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Tuning Techniques of PID controller: A Review

Avtar Singh*, Amrit Kaur**
*(Department of Electronics & Communication Engineering, Punjabi University, Patiala, Punjab-India
Email: avtar2030@gmail.com)
** (Department of Electronics & Communication Engineering, Punjabi University, Patiala, Punjab-India
Email: amrit_aks@yahoo.ca)

ABSTRACT
PID controller is widely used in industries and tuning of PID controller is an important parameter to obtain the optimal values. Different techniques are used for the tuning purpose of PID controller which can be categorized as conventional tuning techniques that are developed for PID tuning and metaheuristic optimization algorithms that are applied to the tuning of PID controller. The main aim of this paper is to provide an overview of tuning techniques of PID controller.
Keywords – conventional techniques, metaheuristic techniques, PID controller, Tuning.

I. INTRODUCTION

PID controller is widely used in industry to control the specific systems such as Automatic Voltage Regulator system and hydraulic system etc. PID controller has three parameters proportional k_p, integrative k_i and derivative k_d. These three parameters have their own importance in controlling purpose. The transfer function of PID is given as:

$$C(s)= K_p + \frac{K_i}{s} + k_d s = {k_d}/{k_p} \; K_p(1+\frac{1}{T_i s}+T_d s)$$

Where k_p =proportional Gain, k_i =Integral Gain, k_d =Derivative Gain, Ti=Reset Time= ${k_p}/{k_d}$, Td=Rate Time or derivative time= ${k_d}/{k_p}$.

The basic diagram of PID controller is shown in Fig.1,

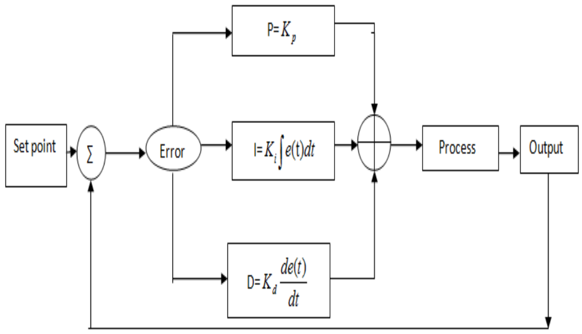

Figure 1: Block Diagram of PID Controller

where *Rise Time* is the time taken by a signal to change from a specified low level to a specified high level, S*ettling Time* is the time required for the response curve to reach and stay within a range of specified percentage of the final value and *Maximum overshoot* is the maximum peak value of the response that is measured corresponding to the desired value. The effect of increasing the parameter of PID controller is shown in table 1.

Table 1: Effect of Parameters

Parameter	Rise Time	Settling Time	Overshoot	Steady State error
k_p	Decrease	Small change	Increase	Decrease
k_i	Decrease	Increase	Increase	Eliminate
k_d	Minor change	Decrease	decrease	No effect

Tuning techniques are classified as:

1.1 Conventional Techniques

Conventional techniques are based on the assumptions about the plant and the desired output. The assumptions are drawn analytically or graphically which are then used for the setting of controller parameter. These conventional techniques are very fast. But because of assumptions made, the required results are not obtained and so additional tuning is required. A few conventional techniques are discussed in this paper.

1.2 Metaheuristic Optimization Techniques

In computer science and mathematical optimization, a metaheuristic is a higher level procedure that is designed to find and generate a sufficient good solution to optimization problems. These optimization techniques basically use the cost or objective function. The objective or cost function is a function of some variable of the optimization problem and so the main goal of the optimization technique is to minimize the cost or objective function by comparing it with their previous iteration result.

This paper is organized as: section 2 describes different types of conventional techniques, section 3 describes different types of metaheuristic optimization techniques and hence conclusion is drawn in section 4.

II. CONVENTIONAL TECHNIQUES

Some of the conventional techniques are discussed as follows:

2.1 Zeigler-Nichols Method

Zeigler-Nichols is a heuristic tuning rule used to obtain the optimal values of three parameters of PID controller and there exist two Zeigler-Nichols methods. In first method, if plant does not consists of integrator or dominant complex conjugate poles, then such a unit step response of curve may look like S-shaped curve as shown in fig.2. The S-shaped curve is characterized by two constants, delay L and time constant T. This method is used to tune PID controller for spindle motor system [1].

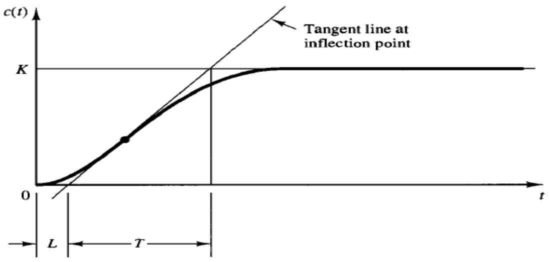

Figure 2: S-Shaped Response Curve

Table 2:Zeigler Nichols Tuning Rule First Method

Controller	k_p	k_i	k_d
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	$2L$	$0.5L$

In second method, proportional controller is used only, K_p increases from 0 to a captious value K_{cr} at which the output first shows the sustained oscillations. Thus the captious gain K_{cr} and corresponding period P_{cr} are experimentally determined and PID parameter setting is given in [1].

2.2 Cohen Coon Method

Cohen and Coon [2] design method for the tuning of PID controller parameters and decision is based on a FOLPD model. The main design requirement is the rejection of load disturbances. The controller parameter settings are given in [2]. Despite a better model, the results of the Cohen Coon method are not much better than the Ziegler Nichols method

III. METAHEURISTIC OPTIMIZATION TECHNIQUES

Some of the optimization algorithms are discussed as follows:

3.1 Particle Swarm Optimization

Particle swarm optimization (PSO) algorithm is one of the optimization techniques and is found to be robust in solving non-linear, non-differentiable problems.

The PSO is motivated from social behavior of bird flocking. It uses a number of particles which fly around in the search space to find best solution. By the meantime, they all look at the best particle (best solution) in their paths. In additional words, particles consider their own best solutions as well as the best solution has found so far that is birds follow the bird which is nearest to the food. Every particle in PSO should consider the current position, the current velocity, the distance to pbest, and the distance to gbest to modify its position. Mathematical equation of PSO algorithm is given as[3]:

$$v_i^{(t+1)} = w*v_i^t + c_1*rand*(\mathrm{pbest}_i - \mathrm{x}_i^t) + \mathrm{c}_2*rand*(\mathrm{gbest} - \mathrm{x}_i^t) \quad (1)$$

$$x_i^{(t+1)} = x_i^t + v_i^{(t+1)} \quad (2)$$

i=1,2,3….n
n=number of particles
t=pointer of iteration
w=inertia weight factor
w=wmx-((wmx-wmi)/maxIterations)*iterationCount;
c1,c2=acceleration constant.
rand=random number between 0 to 1;
x_i^t =current position of i^{th} particle.
v_i^t =velocity of particle i at iteration t.
$\mathrm{pbest}_i = \mathrm{pbest}_i$ of agent i at iteration t

The PSO starts randomly by placing the particles in problem space. In every iteration velocity of the particles calculated using equation (1) and then current position is updated using equation (2).T he process of updating position of the particles continue until the desired results are not obtained. PSO algorithm has been implemented for tuning of PID for Automatic Voltage regulator system [4]. Author gives the comparison of PSO-PID tuning with GA-PID tuning and it found that PSO-PID gives better result as compared to GA-PID.

3.2 Artificial Bee Colony Algorithm (ABC)

Artificial bee colony algorithm is an optimization technique in computer science and operation research and is based on the intelligent foraging behavior of honey bee swarm.

In Artificial Bee Colony (ABC) algorithm, colony consists of three categories of bees: employed bees, onlookers and scouts. First half of the colony consists of the employed bees and second half consists of onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive that is the relationship between the employed bees and food sources is one to one. The employed bee whose food source has been deserted by the bees becomes a scout. A possible solution to the optimization problem is given by the position of a food source and the nectar amount of a food source corresponds to the quality or fitness of the associated solution. The number of employed bees or the onlooker bees is equal to the number of solutions in the population. ABC algorithm is an iterative algorithm starts by associating each employed bee with randomly generated food source. In each iteration, each employed bee discovers a food source in its neighborhood and evaluates its nectar amount or fitness using equation (3), and is given as [5]:

$$v_{nj} = x_{nj} + \psi_{nj} * (x_{nj} + x_{mj})$$

(3) Where v_{nj} = new food source;

x_{nj} =food source;

ψ_{nj} =random number between -1 to +1;

x_{mj} =randomly selected food source;

If fitness of new food source is better than the fitness of the old fitness value then employed bee moves to the new source otherwise it retain the old one. After all employed bees complete the search process, they share the information about their food sources with onlooker bees. An onlooker bee evaluate the nectar information taken from all the employed bees and choose a food source with a probability p_n that is proportional to the fitness of the food sources as given by following equation (4)

$$p_n = \frac{fit_n}{\sum_{n=1}^{k} fit_n} \quad (4)$$

Where fit_n is the fitness value of the solution n which is proportional to the nectar amount of the food source in the position n and k is the number of food sources which is equal to the number of employed bees. The employed bees become scout bees when a food source which is exhausted by the employed and onlooker bees is assigned as deserted. In that position, scout generates randomly a new solution by equation (5):

$$x_n^j = x_{\min}^j + rand(0,1)(x_{\max}^j - x_{\min}^j) \quad (5)$$

j=1,2,3----D

ABC has been implemented for tuning of PID for speed control of DC motor [6]. Author compared the performance of DC motor with tuning of PID controller conventional tuning techniques and artificial bee colony algorithm and it is found artificial bee colony algorithm is best among the other tuning methods.

3.3 Genetic Algorithm

Genetic algorithm has been widely studied, experimented and applied in handling high dimensional and non-linear problems. Genetic algorithm is an optimization technique based on the mechanism of natural selection. GA starts with an initial population containing a number of chromosomes where each one represents a solution of the problem from which performance is evaluated by a fitness function.

Basically, GA consists of three main stages: selection, Crossover and Mutation. The application of these three basic operations allows creation of new individuals which may be better than their parents. This algorithm is repeated for many generations and finally stops when reaching individuals that represents the optimum solution to the problem. The flowchart of GA is shown in fig. 3 [7].

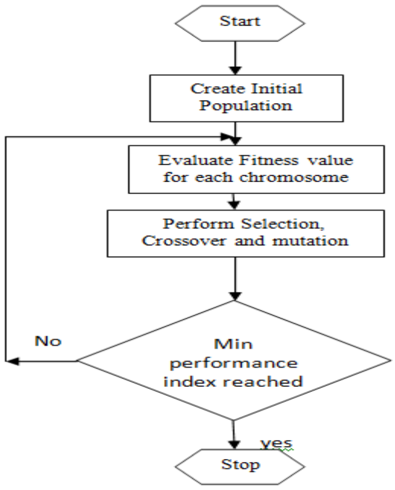

Figure 3: Flow Chart for Genetic Algorithm

Genetic algorithm has been implemented for tuning of PID controller for hybrid electric vehicle [8]. Author compared the performance of hybrid electric vehicle with tuning of PID controller conventional tuning technique such as Zeigler-Nichols method and Genetic Algorithm and it is found that genetic algorithm is best among other technique.

3.4 Firefly Algorithm

Firefly algorithm is an optimization technique inspired by the flashing behavior of fireflies. Firefly's flash is act as a signal to attract other fireflies.

According to the law of inverse square, light intensity decreases as the distance r increases as by a relation as $I \alpha \, 1/r^2$.

Some ideology for Firefly algorithm is given as [9]

a. All fireflies are unisex so that one firefly will attracted to other fireflies regardless of their sex.
b. Attractiveness is proportional to their brightness; thus for any two flashing fireflies, the less bright one will move toward the brighter one. The attractiveness is proportional to the brightness and they both decrease as their distance increases. If there is no brighter one than a particular firefly, it will move randomly.
c. The brightness of a firefly is affected or determined by objective function.

In this algorithm, each firefly has a location X in d-dimension space and light intensity I(x) or attractiveness β(x), which is proportional to the objective function f(x). The attractiveness β is given as in equation (6) [9];

$$\beta = \beta_0 \exp(-\gamma * r^2) \qquad (6)$$

Where r is the distance between the two fireflies i and j at x_i and x_i respectively, β_0 is attractiveness at r=0 and is the light absorption coefficient in the environment. The initial solution is generated as:

$$x_j = rand \times (\mathrm{ub} - \mathrm{lb}) + \mathrm{lb} \qquad (7)$$

Where ub and lb is upper and lower limits. Each firefly i can move toward another more attractive firefly j by

$$x_i^{t+1} = x_i^t + \beta \exp(-\gamma \, \mathrm{r}_{ij}^2) + \alpha_i (\mathrm{rand} - \frac{1}{2}) \qquad (8)$$

Where α is a significance factor of the randomize parameter and rand is random number between 0 to1.the distance between two fireflies i and j at x_i and x_j respectively is given as:

$$r_{i,j} = \left\| x_i - x_j \right\| = \sqrt{\sum_{k=1}^{d} (x_{\mathrm{i,k}} - x_{j,k})^2} \qquad (9)$$

Where $x_{\mathrm{i,k}}$ is the k^{th} component of the spatial coordinate x_i of the i^{th} firefly.

Firefly algorithm has been implemented for the tuning of PID controller [10]. Author compared the performance of PID controller conventional tuning technique such as Zeigler-Nichols method with Firefly algorithm and it is found that Firefly algorithm is best among other technique.

3.5 Fuzzy Logic

Fuzzy logic control is one of the interfaces between control engineering and artificial intelligence. The Fuzzy logic controller (FLC) adds to the conventional PID controller to adjust the parameters of the PID controller on-line according to the change of the signals error and change of the error. The design specifications of the FLC vary with the plant being used and the PID controller parameter ranges in combination with which it is to be used. The basic building block of the controller remains similar. Fig.4 shows the commonly used Fuzzy Logic Control [11].

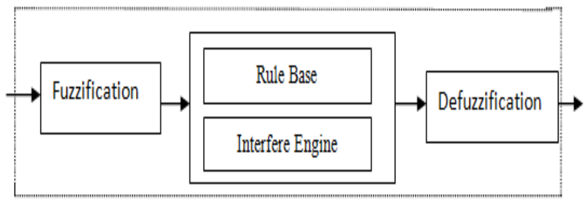

Figure 4: Fuzzy Logic Control

As shown in Fig. 5, the error and derivative of the error are inputs to the fuzzy interface. The model most commonly employed in the fuzzy interface is the Mamdani model. The operation of the Mamdani rule base can be broken down into four parts,

1. Mapping each of the crisp set into fuzzy variable (fuzzification).
2. Determining the output of each rule given its fuzzy antecedents;
3. Determining the whole output(s) of all fuzzy rules;
4. Mapping the fuzzy output(s) to crisp output(s) (defuzzification).

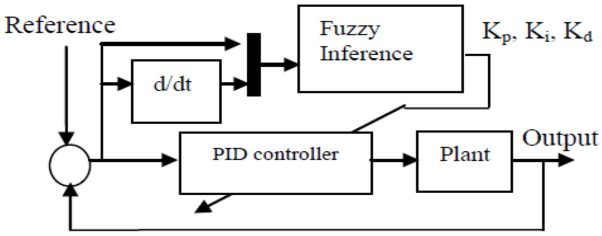

Figure 5: Block Diagram of FLC Based Controller

Fuzzy logic has been implemented for the tuning of PID controller [12]. Author compared the performance of PID controller tuning conventional techniques and such as Zeigler-Nichols method with Fuzzy logic and it is found that fuzzy logic is best among them.

IV. Conclusion

A number of techniques for the tuning of PID controller are reviewed in this paper. A brief discussion of the techniques followed by its implementation by various authors is indicated for tuning and self tuning of PID controller. From the above discussion, it is found that metaheuristic optimization techniques gives correct and object oriented results as compared to conventional techniques.

References

[1] K. Ogata, PID controls and Two-Degree Of freedom control system in *Modern Control Engineering,* (India: Pearson Education,2002) 681-751

[2] G. H. Cohen, and G. A. Coon, "*Theoretical considerations of retarded control*," Transactions of ASME, 75(1), 1953, 827-834.

[3] R.C Eberhart and Y. Shi, "Comparison between genetic algorithm and particle swarm optimization", in *Proc*. IEEE *int. Conf. Evol. Comput.*, 1998, 611-616.

[4] Zwe-Lee Gaing, "A Particle Swarm Optimization Approach for Optimum Design Of PID controller in AVR system", in *IEEE Transaction on energy conversion, 19(2),* 2004

[5] Dervis Karaboga and Bahriye Akay, "A comparative study of Artificial Bee Colony algorithm", in *Applied Mathematics and Computation, 21(4), 2009,*108-132

[6] Akhilesh Kumar Mishra, Navin Kuamr Singh, "Speed Control Of DC motor Using Artificial Bee Colony Optimization Technique", in *Universal Journal Of Electrical and Electronics 1(3),* 2013, 68-75.

[7] T.O Mahony, C.J Downing and K.Fatla,"Genetic Algorithm for PID parameter Optmization: Minimizing Error Criteria ",*process control and Instrumentation,* 2000, 148-153

[8] Jaspreet Kaur, Piyush Saxena and Dr. Prerna Gaur, "Genetic Algorithm Based Speed Control of Hybrid Vehicle" in *IEEE* 978-1-4799-0192-0/13, 2013

[9] X. S. Yang, "Firefly algorithm, stochastic test functions and design optimization," International *Journal of Bio-Inspired Computation, 2(2) ,2010,* 78–84.

[10] D. Kumanan and B. Nagaraj, "Tuning of Proportional integral and derivative controller based on firefly algorithm" in *System Science & Control Engineering,1(1),2013,*52-56.

[11] K.T. Oner, E. Cestinsoy, E. Sirimoglu, C. Hancer, T.Ayken, and M. Unel, "LQR and SMC stabilization of a new unmanned aerial vehicle" *world Academy of Science , Engineering and Technology 58(1),* 2009, 554-559.

[12] Gaddam MALLESHAM, Akula RAJANI, "Automatic Tuning Of PID Controller Using Fuzzy Logic" in *8th International Conference on Development And Application Systems Suceava, Romania,* 2006, 120-127.

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