering department, Pravara Rural Engineering College, Loni (M.S), India. His areas of specialization are process control and sliding mode control. He has published more than 15 National &International papers.