

Implementation of Temperature Process Control using Soft Computing Techniques

P.Poongodi¹, R.Madhusudhanan² and N.Prema³

Abstract — Objective of this paper is to design various controllers for a temperature process control. PID controller is the well known and most widely used in the industries. Internal Model Control (IMC) has become the leading form of advanced control in the process industry. Modified form of IMC-PID and Fuzzy PID Controllers are designed for First Order Plus Dead Time (FOPDT) process model. The comparative performance analysis has been done for PID, IMC, IMC-PID, and Fuzzy-PID controllers. The proposed Fuzzy-PID controller shows better performance than the other.

Index Terms— PID, IMC, IMC-PID, Fuzzy-PID

I. INTRODUCTION

Proportional Integral Derivative controller is one of the earlier control algorithm and strategies. The PID controller was first introduced in 1940 and has most widely used in the industries. The PID controller used for industries application are used to control the variables like fluid flow, pressure, level, temperature, consistency, density. The controller maintains the process output level so that difference between the process variable and the set point is minimal. The real time temperature control system design for PID controller using Zeigler Nichols method, Cohen Coon method and Wange method are detailed [2]. The intelligent fuzzy PID controller for temperature is implemented [7] for different operating range. The temperature process is highly nonlinear and design of robust controllers for such nonlinear systems is a challenge. This paper proposes a novel intelligent method for the control of temperature process. The traditional PI controllers which are in practice produce high overshoot and the design procedure seems complex. The proposed intelligent controller offers better performance in terms of overshoot and settling time and thus increases the robustness of the system. Section II provides the description of temperature process system and its modeling. Section III provides the control strategies applied. Section IV provides the results and discussion.

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P. Poongodi is associated as Senior Professor in Department of Electronics and Communication Engineering, Karpagam College of Engineering, Coimbatore-641 032, Tamilnadu, India. (e-mail: poongodiravikumar@gmail.com).

R.Madhusudhanan is associated as Research Scholar in Department of Electronics and Communication Engineering, Karpagam College of Engineering, Coimbatore-641 032, Tamilnadu, India. (phone: +91 0422 2619047; Mobile: +91 09486185533; fax: +91 0422 261046; e-mail: c_r_madhusudhanan@yahoo.co.in).

N.Prema is associated as Post Graduate scholar in Department of Electronics and Communication Engineering, Karpagam College of Engineering, Coimbatore-641 032, Tamilnadu, India. (e-mail: premanpr@gmail.com).

II. SYSTEM DESCRIPTION

A. Temperature Process System

Temperature process system typically contains a controller unit, temperature input unit and controller output unit. The temperature sensor forms the measuring unit. The Solid State Relay drive is driven by the controller output unit. The aim of the project is to control the temperature within a desired limit. The temperature controller can be used to control the temperature of any system. The temperature process is a non linear system. The process system contains a first order transfer function with a time constant [6]. The block diagram for temperature process is shown in Fig. 1.

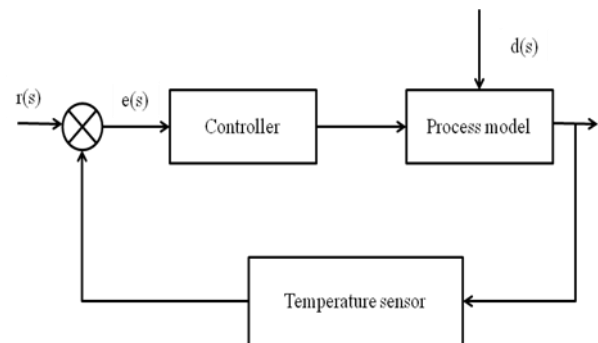


Fig. 1. Block diagram of temperature process control

B. System Modeling

The most commonly industrial process can be modeled by first order plus dead time models. The system modeling can be done in two ways one is the mathematical modeling and another one is the empirical modeling. Temperature process was modeled using the empirical modeling. The process model of the transfer function is obtained from the step response. The FOPDT parameters that are to be determined are the process gain (K), delay time (t_d), time constant (τ) units of minutes or seconds [4]. The First order plus time delay process equation is given by,

$$G_p(s) = \frac{K}{\tau s + 1} e^{-t_d s}$$

Where, K = Process gain, t_d = Delay time, τ = Time constant. The temperature process of the transfer function is experimentally obtained as,

$$G_p(s) = \frac{7}{12s + 1} e^{-1s}$$

III. CONTROLLER STRATEGIES

The control strategies used for temperature control are PID Control, Internal Modal Control, IMC-PID Control, and

Fuzzy PID control. The control using Genetic algorithm is detailed in [5] for temperature process.

A. PID Controller

The PID Controller has Proportional, Integral and Derivative actions inbuilt [12].

- Proportional Action

The output is proportional to the error at the instant time 't'. It is reducing the rise time of process.

$$P = K_p e(t)$$

- Integral Action

The output is proportional to the integral error at the instant time 't'; it can be interpreted at the accumulation of the past error. The controller removes the steady state error but maintain the transient response.

$$I = K_i \int_0^t e(t) dt$$

- Derivative Action

The output is proportional to the derivative error at the instant time 't'; it can be interpreted at the prediction of the future error. The controller affects the system by increasing stability and by reducing overshoot, improving the transient response.

$$D = K_d \frac{de(t)}{dt}$$

The transfer function of the PID controller,

$$G(s) = \left(K_p + \frac{K_i}{s} + K_d s \right) \quad (1)$$

K_p = Proportional gain, K_i = Integral gain, K_d = Derivative gain

The parameters, K_p , K_i , and K_d values are obtained using Cohen and Coon tuning method as 0.17, 0.085 and 0.0213 respectively.

B. IMC Controller

The internal model control (IMC) algorithm is widely used in dead time process industries. IMC controller implementations are becoming more popular than the standard industrial controllers remain the proportional plus integral and derivative (PID) controllers. In the Fig. 2 if the controller transfer function $G_c(s)$ is the inverse of process transfer function $G_p(s)$, set point tracking could be achieved. i.e., $G_c(s) = G_{p1}(s)^{-1}$ if $G_p(s) = G_{p1}(s)$. Where $G_{p1}(s)$ is process model.



Fig 2. Open loop control Strategy

Internal model control philosophy relies on the principle of the internal model principle which states that the control, can be achieved only if the control system encapsulates the representation of process to be controlled. The system often affected by unknown disturbance. The controller has been developed based on the perfect model, so it can be named as internal model controller as detailed in [8]. The model mismatch is common in real time

implementation. The general block diagram is shown in Fig. 3.

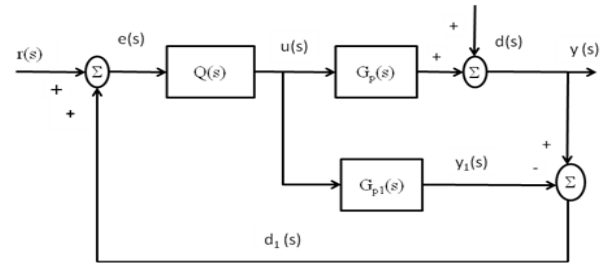


Fig. 3. Block diagram of IMC controller

where, $d(s)$ is disturbance, $d_1(s)$ is estimated disturbance, $Q(s)$ is Internal Model Controller, $r(s)$ is set point, $e(s)$ is error to modify the set point, $u(s)$ is the manipulated input which is introduced to both the real process and its model. $y(s)$ is the measured process output. $d(s)$ is the unknown disturbance at process output. $y_1(s)$ is process model output. $d_1(s)$ is the calculated new disturbance

$$d_1(s) = \{G_p(s) - G_{p1}(s)\}u(s) + d(s) \quad (2)$$

$$e(s) = r(s) - d_1(s) \quad (3)$$

Assume $d(s)$ is zero and if $G_{p1}(s) = G_p(s)$

$$u(s) = \{r(s) - d_1(s)\}G_c(s) \quad (4)$$

$$\text{Since } y(s) = G_p(s)u(s) + d(s) \quad (5)$$

Substituting $d_1(s)$ and rearranging the above equation

$$u(s) = \frac{\{r(s) - d(s)\}G_c(s)}{1 + \{G_p(s) - G_{p1}(s)\}G_c(s)} \quad (6)$$

The closed loop transfer function of IMC Structure after substitution and rearranging

$$y(s) = \frac{G_c(s)G_p(s)r(s) + \{1 - G_c(s)G_{p1}(s)\}}{1 + \{G_p(s) - G_{p1}(s)\}G_c(s)} \quad (7)$$

From this closed loop expression, we can see that if $G_c(s) = G_{p1}(s)$ and if $G_p(s) = G_{p1}(s)$, then perfect set point tracking and disturbance rejection is achieved. Notice that, theoretically even if $G_p(s) \neq G_{p1}(s)$

To improve robustness, the effects of process model mismatch should be minimized. Since discrepancies between process and model behavior usually occur at high frequency end of systems frequency response, a low pass filter $G_f(s)$ is usually added to attenuate the effect of process model mismatch. Thus internal model controller is usually designed as the inverse of process model in series with a low pass filter.

$$G_{imc}(s) = G_c(s)G_f(s) \quad (8)$$

$$\text{Where } G_f(s) = \frac{1}{(\lambda s + 1)^n} \quad (9)$$

Where λ is filter parameter and n is the order of the filter.

$$y(s) = \frac{G_{imc}(s)G_p(s)r(s) + \{1 - G_{imc}(s)G_{p1}(s)\}d(s)}{1 + \{G_p(s) - G_{p1}(s)\}G_{imc}(s)} \quad (10)$$

An internal model controller $Q(s)$ is found by dividing process model, $G_{p1}(s)$ is divided into two parts,

$$G_{p1}(s) = G_m(s)G_n(s) \quad (11)$$

Where $G_m(s)$ and $G_n(s)$ is invertible and non-invertible components. The non-invertible component $G_n(s)$ contain term which if inverted, will lead to instability and reliability problems ie., terms containing positive zeros and time delays.

Next set $G_c(s) = G_m(s)^{-1}$ and $G_{imc}(s) = G_c(s)G_f(s)$

C. IMC-PID Controller

The IMC philosophy can also be used to generate settings for conventional PI or PID Controllers. It provides time delay compensation. The filter can be used to shape both set point tracking and disturbance rejection. For stable processes with a time delay the IMC-based PID procedure will not give exactly the same performance as IMC, because a Pade's approximation for dead time is used in the controller design. IMC based PID controller [10] is achieved by the rearrangement IMC controller block diagram to form a standard feedback control loop as shown in Fig 4.

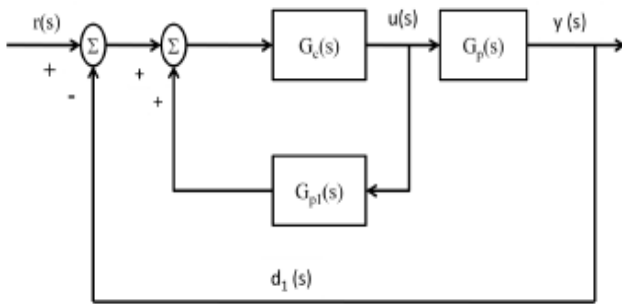


Fig. 4 Modification block diagram of IMC

The above block diagram is reduced IMC PID Controller as shown in Fig 5.

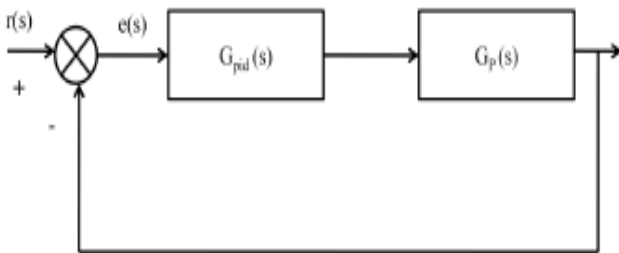


Fig. 5. Block diagram of IMC-PID controller

$$G_{pid}(s) = \frac{G_{imc}(s)}{1 + \{G_{imc}(s) - G_{p1}(s)\}} = \frac{G_m(s)^{-1}G_f(s)}{1 - \{G_n(s) - G_f(s)\}} \quad (12)$$

The common process transfer function is equal to PID-type feedback controller in IMC law. It is an advanced controller. The filter structure for IMC PID is given in [1].

$$G_{p1}(s) = \frac{K}{\tau s + 1} e^{-t_d s} \quad (13)$$

The time delay can be approximated using exponential series of order up to one.

$$\text{ie., } e^{-t_d s} \approx 1 - t_d s \quad (14)$$

Therefore

$$G_p(s) = \left\{ \frac{K}{\tau s + 1} \right\} \{1 - t_d s\} \quad (15)$$

With

$$G_m(s) = \frac{K}{\tau s + 1} \text{ and } G_n(s) = 1 - t_d s$$

$$G_{pid}(s) = \left\{ \frac{\tau s + 1}{K} \right\} \left\{ \frac{1}{\lambda s + 1} \right\} \left\{ 1 - \frac{1 - t_d s}{\tau s + 1} \right\} = \frac{\tau s + 1}{K(\lambda + t_d)s} \quad (16)$$

Rearranging the above

$$G_{pid}(s) = \left\{ \frac{\tau}{K(\lambda + t_d)} \right\} \left\{ 1 + \frac{1}{\tau s} \right\} \quad (17)$$

Comparing this with ideal PID controller,

$$K_C \left\{ 1 + \frac{1}{T_i s} + T_d s \right\} \quad (18)$$

we find the corresponding proportional gain and integral time as

$$K_C = \frac{\tau}{K(\lambda + t_d)} \text{ and } T_i = \tau$$

We can also replace the time delay with its pade approximation,

$$e^{-t_d s} \approx \frac{1 - \frac{t_d}{2} s}{1 + \frac{t_d}{2} s} \quad (19)$$

$$G_{p1}(s) = \left\{ \frac{K}{\tau s + 1} \right\} \left\{ \frac{1 - \frac{t_d}{2} s}{1 + \frac{t_d}{2} s} \right\} \quad (20)$$

With

$$G_m(s) = \left\{ \frac{K}{\{\tau s + 1\} \left\{ 1 + \frac{t_d}{2} s \right\}} \right\} \quad (21)$$

$$G_n(s) = 1 - \frac{t_d}{2}s \quad (22)$$

Substituting the above in $G_{pid}(s)$ and rearranging we get

$$G_{pid}(s) = \left\{ \frac{\{1 + \tau s\} \{1 + \frac{t_d}{2}s\}}{K(\lambda + \frac{t_d}{2})s} \right\} \quad (23)$$

Comparing the above with ideal PID controller, The corresponding proportional gain and integral time and derivative time as

$$K_c = \frac{\tau + \frac{t_d}{2}}{K(\lambda + \frac{t_d}{2})} \quad (24)$$

$$T_i = \frac{t_d}{2} + \tau \quad (25)$$

$$T_d = \frac{\tau t_d}{2\{\frac{t_d}{2} + \tau\}} \quad (26)$$

D. Fuzzy-PID Controller

The design of fuzzy controller generally comprises of three steps: Fuzzification, applying the fuzzy rules, and defuzzification. Fuzzification aims to convert a single (crisp) input value into corresponding fuzzy-set values. Applying the fuzzy rules entails processing the “fuzzy” information. The third step, defuzzification, converts the internal fuzzy results back to a crisp output value. In Fuzzy PID controller the three parameters of PID controller (i.e.) K_p , K_i , K_d are tuned using Fuzzy logic. The conventional PID controller coefficients are not proper for the nonlinear with unpredictable parameters variation. The design of fuzzy PID controller is detailed [13]. The design of PD and PID controllers using fuzzy in industrial application is given in [9]. The membership functions associated to the control variables have been chosen with triangular shapes. Universe of discourse is divided into five overlapping fuzzy sets: NB (Negative Big), NM (Negative Medium), ZE (Zero), PM (Positive Medium), and PB (Positive Big) [11]. The block diagram for Fuzzy Logic Controller (FLC) is shown in Fig. 6.

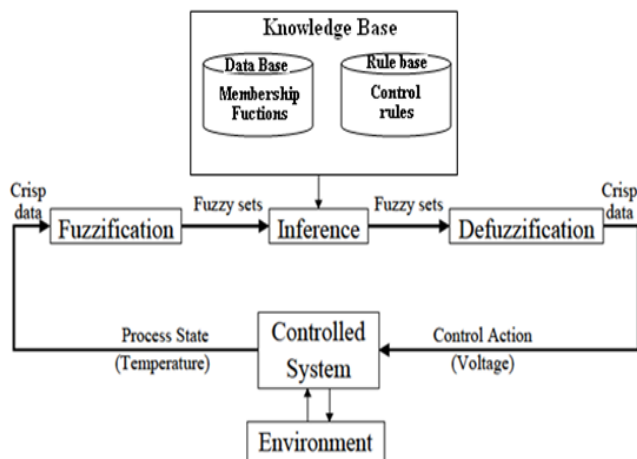


Fig. 6. Block diagram of fuzzy logic controller

In the fuzzy membership function editor, the number of membership function and type of membership function is chosen as triangular. The Fig.7 shows the Fuzzy PID controller implementation

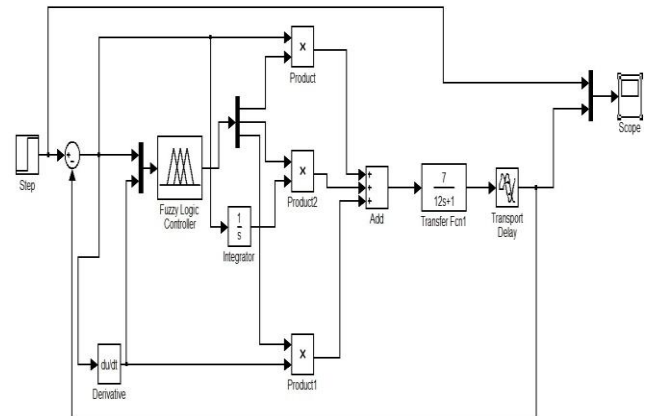


Fig. 7. Fuzzy PID Controller using MATLAB/ simulink

The implementation of Fuzzy PID Controller is done by using a FLC simulink block. The FLC block has a parameter to be Fuzzy Inference System (FIS) file or a structure. In the FIS editor the input to the controller i.e., error and change in error is defined. The output of the controller i.e., the K_p , K_i , K_d gains are defined. The error and change in error are chosen between (-5 5) and (-1 1) respectively. The input crisp values are converted to fuzzy values by fuzzification process. The linguistic variables for the inputs are defined as Negative Big(NB), Negative Medium (NM), Zero(Z), Positive Medium(PM), Positive Big (PB). Similarly, for output the K_p , K_i and K_d range are (-1 100), (3 15) and (0.1 0.9). The gains and the inputs are converted to fuzzy values by the triangular membership function with values between (0 1). The linguistic variables for the outputs are also defined as NB, NM, Z, PM, PB. Based on the linguistic variables the input and output rules are formed. Around 25 rules are formed. The simulation is carried using MATLAB with Fuzzy Logic Tool Box [3].

IV. RESULT AND DISCUSSION

First Order plus Dead Time model is taken for a temperature process. The controller design is carried out for Conventional PID, IMC, IMC-PID and Fuzzy PID controllers. The implementation of IMC and IMC-PID are done by writing coding in MATLAB M-File. The MATLAB Simulink block diagram method is used for implementation of conventional PID and Fuzzy PID controllers. Conventional PID controller has high settling time and rise time of 47.8 and 5.01 respectively with 1.5% overshoot. The settling time and rise time of IMC controller is 30sec and 17.6sec respectively with a small overshoot of 1%. But in IMC-PID the settling time and rise time is 1.47sec and 0.9sec respectively with no overshoot. In Fig. 8 the step response of conventional PID (T_1), IMC (G_{imc}), IMC-PID (T_2), is shown

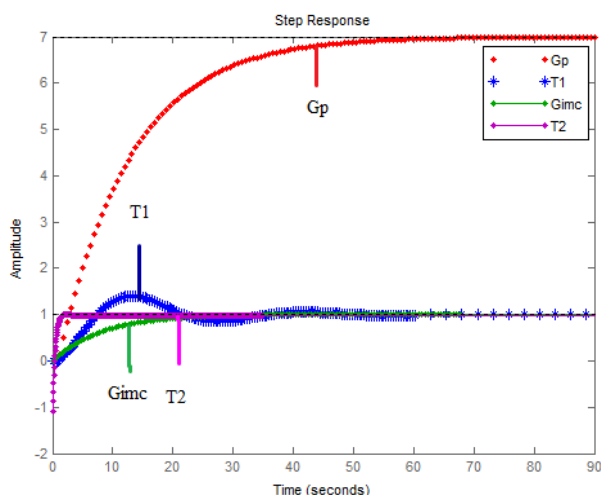


Fig. 8. Comparative response of various controllers

A reference unit step input at time =0 is given as the input to the Fuzzy PID controller has the least settling time and rise time of 0.1sec and 0.05 sec. The step response of Fuzzy PID is shown in Fig. 9.

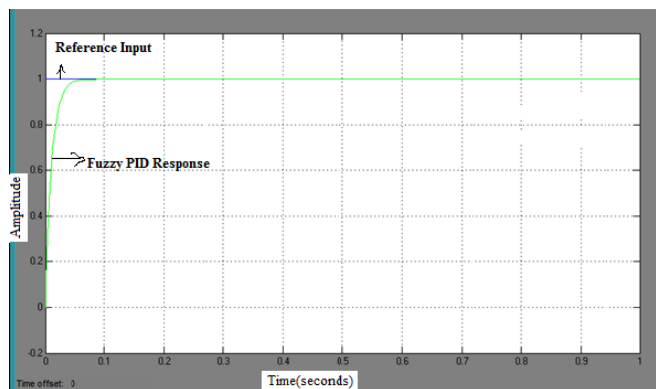


Fig. 9. Step response of Fuzzy- PID controller

The Table 1 shows the summarized performance indices of conventional PID, IMC, IMC-PID, and Fuzzy PID Controllers

TABLE I
 Performance indices of various controllers

Controller Type	Settling Time Sec	Rise Time Sec	Over shoot %
Conventional PID	47.8	5.01	1.5
IMC	30	17.6	1
IMC-PID	1.47	0.9	0
Fuzzy-PID	0.1	0.05	0

The proposed fuzzy PID controller response has the least settling time and rise time of 0.1sec and 0.05 sec respectively with no overshoot.

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