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A Review on Tuning Methods for PID Controller

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Abstract— **PID controller tuning is important for having minimal overshoot in steady state response and lesser settling time. Apart from two conventional methods of tuning such as Ziegler Nichols closed loop oscillation and Cohen-Coon's process reaction curve method there are other methods such as fuzzy set-point weight (FSPW) tuning and genetic algorithm (GA) are drawing the interest of researchers. This reports a survey on works related to PID controller tuning methods using fuzzy-logic and GA. A comparison is made between conventional two methods and fuzzy-logic based tuning methods through simulation using MATLAB Simulink.**

Keywords— PID controller; Ziegler Nichol's (ZN) method; process reaction curve; FSPW; GA; Simulink.

I. INTRODUCTION

Feedback control systems have made their strong establishment in the field of industrial manufacturing, process control and robotics since the last three decades. Many robust and adaptive control mechanisms [1]-[3] have been proposed in recent past. Still the popularity of PID controller in feedback control system is unmatched. This control scheme can be used in proportional only (P-mode), proportional – integral (PI mode), proportional- derivative (PD) and proportional-integral-derivative (PID mode) as per the process requirement [4]. A number of works [5]-[7] reported for use of standard PID controller along with neuro-fuzzy controllers.

The area of controller tuning is an old and important domain of research. A significant amount of papers these days reports the use of fuzzy logic and more especially genetic algorithm (GA) in PID controller tuning. Therefore, a literature survey in this field becomes a necessary to proceed further for in depth research work.

The organization of the paper is such that section II gives a brief overview on PID control algorithm and two conventional PID controller tuning. Section III provides a literature survey on PID controller tuning using fuzzy logic and genetic algorithm (GA). Section IV makes a comparison between three types of controller tuning mechanism through MATLAB simulation. Finally section V concludes the paper.

II. BACKGROUND THEORY

A. PID controller basic

A PID (proportional- integral- derivative) controller has a control loop feedback mechanism. It continually calculates an error e(t) which is the difference between the process variable and set point and then applies a correction based on proportional, integral and derivative action. That means it automatically applies accurate and responsive correction to a control function. For example in cruise control of a motor where external influences such as increase of mechanical load would decrease the speed of motor, then a PID algorithm increases the speed of motor in an optimal way by minimizing the overshoot and by controlling input current or power of the motor.

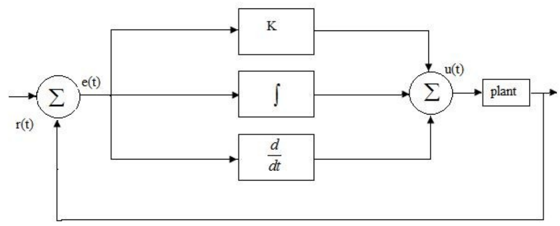

Fig 1 Block diagram of fundamental operation of PID Controller

The above block diagram depicts the fundamental operation of PID controller, here r(t) is the reference input signal and e(t) is the error signal. The control action is produced by proportional, differentiator and integrator operating in parallel on the error signal. The controller attempts to minimize the error over time by adjustment of control variable u(t).

The mathematical form of PID control action is given by

$$u(t) = K_P(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d \frac{de(t)}{dt}) \quad (1)$$

B. PID controller tuning

Selection of the value of P,I and D parameter is dependent on process, so the knowledge of plant dynamics is important for selection of parameters. It is quite difficult to obtain the mathematical model of the plant. So we have to find experimentally the optimum settings of controller in which it is possible experimentally find the optimum values of the controller parameter which is known as tuning. There are two widely used methods for controller tuning: 1. Ziegler Nichol's continuous cycle method [8] 2.Cohen Coon's process reaction curve method [9].

Ziegler Nichols closed loop oscillation method (Continuous Cyclic Method) – This method is used to tune the controller in closed loop mode. The control action is first set to proportional mode where then gain K_p is set to K_u (large possible value of K_p) for which closed oscillation are allowed to occur around the set-point. The time period of oscillation (T_u) is taken into account. The values for optimum K_p, T_i and T_d are shown in table I.

The method of Process reaction curve is an open loop method of tuning. Here a closed loop system is first broken and then a step input is given to the process. An overlap of output response and input is plotted in the graph as shown in Fig 2.

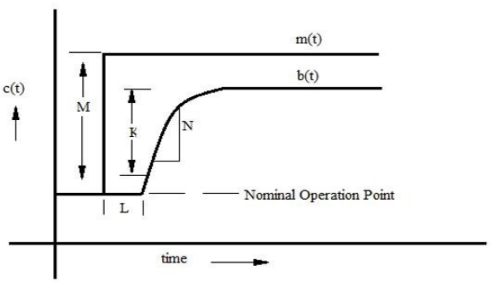

Fig 2. Process reactic

In Fig 2. M, L and K is measured; N=slope of the curve, Time constant (T) = k/N; Lag ratio=L/T. The optimum settings of PID are mentioned in table I.

TABLE I. OPTIMUM SETTINGS FOR PID CONTROLLER PARAMETERS

Controller settings	Ziegler Nichols closed loop oscillation method	Cohen-Coon's process reaction curve
K_p	$0.6K_u$	M/NL(4/3+R/4)
T_i	$T_u/2$	L(32/13+6R/20R)
T_d	$T_u/8$	L(4/11+2R)

III LITURATURE SURVEY

There has been several works reported for the PID controller tuning using Ziegler-Nichols method and the process reaction curve methods as discussed in the previous section. As the methodology says the first method is a kind of trial-and-error method so it is highly dependent on operator's skill. The second method i.e. method of PRC can sometimes be misleading as disturbances may cause misleading results.

Alternatively, in recent past two methods of tuning namely fuzzy set-point weight (FSPW) tuning and tuning using genetic algorithm has been reported in some literature. Genetic algorithm based tuning has been emerged as more competitive these days.

Fuzzy logic based tuning method is proposed by A. Visioli in [10]. As we know, fuzzy logic converts the user supplied human rules into their mathematical equivalents. The fuzzy logic contains number of if-then statement. In fuzzy logic, the truth of any statement is always a matter of degree. The system depends on a function, which is known as the membership function, which helps to calculate the correct value between 0 and 1. In other words, we can say that a membership function represents the degree of truth in the fuzzy logic. As proposed by Visioli, this method is referred to as fuzzy set-point weight tuning. The control law can be written as

$$K_p(b(t)\, y_{sp}(t) - y(t)) \quad (2)$$

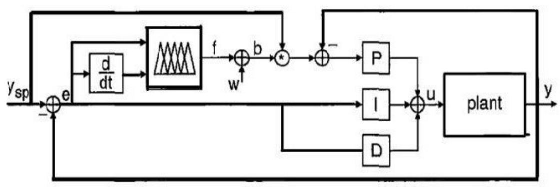

Fig 3. Fuzzy set-point weight tuning [10]

Where $b(t) = w + f(t)$

K_p, K_d, K_i, are the gains for the proportional, differential, integrator respectively. On the expression of b(t), w is a fixed positive parameter, whose value is in between 0 and 1. The function f(t) is the output of the fuzzy inference system. The fuzzy inference system for this case consist of five triangular membership functions for the two inputs (one is the error input, other one is the time derivative of the error input), and nine triangular membership function for the output.

G. Mallesham and A. Rajani described the way by which the optimum response of a system is obtained by fuzzy logic controllers by using fuzzy set point weighting method in [11]. Here, a comparison has also been made with the fuzzy set point controllers with the conventional methods and with the different shapes and numbers of designed membership function.

Genetic algorithm has extensively been used as a tuning methodology. The genetic algorithm is also used in fault analysis, stability analysis, robot path planning's etc. It is a global, parallel, search and optimization method. In this method, for a particular problem, a set of potential solution is made, that is known as the population. Every individual in these populations represents a potential solution. Every individual, those are the solution for a particular problem is assigned a value, which is known as the fitness value, and for every fitness value in the genetic algorithm domain, there corresponds a cost value in the problem domain. An explicit mapping is done between the two domains. There are operators present in genetic algorithm, which makes the reproductions of the individual in the population. Two main operators are single point crossover operator and the binary mutation operator.

M. J. Neath, A. K. Swain, U. K. Madawala and D. J. Thrimawithana described that in a normal traditional PID tuning method, there are many difficulties, and to overcome those, the paper proposes a derivative free optimization technique, which is based on genetic algorithm to determine the optimal parameters of PID controllers used in bidirectional inductive power transfer systems in [12]. B. Porter and A.H. Jones, described the technique of genetic algorithm as an alternative means for tuning of digital PID controllers in their work [13]. K. Valarmathi, D. Devaraj and T. Radhakrishnan [14] described the enhanced genetic algorithm used in tuning the PI controller for the pH control process to avoid premature convergence and to reduce computation time. Here a comparison is also made between the performances of the proposed genetic algorithm tuning method with the traditional Ziegler Nichols tuning. D. Devaraj and B. Selvabala described in [15], the real tuning of PID controllers in automatic voltage regulator system. Here, real coded genetic algorithm and sugeno fuzzy logic approach is used for obtaining the optimal gains of PID controllers. Here, blend crossover and uniform mutation operator is used for the real variables in the genetic population.

IV RESULTS AND DISCUSSION

Comparative analysis between Ziegler-Nichol's method, PRC method and FSPW method for PID controller tuning has been considered for the second order process mentioned below.

$$G(s) = \frac{1}{s^2 + 2s + 1}$$

The simulation has been performed using MATLAB Simulink. The Simulink model for FSPW tuning is shown in Fig. 4.

The comparative results of step response for three types of tuning methods are shown in the fig 5.

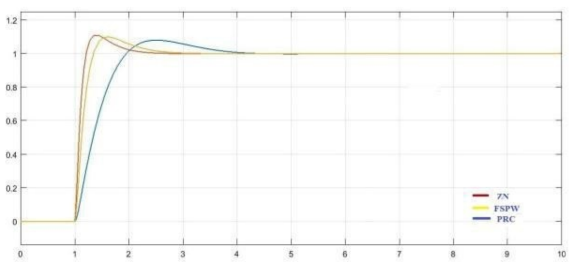

Fig 5. Step response of second order system

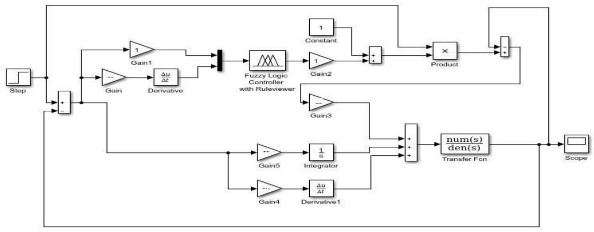

Fig 4. FSPW subsystem in Simulink

The performance of the second order system with three types of PID controller tuning method is depicted in table II.

TABLE II. PERFORMANCE ANALYSIS OF PID CONTROLLER

Factors	Continuous cycle method [9]	Process reaction curve [8]	Fuzzy logic [10]
rise time t_r	1.1	1.9	1.4
delay time t_d	1.13	1.47	1.27
peak Overshoot M_p (%)	10	7.5	9
ITAE	0.16	0.05	0.07
ITSE	0.02	0.00	0.00

V. CONCLUSION

Proper tuning of PID controller is found to be a necessary in any industry. With incorrect or no tuning a plant cannot run efficiently. There are several tuning methodologies which require significant knowledge about the process can sometimes be very challenging. Methods of ZN as in [8] and PRC [9] are not always efficient as the former is a kind of trial-and-error method and the later can give misleading results while the disturbance in a process in high. So, a demand of more efficient tuning methodology has forced the researchers to use methods of fuzzy logic based tuning as in [10] and methods of genetic algorithm. A comparison between ZN continuous cycle method, Cohen-Coon's PRC method and FSPW [10] method (with 7 membership function for both error and error rate) have been made. The comparison shows FSPW method has reduced overshoot than ZN method and least rise time but greater ITAE than PRC method.

The area of GA based tuning is not considered for simulation at present but it is a part of our literature and future works of GA based tuning can be associated with fuzzy logic based methods also.

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