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Comparative study of PID, IMC and IMC based PID controller for pressure process

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ABSTRACT

The ability of PI and PID controller has widespread acceptance in control industry. The Internal Model Controller (IMC) based approach for controller design is one of them using IMC and its equivalent IMC based PID is also one of the control approach in industries .The real time implementation is done in simulink using MATLAB. The result of comparison shows that IMC based PID has good settling time, tracking ability and disturbance rejection responses.

Keywords: PID, IMC, IMC based PID, Pressure process, MATLAB.

INTRODUCTION

Generally different analysis is made between conventional controller and IMC controller for nonlinear pressure process. Pressure process is a continuous time process and is controlled by a digital controller. To improve the control quality in a pressure process adaptive digital PID with methods like online identification, sampling period and optimization of closed loop parameters they require large computational methods. PID is first used in all pneumatic devices but nowadays used in both analog and digital electronics. Nowadays plants are becoming more complex because of huge development in industries therefore its application is limited. If the system has external disturbances like variation in output pressure it may cause transient response poorer. To overcome neural network PID has been implemented. Even though it has advantages of less overshoot, settling time and better rise time it requires design experience which makes them complicated. Later various modified PID controllers were developed. It is a fact that PID controllers are not well suited for nonlinear systems. Tuning of PID controller is quiet difficult. The major disadvantage is disturbance rejection and tracking inability .It has wider application in field of automation. To overcome load disturbance and variation in parameters, IMC is implemented. But the IMC based PID also shows better transient, load disturbance responses and better tracking ability. The design of IMC based PID controller is used mainly to control the speed of the system. It is one kind of automatic technology. The design is mainly on the controller design and PID approximation. Here in both the transient state and the steady state the IMC based PID could be easily adjusted to get the desired control system. The result of comparison shows that IMC based PID is high and has better performance.

Pressure Process: Pressure process is a module for analyzing and controlling the pressure in process tank. Pressure is a process variable is sensed and given to computer. PC acts a controller and gives control signal to I/P converter.

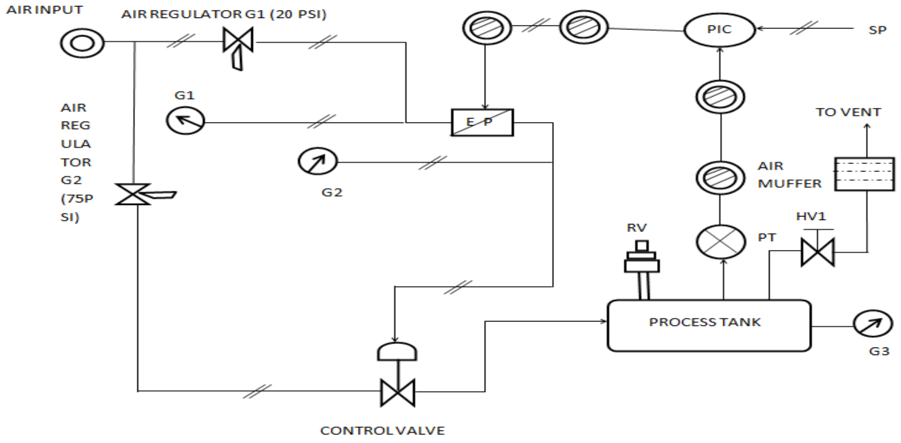


Figure.1.Pressure Process

Using the pressure process, the open loop response is obtained

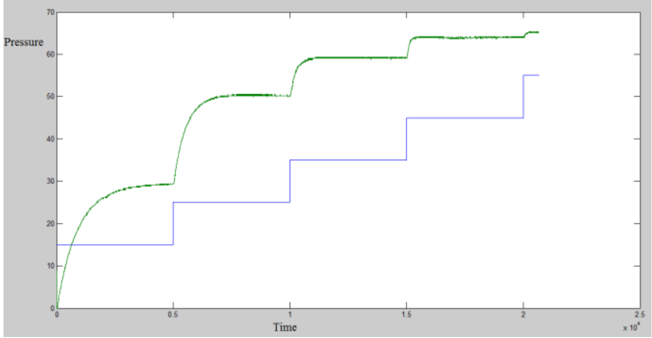


Figure.2.Real time open loop response

Estimation of Process Parameters: Consider the first order system represented by the following transfer function equation

$$y(s) = \frac{k_p}{\tau_p s+1} u(s)$$

The measured output is in deviation variable form. The process parametersτ_p; k_p can be estimated by performing a single step test on process input. The process gain is found as simply the long term change in process output divided by the change in process input. There are several ways to estimate time constant for this model.

Two Point Method for Estimating the Process Parameters:

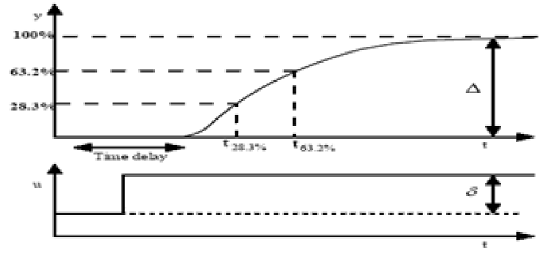


Figure.3.Two point method for estimating the process parameters

Two point method for estimating process parameter
The process gain is calculated by;

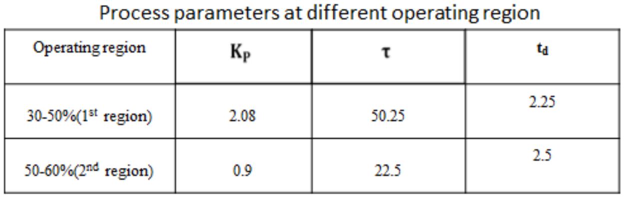
$$K_p = \frac{\Delta}{\delta} = \frac{Change\ in\ process\ output}{Change\ in\ process\ input}$$

The parameters of FOPTD transfer function model by letting the response of the actual system and that of the model to meet at two points which describe the two parameters τ and θ. Here the time required for the process output to make 28.3% and 63.2% respectively. The time constant and time delay can be estimated from the equations given below

$$\tau_p = 1.5(t_{63.2\%} - t_{28.3\%})$$
$$\theta = t_{63.2\%} - \tau_p$$

The proposed works objective is to find the two different models at different operating regions. The obtained parameters are reported in Table I.

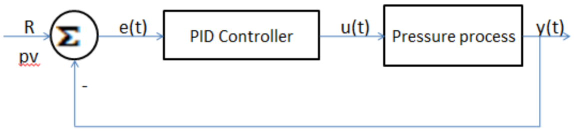
Table.1.Process Parameters



Process parameters at different operating region

Operating region	K_p	τ	t_d
30-50%(1st region)	2.08	50.25	2.25
50-60%(2nd region)	0.9	22.5	2.5

PID Controller: A Proportional Integral Derivative Controller (PID) is a control loop feedback mechanism widely used in industrial control systems. In PID controllers the open loop oscillation technique developed by Ziegler and Nichols results in controller with PID structure.



$$U(t) = k_p e(t) + k_i \int e(t)d(t)$$

Figure.4.PID Controller

The transfer function of the PI controller looks like the following;

$k_p+(k_i/s)$

where

kp – Proportional gain
ki – Integral gain

By using Ziegler – Nichols tuning method the controller parameters had been obtained (Table II)

Table.2.Ziegler – Nichols Method

PID TYPE	k_p	T_i	T_d
P	$\frac{\tau}{t_d.k_p}$	-	-
PI	$0.9\frac{\tau}{t_d.k_p}$	$T_i = 3.33t_d$	-
PID	$1.2\frac{\tau}{t_d.k_p}$	$T_i = 2t_d$	$T_d = 0.5t_d$

Here the PID controller parameter at different operating regions for pressure process is obtained and the values are shown in the Table 3.

IMC Controller: In process control applications, model based control systems are often used to track set points and reject low disturbances. The internal model control (IMC) philosophy relies on the internal model principle which states that if any control system contains within it, implicitly or explicitly, some representation of the process to be controlled then a perfect control is easily achieved. In particular, if the control scheme has been developed based on the exact model of the process then perfect control is theoretically possible.It show that if we have complete knowledge about the process (as encapsulated in the process model) being controlled, we can achieve perfect control.This ideal control performance is achieved without feedback which signifies that feedback control is necessary only when knowledge about the process is inaccurate or incomplete.

Although the IMC design procedure is identical to the open loop control design procedure, the implementation of IMC results in a feedback system. Thus, IMC is able to compensate for disturbances and model uncertainty while open loop control is not. Also IMC must be detuned to assure stability if there is model uncertainty.The IMC design procedure is exactly same as the open loop design procedure. Unlike open loopcontrol, the IMC structure compensates for disturbance and model uncertainties.As stated above that the actual process differs from the model of the process i.e. process model mismatch is common due to unknown disturbances entering into the system. Due to which open loop control system is difficult to implement so we require a control strategy through which we can achieve a perfect control. Thus the control strategy which we shall apply to achieve perfect control is known as INTERNAL MODEL CONTROL (IMC) strategy. Also to improve the robustness of the system the effect of model mismatch should be minimized. Since mismatch between the actual process and the model usually occur at high frequency end of the systems frequency response, a low pass filter Gf(s) is usually added to attenuate the effects of process model mismatch.. It should be noted that the standard IMC design procedure is focused on set point responses but good set point response do not guarantee good disturbance rejection , particularly for the disturbance that occur at the process input. A modification of the design procedure is developed to improve input disturbance rejection. Tolerance to modernuncertainty is called robustness. Like open –loop control the disadvantage is compared with standard feedback control.IMC doesn't handle integrating or open loop unstable systems.

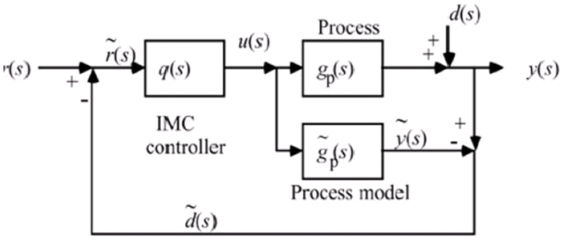


Figure.5.Closed Loop Structure with IMC

The closed loop structure is based on general structure of the IMC(Internal Model Control).The process model receives manipulated variable as input signal as the actual process .Generally on subtracting model output from process output we could determine the model error. We could also realize that the disturbance can enter the system. The characteristics of the structure is the process model which is in parallel with the actual process.The ~ symbol is used to represent that the signal is associated with the model. The disturbance is applied and both the disturbance and the model error passed through the feedback as the estimated disturbance and modifies the set point. The modified set point corrects the error and the modified set point. Thus an error free output is obtained as the measured process output.

IMC Design 1st Order System

- **Process model for 1st order system : Gp*(s) = Kp*/[Tp*(s)+1]**
- Gp*(s) = Gp*(+)(s) . Gp*(-) (s) = 1 . Kp*/[Tp*(s)+1]
- Qc*(s) = inv[Gp*(-) (s)] = [Tp*(s)+1] / Kp*
- Qc(s) = Qc*(s). f(s) = [Tp*(s)+1] / [Kp*. (lem(s) + 1)]
- f(s) = 1 / (lem. s + 1)
- y(s) = Qc(s). Gp(s).r(s) = Gp*(+)(s) . f(s). r(s)
- Output variable:
- y(s) = r(s)/(lem. s +1)
- Manipulated variable:
- u(s) = Qc(s) . r(s) = [Tp*(s)+1].r(s)/ [Kp. (lem. s +1)

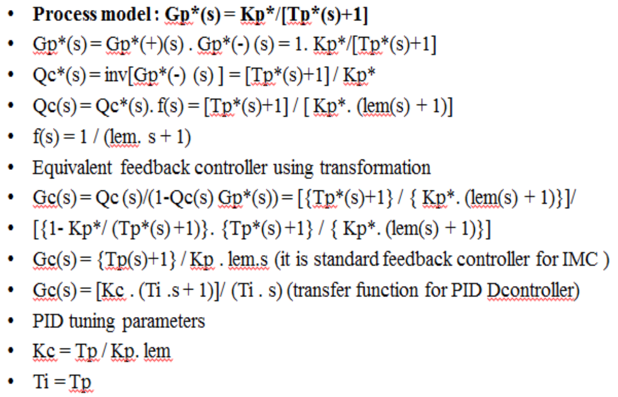
IMC based PID Controller: The IMC-PID controller allows good set-point tracking but sulky disturbance response especially for the process with a small time-delay/time-constant ratio. But, for many process control applications, disturbance rejection for the unstable processes is much more important than set point tracking. Hence, controller design that emphasizes disturbance rejection rather than set point tracking is an important design problem that has to be taken into consideration. We propose an optimum IMC filter to design an IMC-PID controller for better set-point tracking of unstable processes. The proposed controller works for different values of the filter tuning parameters to achieve the desired response As the IMC approach is based on pole zero cancellation, methods which comprise IMC design principles result in a good set point responses. However, the IMC results in a long settling time for the load disturbances for lag dominant processes which are not desirable in the control industry. In our study we have taken several transfer functions for the model of the actual process or plant as we have exactly little or no knowledge of the actual process which incorporates within it the effect of model uncertainties and disturbances entering into the process. 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. Then we tried to tune our IMC controller for different values of the filter tuning factor.

Since all the IMC-PID approaches involve some kind of model reduction techniques to convert the IMC controller to the PID controller so approximation error usually occurs. This error becomes severe for the process with time delay. For this we have taken some transfer functions with significant time delay or with noninvertible portions i.e. containing RHP poles or the zeroes. Here we have used different techniques like factorization to get rid of these error containing stuffs. It is because if these errors are not removed then even if IMC filter gives best IMC performance but structurally causes a major error in conversion to the PID controller, then the resulting PID controller could have poor control performance.

Thus in our approach to IMC and IMC based PID controller to be used in industrial process control applications, there exists the optimum filter structure for each specific process model to give the best PID performance. For a given filter structure, as λ decreases, the inconsistency between the ideal and the PID controller increases while the nominal IMC performance improves. It indicates that an optimum λ value also exist which compromises these two effects to give the best performance. Thus what we mean by the best filter structure is the filter that gives the best PID performance for the optimum λ value.

The IMC structure can be rearranged to form a standard feedback control system that can easily handle open loop unstable system as not the case with IMC. This modification of the IMC design procedure is developed to improve the input disturbance rejection. The IMC based PID structure which uses a standard feedback structure uses the process model in an implicit manner i.e. PID tuning parameters are often adjusted based on the transfer function model but it is not always clear how the process model affects the tuning decision. In the IMC procedure the controller Qc(s) is directly based on the good part of the process transfer function. Also the IMC formulation generally results in only one tuning parameter, the close loop time constant (filter tuning factor). The IMC based PID tuning parameters are then the function of this time constant. Here in both the transient state and the steady state the IMC-based PID could be easily adjusted to get the desired control system performances. That is on comparing the simulation results with respect to the same parameters of proportional gain, integral gain, derivative gain and the acceleration gain accuracy and efficiency on IMC-based PID is high. The response can also be improved significantly.

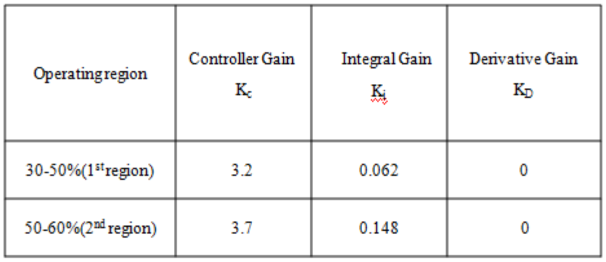
IMC based PID design 1st order system



- **Process model : Gp*(s) = Kp*/[Tp*(s)+1]**
- Gp*(s) = Gp*(+)(s) . Gp*(-) (s) = 1. Kp*/[Tp*(s)+1]
- Qc*(s) = inv[Gp*(-) (s)] = [Tp*(s)+1] / Kp*
- Qc(s) = Qc*(s). f(s) = [Tp*(s)+1] / [Kp*. (lem(s) + 1)]
- f(s) = 1 / (lem. s + 1)
- Equivalent feedback controller using transformation
- Gc(s) = Qc (s)/(1-Qc(s) Gp*(s)) = [{Tp*(s)+1} / { Kp*. (lem(s) + 1)}]/
- [{1- Kp*/ (Tp*(s) +1)}. {Tp*(s) +1} / { Kp*. (lem(s) + 1)}]
- Gc(s) = {Tp(s)+1} / Kp . lem.s (it is standard feedback controller for IMC)
- Gc(s) = [Kc . (Ti .s + 1)]/ (Ti . s) (transfer function for PID Dcontroller)
- PID tuning parameters
- Kc = Tp / Kp. lem
- Ti = Tp

Here the IMC based PID controller parameter at different operating regions for pressure process is obtained and the values are shown in Table 4.

Table 4. IMC based pid controller parameter at different operating regions



Operating region	Controller Gain K_c	Integral Gain K_i	Derivative Gain K_D
30-50%(1st region)	3.2	0.062	0
50-60%(2nd region)	3.7	0.148	0

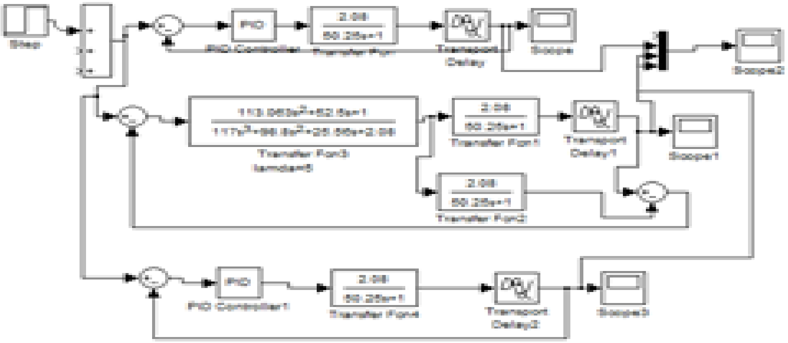


Figure 6. Block diagram of first order Region

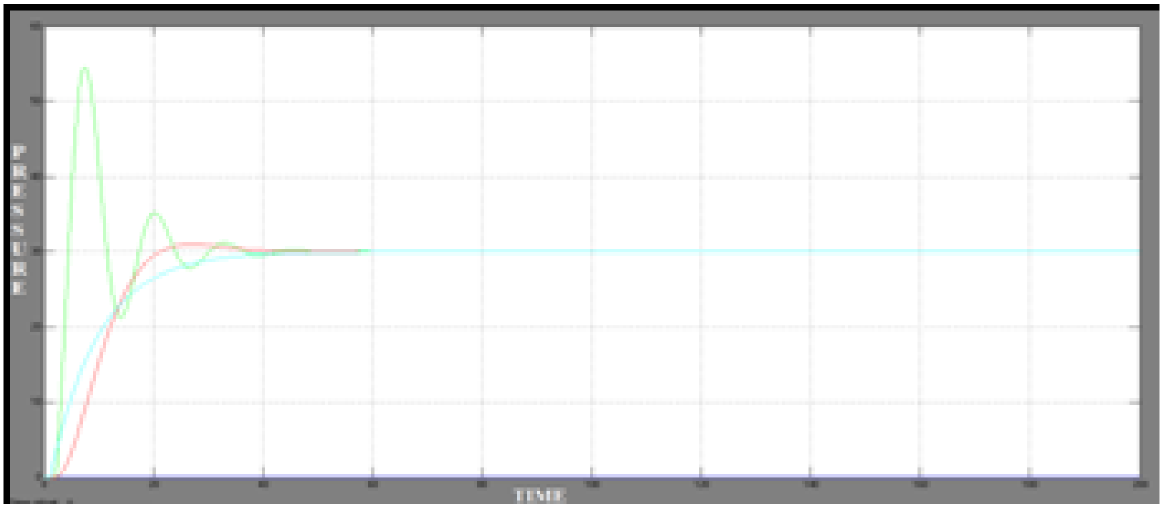


Figure.7.Comparison graph of first region

● PID ●IMC ● IMC based PID

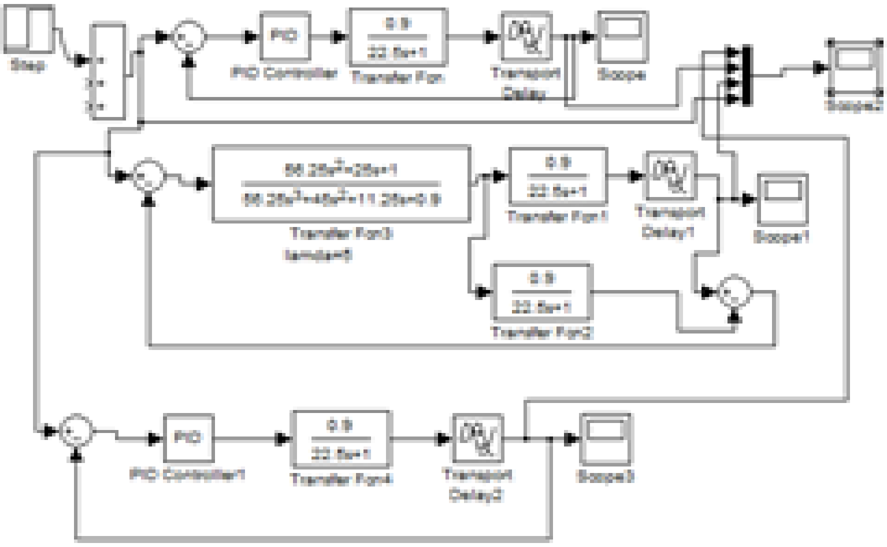


Figure.8.Block diagram of second order region

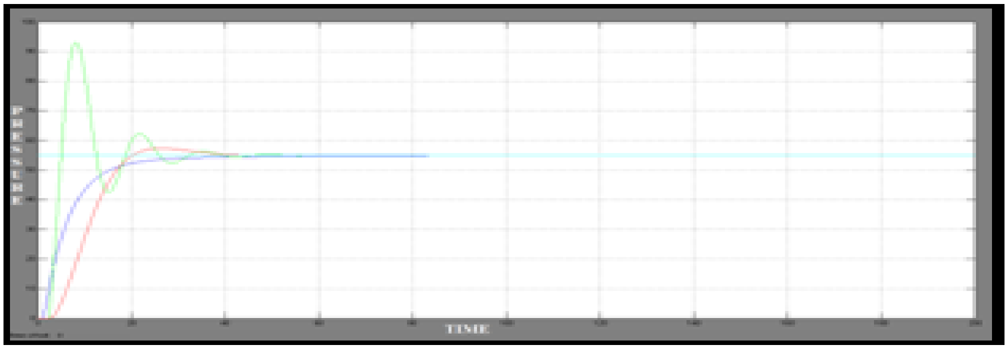


Figure.9.Comparison Graph of second region

● PID ● IMC ● IMC based PID

CONCLUSION AND FUTURE ENHANCEMENT

The main advantage of this IMC based PID controller is that it provides time delay compensation with very greater accuracy and moreover the controller can give offset free response even under steady state condition that is perfect control is achieved at steady state. The controller can be used to shape both input tracking and disturbance rejection responses. Some model inaccuracies could be easily overcome by an IMC based PID controller while this is not achieved in a conventional PID system. The result of simulation shows that IMC based PID is better. The future scope is to implement it in real time.

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