International Journal on Emerging Technologies (Special Issue NCETST-2017) **8**(1): 481-485(2017)
(Published by Research Trend, Website: www.researchtrend.net*)*

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Tuning Techniques of PID controller: A review

Bhawana Singh and Neelu Joshi
Electrical and Instrumentaion Department, SLIET, Longowal, Punjab, India

ABSTRACT: PID controllers have wide applications in industries that require a comprehensive and easy control. But the performance of controllers depends on the selection of tuning parameters, which is a topic of discussion and research. Many techniques have been proposed over the past years including conventional methods and the methods that involve the application of artificial neural networks, fuzzy logics and heuristics. The non-linearties and non-minimum phase characteristics are systems are difficult to be dealt with conventional methods. In recent times these types of systems are very well dealt with the application of fuzzy logics and heuristics for the tuning of PID controller parameters. A comparison is also made between some of the techniques. The main objective of this paper is to provide inclusive source of reference for persons doing research in PID controller. This paper presents a review of conventional as well as current techniques used for tuning the PID controller. The techniques reviewed are categorized into the conventional techniques developed for tuning PID controller and the heuristic techniques applied for tuning. The techniques developed for tuning PID controller for systems like Coupled Tank System, trajectory tracking of Unmanned Air Vehicle, Quadorotor Stabilization etc is also reviewed.

Index Terms: Classical techniques, Optimization techniques, PID controller, tuning methods.

I. INTRODUCTION

A controller is the heart of an automatic control system. According to the error present between the plant output and the reference value the controller gives the actuating signal to the actuator, so as to minimize the error [1]. PID (Proportional-Integral-Derivative) controller is a three term control that has been widely used in control applications due to its efficiency and simplicity. It improves the steady state response and transient response of the system [2]. It calculates the estimated adjustment whenever the tangible state of plant differs from the reference state according to the terms Proportional term, Integral term, Derivative term [3]. Mathematically, actuating signal from the PID controller taking error as input in Laplace transform is given as [4].

$$u(s) = K_P + K_I \frac{1}{s} + K_D s \qquad (1)$$

where K_P , K_I , K_D are the PID parameters. Three terms of PID controllers are described as below:

Proportional term: This term commands the actuator with regard to the errors and makes the system hasty but high proportional gain causes the system oscillatory and sensitive. It reduces but does not get rid of the steady state error.

Integral term: This term integrals the error with time and adjust the output of the controller to eliminate the error. High value of the gain causes the system oscillatory and as a result stability decreases.

Derivative term: This term makes the system slow but stability of the system increases [5]. It neither changes the order and type of the system nor affects the offset error.

This paper discussed the various PID controller tuning techniques existing in literature and comparison is made between some of the techniques. These techniques can be generally classified as Classical techniques and Optimization techniques [6].

A. Classical techniques

The classical techniques are the techniques in which controller settings are decided by making certain assumptions of the plant and its desired output. These techniques try to acquire some characteristics of the process graphically and analytically. These techniques are fast and their implementation is also simple but due to some assumptions taken, the settings of the controller parameters do not give the preferred results directly, advance settings of the controller parameters is necessary. A few of the classical techniques have been discussed in this paper.

B. Optimization techniques

Optimization can be explained as the process of finding the points that give minimum or maximum value of a function. The optimization techniques are important in evaluating the optimal solution or unconstrained minima or maxima of differentiable and continuous systems. These techniques are utilized in finding the optimal parameters of the PID controller by optimizing objective functions. Objective functions can be error functions or transient performance parameters functions. Some of the optimization techniques have been reviewed in this paper.

II. CLASSICAL TECHNIQUES

There are various methods used for PID controller tuning which are discussed in the given below section:

A. Zeigler Nichols Tuning Criteria

This tuning method is also called as continuous cycling method which can be described as sustained oscillation with fixed amplitude. In this method derivative and integral gains are first disabled and there is increase in proportional gain until continuous oscillations are observed at the output of closed loop system at this critical gain. Another important parameter is ultimate period which is the time period required to complete one full oscillation when the system is in steady state. These two parameters critical gain and the ultimate period are employed in calculating the P, I, D parameters of PID controller. The following Table I shows the calculation of controller parameters by using critical gain and ultimate period [7].

Table 1: Zeigler Nichols Controller Settings.

Controller	K_P	T_I	T_D
P	$.5K_C$	…..	…..
PI	$.45K_C$	$T_C/1.2$	……
PID	$.6K_C$	$T_C/2$	$T_C/8$

K_D and K_I can be calculated as:

$K_I = \frac{K_P}{T_I}$, where T_I is the integral gain

$K_D = K_P\ T_D$, where T_D is the derivative gain

The Zeigler Nichols Controller settings is the one of the tuning method which is based on some assumptions, further tuning is required because the controller settings results in excessive overshoot and the causes the system to oscillate.

B. Cohen Coon Method

In this method, the response of the system is modeled as first order response having dead time as:

$$G(s) = \frac{Ke^{-t_d s}}{(\tau s+1)} \quad (2)$$

Where τ is the time constant of the system, t_d is the dead time,

K is the proportional gain

The above three parameters are calculated from Figure I, and then these parameters are utilized to calculate the tuning parameters.

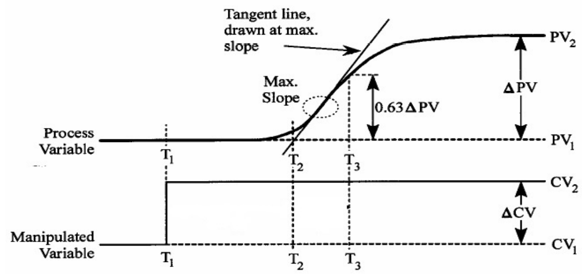

Fig. 1. Cohen Coon Method.

where $t_d = T_2 - T_1$, $\tau = T_3 - T_2$

Table 2: Cohen Coon Controller Settings.

Controller	K_P	T_I	T_D
P	$\frac{1}{K}\frac{\tau}{t_d}\left[1+\frac{t_d}{\tau}\right]$	…….	………
PI	$\frac{1}{K}\frac{\tau}{t_d}\left[0.9 + \frac{t_d}{12\tau}\right]$	$\frac{t_d[30+3(t_d/\tau)]}{9+20(t_d/\tau)}$	……..
PID	$\frac{1}{K}\frac{\tau}{t_d}\left[\frac{16\tau+30}{12\tau}\right]$	$\frac{t_d[32+6(t_d/\tau)]}{13+8(t_d/\tau)}$	$\frac{4t}{11+2(}$

This method utilizes the FOPDT model to obtain the tuning parameters [8]. It has been proved that Zeigler Nichols Method provides better results than Cohen Coon Method [9].

III. OPTIMIZATION TECHNIQUES

Optimization technique is used to find the optimal solution under given circumstances. Optimization is referred to as maximizing or minimizing the Optimization problem.

Different techniques of Optimization are reviewed in this paper:

A. Classical Optimization Techniques

These techniques are used to find the optimal solution or constrained or unconstrained maxima or minima of differentiable and continuous functions. These techniques are known as analytical methods and uses differential calculus methods in finding optimal solution. These methods have limited scope for the non-continuous and non-differentiable functions. These techniques are used to handle problems such as single-variable, unconstrained multivariable functions.

There are some classical optimization techniques:

A. Calculus Methods
B. Linear Programming
C. Dynamic Programming
D. Stochastic Programming

Various new algorithms have been proposed by using these classical optimization techniques as in [10].

B. Advanced Optimization techniques.

Advanced Optimization techniques overcome the problems of classical optimization technique such as it can be applicable for functions that are discontinuous and non differentiable. There are different methods of advanced Optimization techniques which are as follows:

Stimulated annealing. In this method, each position in the search space is compared with the state of the real system inspired from the process of annealing in metallurgy and the minimization function is treated as internal energy of that state of the system. The objective of this algorithm is to move the system from an arbitrary initial state to the desired state with minimum energy. An intelligent idea for tuning PID controllers is proposed using Stimulated Annealing for Multi-objective problem and its performance is compared with conventional PID which proves that Stimulated annealing tuned PID controller have better results than traditional PID controller [11]. In [12], Stimulated annealing method is used to find optimal parameters of Yagi-Uda Antenna. A design called OED [13] based on Stimulated annealing method is proposed. The Stimulated annealing method is used to obtain optimal parameters of engine cooling fan as described in [14]. In [15] Fuzzy control is used for tuning the PID parameters for pendubot system.

Evolutionary Algorithms. These algorithms are used to optimize large optimization problems. Evolutionary algorithms imitate the metaphor of the social behavior or biological solution such as how ants select the shortest path for finding the source of food and how birds migrate to find their destination. Learning and adaptation guide the behavior of these natural species. Evolutionary algorithm tuned PID controller is proposed for greenhouse climate system based on different criteria such as better set point tracking as shown in [16]. An Immune algorithm tuned robust PID controller is proposed for disturbance rejection and results are compared with FNN [17]. An Evolutionary algorithm tuned PID controller is designed and results are compared with RGA, SPSO, and MPSO as shown in [18].

Genetic Algorithms. It is a local search technique employed to evaluate the approximate solutions to search and optimization problems. These are the class of Evolutionary algorithms that utilize techniques inspired by natural species. GA algorithm optimizes the fitness function through evolution. In every generation the fitness of the population is evaluated, individuals are selected from the present population, modified to get new population. The new population is required in the next iteration. This process is repeated for large generations to obtain an optimum solution. The Genetic Algorithm tuned PID controller is designed for synchronous generator to improve damping and to maintain stability of power systems as described in [19]. Genetic algorithm tuned fractional and integer PID controller is designed to control level in the plant. The results have shown that fractional PID have better control signal stabilization than integer PID as shown in [20]. Neuro Fuzzy tuned PID controller based on Genetic Algorithm is proposed for a temperature water bath using Feed forward control as shown in [21].

Particle Swarm Optimization. PSO technique is a population based search algorithm in which particles change their state with time. In a PSO search algorithm, particles (swarm) flown in multidimensional search space. During flight, each swarm will adjust its present position based to its own skill and the skill of a nearby particle to acquire the best position. The PSO and LQR tuned PID controller is proposed for Coupled Tank System and results are compared with LQR in [22] and results showed that LQR controller provides better results than traditional controller. In [23], PSO is used for tuning parameters of PID controllers for position of camera in UAV and the results are compared with traditional PID controller. In [24], PSO method is implemented in tuning of PID controllers for different transient conditions of PMDC motor and results have shown that both disturbance rejection and set point tracking performances are enhanced using the proposed method.

Ant Colony Optimization (ACO). ACO is one of the evolutionary meta-heuristic approaches for solving Optimization Problems which was introduced in 1992 by Marco Dorigo. ACO algorithm is inspired by laid pheromone trail and the following motion of real ants where communication medium between ants is pheromone. In the physical world, ants move randomly in search of food and when they reach the food return to their ant colony laying pheromone trails. If remaining ants find such a route, they follow the pheromone trail laid by previous ants rather travelling randomly. With time, there is evaporation of pheromone trail as a result its attractive strength reduces. Pheromone evaporation avoids the convergence of optimum solution. Ife there is no pheromone evaporation the path taken by initial ant would tend to be attractive to the remaining ants. Therefore when any one ant finds the shortest path from ant colony to the destination (food source) remaining ants more likely follows that path and in this way positive feedback leaves the ants to follow single path. The movement of the ant is given by the following probability equation [25]:

$$p_j^{(k)} = \frac{\tau_j^{(k)}}{\sum_{j=1}^{n} \tau_j^{(k)}} \quad (3)$$

The ACO tuned PID controller for DC motor of a robotic arm in [26] and its results are compared with conventional tuning methods which indicates that better results of ACO-PID than Zeigler Nichols tuned PID. PID controller is designed for Quadrotor Stabilization based on ACO algorithm as shown in [27].

Artificial Bee Colony (ABC) technique. Artificial Bee Colony is one of the meta-heuristic optimization approaches which were proposed by Dervis Karaboga in 2005. This technique basically lies in the group of swarm intelligence algorithm used to mimic the behavior of honey bees in the search of food. There are three groups of honey bees employed bees, onlooker bees, scout bees. The number of employed bees is equal to the no of food sources in the search space. At starting the employed bee goes for the search of food, gathers the information, come back and shares its information. The onlooker bees calculates the probability of selecting a food source and select the most profitable source then explore that food source. If the food source is not modified then scout bee is send to discover new food source. In the last the algorithm memorizes the best food source. Here the quality of food is selected by the fitness function [28].

Initially the basic ABC algorithm was proposed for unconstrained optimization problem. But Karaboga have later modified the ABC algorithm for constrained optimization problem [29].

ABC is used for the optimal tuning of PID parameters. The algorithm is tested on some benchmark functions. The test functions are taken for computation of PID parameters. The performance is compared with other techniques on the basis of overshoot, settling time and minimum error [30].

Teaching Learning Based Optimization. This method was introduced by Rao et al. [31] for huge scale non-linear optimization problems to find the global solution. It is based on the effect of the influence of a teacher on the output learner in a class. It gives better results in less time and has stable convergence characteristics. This algorithm mainly consists of two parts (i) Teacher phase (ii) Learner phase. In teacher phase the students learns from the teacher and in learner phase the learner learns from each other. Here the learners' result is equivalent to the fitness and the teacher is considered as the finest solution obtained so far.

The fuzzy PID controller is designed for automatic generation control (AGC) of a thermal system with the help of teaching learning based optimization [32]. One degree of freedom and two degree of freedom PID controller design is implemented on automatic voltage regulator system using teaching learning based algorithm [33].

IV. CONCLUSION

The techniques used for design and tuning of PID controller have been reviewed in this paper. Brief descriptions of conventional techniques as well as the new modern optimization techniques were also discussed in this paper. The modern optimization techniques for the optimal tuning of PID controller give better results than the conventional method and this has been proved with the help of simulation results on the basis of transient response characteristics. The selection of tuning should be based on the characteristics and performance necessity of the system.

REFERENCES

[1] B. Doicin, M. Popescu, and C. Patrascioiu, "PID Controller optimal tuning," in *eighth International Conference on Electronics, Computers and Artificial Intelligence (ECAI), 2016*, pp.1-4.

[2] A. Jacknoon and M. A. Abido, "Ant Colony based LQR and PID tuned parameters for controlling Inverted Pendulum," in IEEE *International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE), 2017*, pp.1-8.

[3] A.P. Antony, and E. Varghese, "Comparison of performance indices of PID controller with different tuning methods," in IEEE *International Conference on Circuit, Power and Computing Technologies (ICCPCT), 2016*, pp.1-6.

[4] N.A.Selamat,F.S. Daud, H.I.Jaafar, and N. H. Shamsudin , "Comparison of LQR and PID controller tuning using PSO for Coupled Tank System," in *IEEE 11th International Colloquium on Signal Processing & Its Applications (CSPA), 2015*, pp.46-51.

[5] N.S. Narkhede, A. B. Kadu, and S. Y. Sondkar, "LabVIEW based system for PID tuning and implementation for a flow control loop," in *2016 IEEE International Conference on Advanced Communication Control and Computing Technologies (ICACCCT)* , pp.436-442.

[6] D.N.Kumar, "Introduction and basic concepts of classical and advanced technique for optimization."

[7] G Mallesham, S. Mishra, and A. N. Jha, "Ziegler-Nichols based controller parameters tuning for load frequency control in a microgrid," in IEEE *International Conference on Energy, Automation, and Signal (ICEAS), 2011*, pp.1-8.

[8] G.H. Cohen, and G. A. Coon , "Theoretical considerations of retarded control ," Transactions of ASME, vol.75, 1953,pp.827-834.

[9] N. Gireesh, and G. Sreenivasulu, "Comparison of PI Controller Performances for a Conical Tank Process using different tuning methods," in IEEE *International Conference on Advances in Electrical Engineering (ICAEE), 2014*, pp.1-4.

[10] M.F.Miranda, and K. G. Vamvoudakis, "Online optimal auto-tuning of PID controllers for tracking in a special class of linear systems," in IEEE *American Control Conference (ACC), 2016*, pp. 5443-5448.

[11] R. Bansa, M. Jain, and B. Bhushan. "Designing of Multi-objective Simulated Annealing Algorithm tuned PID controller for a temperature control system." In 6th IEEE *Power India International Conference (PIICON), 2014*, pp. 1-6.

[12] B. Sumana, N. Hodda, S.Jhab, "Orthogonal simulated annealing for multiobjective optimization, " in computer and engineering elesevier, Issue 10, vol.34,2010,pp.1618-1631.

[13] S.M.G. Kumar, B. Rakesh, N. Anantharaman, "Design of controller using simulated annealing for a real time process, "in international journal of computer applications,2010, vol.6.

[14] J. Liu, J. Zhu , "Intelligent optimal design of Transmission of cooling fan of engine, " in 3rd international conference on Information and Computing ,vol.4,2010,pp.101-104.

[15] C. J. Wu ,T.L. Lee, Y.Y. Fu, L.C.Lai, "Auto-tuning fuzzy PID control of a pendubot system, " in Proceedings of international conference on mechatronics ,Kumamoto Japan ,may 2017.

[16] H. Hu, L. Xu, R.Wei, and B. Zhu, "Multi-objective tuning of nonlinear PID controllers for greenhouse environment using Evolutionary Algorithms," in *IEEE Congress on Evolutionary Computation (CEC), 2010*, pp.1-6.

[17] D.H. Kim, and J. H. Cho, "Robust tuning for disturbance rejection of PID controller using evolutionary algorithm," in *IEEE Annual Meeting of the Fuzzy Information, 2004. Processing NAFIPS'04.*, vol. 1, pp.248-253.

[18] L. Junli, M. Jianlin, and Z. Guanghui, "Evolutionary algorithms based parameters tuning of PID controller," in IEEE *Control and Decision Conference (CCDC), 2011 Chinese*, pp.416-420.

[19] N.F. Mohammed, E. Song, X. Ma, and Q. Hayat, "Tuning of PID controller of synchronous generators using genetic algorithm," in *IEEE International Conference on Mechatronics and Automation (ICMA), 2014*, pp. 1544-1548.

[20] F.A. de Castro., N. D. Bernardes, M. A. de SL Cuadros, and G. M. de Almeida, "Comparison of fractional and integer PID controllers tuned by genetic algorithm," in *12th IEEE International Conference on Industry Applications (INDUSCON), 2016*, pp. 1-7.

[21] A. Mittal, P. Jain, T. K. Saxena, and A. Kapoor, "Genetic algorithm based neuro fuzzy tuning of pid controller for a nonlinear temperature water bath with feedforward control,"in IEEE *International Conference on Advanced Electronic Systems (ICAES), 2013*, pp. 34-38.

[22] N.A. Selamat, F. S. Daud, H. I. Jaafar, and N. H. Shamsudin, "Comparison of LQR and PID controller tuning using PSO for Coupled Tank System," in *IEEE 11th International Colloquium on Signal Processing & Its Applications (CSPA), 2015*, pp. 46-51.

[23] R.J. Rajesh, and C. M. Ananda, "PSO tuned PID controller for controlling camera position in UAV using 2-axis gimbal," in IEEE *International Conference on Power and Advanced Control Engineering (ICPACE), 2015*, pp. 128-133.

[24] P.G. Medewar and R. K. Munje, "PSO based PID controller tuning for PMDC motor," in *International Conference on Energy Systems and Applications, 2015*, pp. 522-526.

[25] K. Sundareswaran, and P. S. Nayak, "Ant colony based feedback controller design for soft-starter fed induction motor drive," *Applied Soft Computing* 12, no. 5 ,2012,pp. 1566-1573.

[26] D. Sandoval, I. Soto, and P. Adasme, "Control of direct current motor using Ant Colony optimization," in IEEE *2015 CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON)*, pp.79-82.

[27] Priyambodo, T. Kuntoro, A. E. Putra, and A. Dharmawan, "Optimizing control based on ant colony logic for Quadrotor stabilization," in *IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES), 2015*, pp.1-4.

[28] D. Karaboga, ‘‘An idea based on honey bee swarm for numerical optimization,’’ Vol. 200. Technical report-tr06, Erciyes university, engineering faculty, computer engineering department, 2005.

[29] D. Karaboga , and A. Bahriye, "A modified artificial bee colony (ABC) algorithm for constrained optimization problems," *Applied Soft Computing* **11**, no. 3, 2011, pp.3021-3031.

[30] M. Abachizadeh, M.R.H. Yazdi, and A.Y.Koma, "Optimal tuning of pid controllers using artificial bee colony algorithm," in *IEEE International Conference on Advanced Intelligent Mechatronics (AIM), 2010* , pp.379-384.

[31] R. V. Rao, V. J. Savsani, and D. P. Vakharia, "Teaching–learning-based optimization: an optimization method for continuous non-linear large scale problems," *Information sciences* 183, no. 1, 2012, pp.1-15.

[32] B. K. Sahu, S. Pati, P. K. Mohanty, and S. Panda. "Teaching–learning based optimization algorithm based fuzzy-PID controller for automatic generation control of multi-area power system." *Applied Soft Computing* 27, 2015,pp.240-249.

[33] V. Rajinikanth, and S.C. Satapathy, "Design of controller for automatic voltage regulator using teaching learning based optimization," *Procedia Technology* **21** (2015),pp. 295-302.