Tuning of PID Controller for Different Order Process using Intelligent Control Algorithm

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ABSTRACT
Proportional-Integral-Derivative (PID) control propose the simplest and yet the most efficient solution to many real-world control. The PID controller design problem is formulated by minimizing the error and adjusting the controller outputs.. It calculates an error as the difference between process variable and set point. It has three control parameters like (k_p, τ_i, τ_d). The main objective this paper is used to determine the controller parameters for different order process using conventional and intelligent control tuning algorithm. The controller performance seems to be better for both set point tracking (servo problem) and load regulation (regulator problem). The performance is analysed by using the parameters such as rise time, settling time, overshoot, and maximum peak sensitivity.

Keywords
SIMC, Half Rule, Fuzzy PID, Integral Square Error (ISE)

1. INTRODUCTION
The ability of proportional-integral (PI) and proportional-integral-derivative (PID) controllers to meet most of the control objectives has led to their widespread acceptance in the control industry. Let us consider the single input single output (SISO) system. [7]

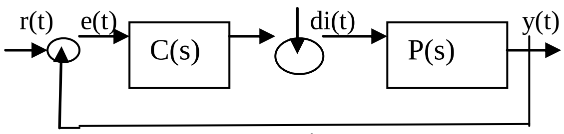

Fig.1

Where C and P represent the controller and plant, and r(t), e(t), di(t) and y(t) denote the reference input, error, load disturbance, and an output signals respectively. The objective of this paper is to derive controller tunings based on closed loop experiments. The ideal PI and PID control structures are,[1]

$$c_s = K_c\left(1+\frac{1}{\tau_1 s}\right) \quad (1)$$

$$C_s = K_c\left(1+\frac{1}{\tau_i s}+\tau_D s\right) \quad (2)$$

Where τ_i – Integral time, τ_d - Derivative time, k_c - controller gain. The basic Ziegler-Nichols is not applicable for wide range of process.

2. SIMC (SKOGESTED INTERNAL MODEL CONTROL) TUNING
The SIMC (Skogested Internal Model Control) is applicable for wide range of process.(26) In this method the original plant approximated into first and second order time delay process in the form

$$g_s = \frac{k}{(\tau_1 s+1)(\tau_2 s+1)} e^{-\theta \cdot s} \quad (3)$$

k - Plant gain, θ - time delay

τ_1 -time constant 1 & τ_2 - time constant 2

The tuning rules presented in this paper have several objectives. They are, [6]

1. The tuning rules should be well motivated, and preferably model-based and analytically derived.
2. They should be simple and easy to memorise.
3. They should work well on a wide range of process.

2.1 Half Rule Method
The two major approximation methods are used frequently they

1. Taylor Approximation
2. Half Rule Method

In this paper Half rule method is used because the time delay will be less to compare other method. The largest neglected time constant (lag) is dispersed evenly to the efficient delay and the smallest reserved time constant. [5]

Example:

$$g(s) = \frac{1}{(s+1)(0.2s+1)}$$

$$k = 1, \theta = 0.1, \tau_1 = 1.1$$

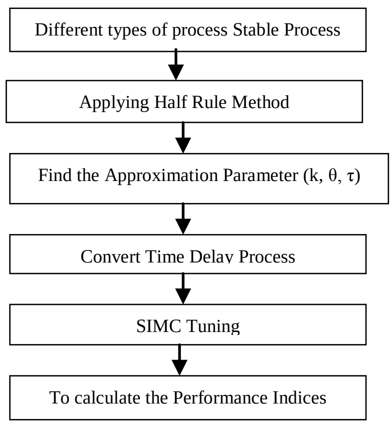

Fig.2. Flow Diagram of SIMC Tuning Method

2.2 Determination of PID Controller Parameters using SIMC

The SIMC rules may be derived using the method of direct synthesis for set-points or equivalently the Internal Model Control approach for set points. For the system in fig 1.1the closed-loop setpoint response is

$$\frac{y}{y_s} = \frac{g(s)c(s)}{g(s)c(s)+1} \qquad (4)$$

$$c(s) = \frac{1}{g(s)} \frac{1}{\frac{1}{\left(y/y_s\right)desired} - 1} \qquad (5)$$

Consider the second order time delay model g(s).

$$\left(y/y_s\right)desired = \frac{1}{\tau_{c+1}} e^{-\theta \cdot s}$$

The delay θ is kept in the desired response because it is unavoidable. Substituting

$$c(s) = \frac{(\tau_1 s+1)(\tau_2 s+1)}{k} \frac{1}{\left(\tau_c s+1-e^{-\theta \cdot s}\right)} \qquad (6)$$

τ_c -Tuning parameter for the controller

Introduce a first order Taylor series approximation of the delay, $e^{-\theta \cdot s} \approx 1-\theta \cdot s$

$$c(s) = \frac{(\tau_1 s+1)(\tau_2 s+1)}{k} \frac{1}{(\tau_c+\theta)s} \qquad (7)$$

Which is a ideal form PID controller

$$k_c = \frac{1}{k}\frac{\tau_1}{\left(\tau_{c+\theta}\right)} = \frac{1}{k'}\frac{1}{\left(\tau_c+\theta\right)} \qquad (8)$$

$$\tau_1 = \tau_1 ; \tau_D = \tau_2 \qquad (9)$$

For good trade-off between disturbance response and robustness is obtained by selecting the internal time like,

$$\tau_1 = 4(\tau_c + \theta) \qquad (10)$$

3. INTRODUCTION ABOUT FUZZY LOGIC PID CONTROLLER

Fuzzy logic is logic have many values. Diverse the binary logic system, hear the thinking is not crusty, rather it is approximate and having a ambiguous boundary. The variables in the fuzzy logic system may have any value in between 0 and 1 and hence this type of logic system is able to address the values of the variables which lie between complete truths and completely false. The variables are called grammatical variables and each grammatical variable is described by a membership function which has a certain degree of membership at a particular instance. A System based on fuzzy logic carries out the process of bureaucratic by incorporation of human knowledge into the system. Fuzzy inference system is the dominant unit of a fuzzy logic system. The managerial is an important part of the full system. The fuzzy inference system formulates suitable rules and based on these rules the decisions are made. This whole process of managerial is mainly the combination of the concepts of fuzzy set theory, fuzzy IFTHEN rules and fuzzy reasoning. The fuzzy inference system makes use of the IF-THEN statements and with the help of connectors present (such as OR and AND), necessary decision rules are constructed

3.1 General Structure of Fuzzy PID Controller

The fuzzy sets are basically used as inputs for the fuzzy interference system. The inputs are always crusty due to the process.

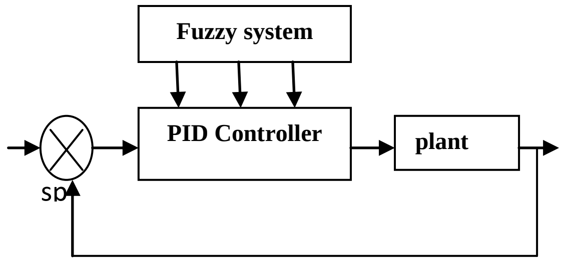

Fig.3. Fuzzy PID Controller

The fuzzy inference system in Fig. 2 can be called as a pure fuzzy system due to the fact that it takes fuzzy sets as input and develop output that are fuzzy sets.The rules are framed with respect to the process and it will be stored in the fuzzy rule base which is the knowledge base of the fuzzy system. The decision making can be done by the Fuzzy inference system to produce a required output. In most of the practical applications where the system is used as a controller, it is crave to have crisp values of the output fairly than fuzzy set values. Therefore a design of defuzzification is needed in such case which converts the fuzzy values into comparable crisp values [2]. In general there are three main types of fuzzy inference systems such as Mamdani model, Sugeno model and Tsukamoto model. Mamdani model is the most popular one. There are also various defuzzification techniques such as the Mean of maximum method, Centroid of area method, Bisector of area method etc. In this work Mamdani fuzzification technique [1] is used. There are two types of Mamdani fuzzy inference system such as, "min and max" and "product and max". In our example, the "min and max" Mamdani system is used. For this type of system, min and max operators are used for AND and OR approach respectively

In this paper, a different approach based on the fuzzification of the set-point weighting and load disturbance rejection is presented. The idea of multiplying the set-point value for the proportional action by a constant parameter less than one is active in compressing the overshoot but has the defect of increasing the rise time. To achieve both the aims of reducing the overshoot and decreasing the rise time, a fuzzy module can be used to modify the weight depending on the current output error and its time derivative. The major drawback to this design method is that it is ambitious to write rules for the integral action [7]. The integral term may become very large and it will then take a long time to wind it down when the error changes sign. Large overshoots may be the consequence.

3.2 Design of fuzzy PID controller

- The fuzzy PID controller, which takes error "e" and rate of change-in-error "ec" as the input to the controller makes use of the fuzzy control rules to modify PID parameters on-line.

- The fuzzy PID controller refers to find the fuzzy correlation between the parameters of PID such as K_p, K_i, and K_d. According to the principle of fuzzy control, modifying the those parameters in order to congregate different requirements for control parameters, when "e" and "ec" are dissimilar and making the control object to generate a better dynamic and static performance.
- Seven fuzzy values (NB, NM, NS, ZO, PS, PM, PB) are chosen by selecting the linguistic variables of parameters “e”, “ec”, K_p, K_i, and K_d.
- The region of these variables, in this case, is taken to be {-3,-2,-1, 0, 1, 2, 3}. Here (NB, NM, NS, ZO, PS, PM, PB) is the set of linguistic values which respectively represent “negative big”, ”negative medium”, ”negative small”, ”zero”, ”positive small”, ”positive medium” and “positive big”. The following figure is the block diagram of a fuzzy tuning PID controller.
- As it can be seen from the block diagram, the fuzzification takes two inputs (e and ec) and gives three outputs (K_p, K_i, K_d).

4. SIMULATION RESULTS

Two groups of systems, with different values for the parameters, have been chosen in order to test the effectiveness of the methodology.

$$G_1(s) = \frac{1}{(s+1)(s+1)(s+1)}$$

$$G_2(s) = \frac{1}{(s+1)(0.2s+1)(0.004s+1)(0.008s+1)}$$

The unit step response for simulated with MATLAB software. The variations between the three tuning methods were analyzed in the two above process $G_1(s)$ and $G_2(s)$ for both Servo and Regulator problem. In both process the basic Z-N method has large overshoot, settling time and IAE also high for servo and regulator problem. The robustness indicator Maximum peak sensitivity is also high. Normally the Maximum peak sensitivity value range should be 1.2< x<1.7.

In Table 1 the time domain specifications and Robustness performance i.e. maximum peak sensitivity will be displayed for two different processes. In $G_1(s)$ the ZN method has large overshoot and robustness performance also very poor. The SIMC (Skogestad Internal Model Control) Rise time, settling time will be large compared to ZN method but it has less overshoot and good robustness. Finally the non-conventional method fuzzy gives better settling time, less overshoot and good robustness to the process. In $G_2(s)$ is a higher order process this process is approximated as a time delay process in SIMC tuning method using half rule method. It gives better result to compare ZN method for all time domain specifications as mentioned below in table 1 and robustness specification.

In Table 2 error performance should be analyzed for both servo problem and regulator problem. The first process $G_1(s)$ ZN method error value is low to compare the SIMC method but fuzzy gives lowest error values to compare the two conventional tuning methods but the second process $G_2(s)$ SIMC and fuzzy gives lowest error compared with a ZN method. The simulation results are shown in Figure (4-7)

Table1: Time Domain Specifications for $G_1(s)$ and $G_2(s)$

Process	Tuning Methods	Rise Time	Settling Time	Over shoot	Maximum Peak Sensitivity
$G_1(s)$	ZN	0.889	9.439	40.14	2.11
	SIMC	4.096	18.64	15.51	1.31
	FUZZY	2.331	9.14	0.83	1.39
$G_2(s)$	ZN	0.118	1.651	55.89	2.359
	SIMC	0.079	0.401	11.311	1.519
	FUZZY	0.250	0.441	0.2928	1.2

Table 2 Error Performance for $G_1(s)$ and $G_2(s)$

Process	Tuning Methods	ISE (Integral Square Error)	
		Servo problem	Load rejection
$G_1(s)$	ZN	1.57	0.563
	SIMC	2.41	0.9472
	FUZZY	1.51	0.0513
$G_2(s)$	ZN	0.23	0.0086
	SIMC	0.17	0.0015
	FUZZY	0.15	0.0008

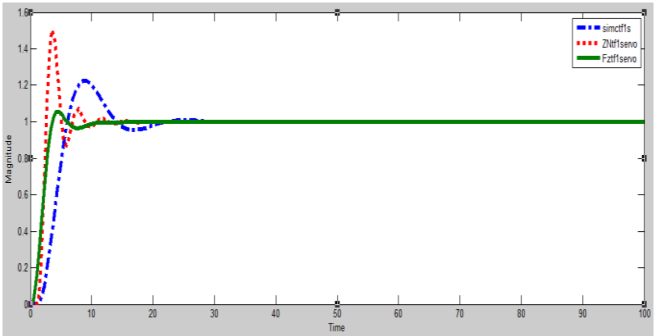

Fig.4. $G_1(s)$ Servo problem

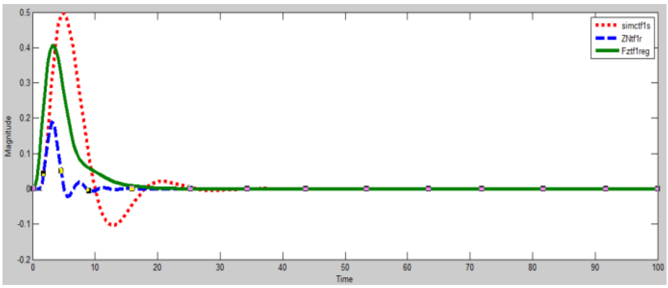

Fig.5. G1(s) Regulator problem

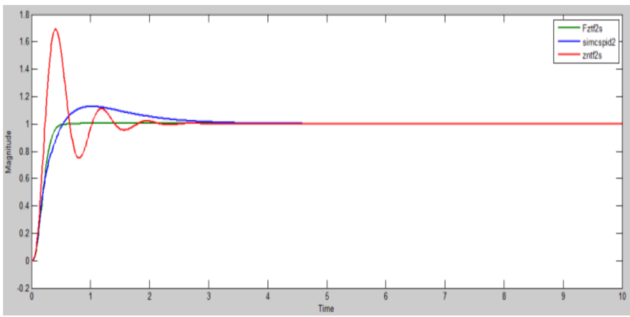

Fig.6. G2(s) Servo problem

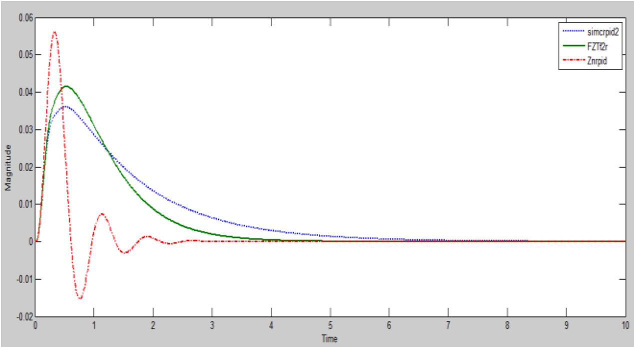

Fig.7. G2(s) Regulator Problem

5. CONCLUSION

In this paper Conventional and Non- Conventional PID tuning methods are performed. The PID tuning involves ZN method, SIMC method and Fuzzy based PID tuning method, which is accomplished by set point tracking and load disturbance rejection problem using gain parameters (k_p, τ_i, τ_d). In these tuning processes, the ZN tuning method is convenient for a smooth process $G_1(s)$, whereas the higher order process $G_2(s)$ has erroneous time domain specifications and unreliable Error Performance, shown in Table.1 and Table.2. Another conventional Tuning SIMC method is applicable for a wide range of process like higher order process, time delay process and integrating process. In SIMC tuning, the process should be converted into a time delay process using half-rule method. Table.1 & Table.2 shows the results for Fuzzy PID tuning, which is more reliable when compared to the other tuning method. Time delay process and process without time delay has different ways to frame the rules for fuzzy based tuning. Processes $G_1(s)$ and $G_2(s)$has controlled Peak Overshoot, Settling time and smooth oscillation for Fuzzy PID tuning. As a conclusion, fuzzy based PID tuning provides better response for both the setpoint tracking and Load disturbance rejection. In future the non conventional fuzzy pid is compared with PSO, GA Tuning algorithm and also minimize the performance criteria.

6. REFERENCES

[1] S.Alcantra, R.Vilanova, C.Pedret (2013) "PID control in terms of robustness/performance and servo/regulator trade-offs: A unifying approach to balanced auto tuning". Journal of process control 23 527-542.

[2] Bonissone, P.P. et.al, "Industrial Applications of Fuzzy Logic at General Electric". Proceedings of the IEEE, March 1995, pp.450-465.

[3] Kiam Heong Ang, Gregory Chong, (2005) "PID Control System Analysis, Design and Technology" IEEE Transactions on Control Systems Technology, Vol. 13, No. 4.S.

[4] Alcantra.S, Pedret.C, Vilanova. R (2010), "On the model matching approach to PID design: Analytical perspective for robust Servo/Regulator tradeoff tuning", Journal of Process Control 20, 596-608.

[5] Alcantra.S, Zhang.W.D, Pedret.C, Vilanova.R, S.Skogested (2010), "IMC-like Analytical H-∞ design with S/SP mixed sensitivity consideration: Utility in PID tuning guidance", Journal of Process Control.

[6] Sigurd Skogestad, (2003) "Simple Analytic Rules for Model Reduction and PID Controller Tuning", Journal of Process Control 13, 291-309.

[7] Sigurd Skogestad, Ian Postlethwaite, (2000) "Multivariable Feedback Control Analysis and Design".

[8] Kealy T and O'Dwyer A.(2003) 'Analytical ISE calculation and optimum control system design' School of Electrical Engineering system Conference, pp. 418-423

[9] Sigurd Skogestad, (2003) 'Simple analytic rules for model reduction and PID controller tuning', Journal of Process Control 13 291-309.

[10] Richard H.Middleton, Stefan F.Graebe, (1999) 'Slow stable open-loop poles: to cancel or not to cancel', Automatica 35, 877-886.