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A Review On Optimization Techniques For PID Controller With Ziegler-Nichols Method

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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. 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. PID controller establishes a broad range of applications with industrial process control. PID controllers operation used closed-loop of any sector approximately 95-97%. These three controllers are joined in such a way that it produces a control signal. It consists of three basic coefficients; proportional, integral and derivative. Which are altered to get wide ranges of response. Closed loop systems and tuning of PID controller, the theory of classical PID and the effects of tuning a closed loop control system are discussed in this work. 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.

Keywords– control system, PID control, Optimization techniques, Tuning method.

I. INTRODUCTION

A Proportional–Integral–Derivative (PID) controller is a three-term controller that has a long history in the automatic control field, starting from the beginning of the last century (Bennett, 2000). Owing to its intuitiveness and its relative simplicity, in addition to satisfactory performance which it is able to provide with a wide range of processes, it has become in practice the standard controller in industrial settings. It has been evolving along with the progress of the technology and nowadays it is very often implemented in digital form rather than with pneumatic or electrical components. Fig.1 shows PID as the control system. It can be found in virtually all kinds of control equipments, either as a stand-alone (single-station) controller or as a functional block in Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCSs).

Actually, the new potentialities offered by the development of the digital technology and of the software packages has led to a significant growth of the research in the PID control field: new effective tools have been devised for the improvement of the analysis and design methods of the basic algorithm as well as for the improvement of the additional functionalities that are implemented with the basic algorithm in order to increase its performance and its ease of use. The success of the PID controllers is also enhanced by the fact that they often represent the fundamental component for more sophisticated control schemes that can be implemented when the basic control law is not sufficient to obtain the required performance or a more complicated control task is of concern.

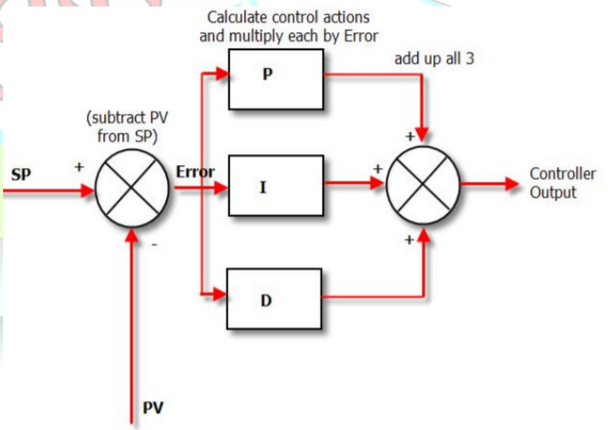

Fig 1. PID as the control system

In this paper, the fundamental concepts of PID control are introduced with the aim of presenting the rationale of the control law and of describing the framework of the methodologies presented in this. In particular, the meaning of the three actions is explained and the tuning issue is briefly discussed. The different forms for the implementation of a PID control law are also addressed.

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II. WORKING OF PID CONTROLLER

A proportional–integral–derivative controller (PID controller) is a control loop feedback mechanism. The entire idea of this algorithm turns around wielding the error. The error as visible is the difference between the process variable (PV) and the set point (SP).

ERROR=PV-SP.

These three modes are used in different combinations:

- P-Sometimes used
- PI-Most often used
- PID-Sometimes used
- PD-Very rare, useful for controlling servo motors.

With the use of the low cost simple ON-OFF controller, only two control states are desirable, like fully ON or fully OFF. It is used for finite control application where these two control states are sufficient for control objective. However oscillating nature of this control limits its use and hence it is being replaced by PID controllers.

PID controller maintains the output such that there is zero error between the process variable and set point /desired output by closed-loop operations. PID uses three basic control performance that are described.

A) P- Controller:

P controller or proportional provides an output. Which is proportional to e(t) (current error). It gives absolute value or feedback process value with contrasts desired or set point. The appearing error is added by a proportional constant to gain the output. Fig 2 shows P-controller. When the controller output is nil then the error value also zero.

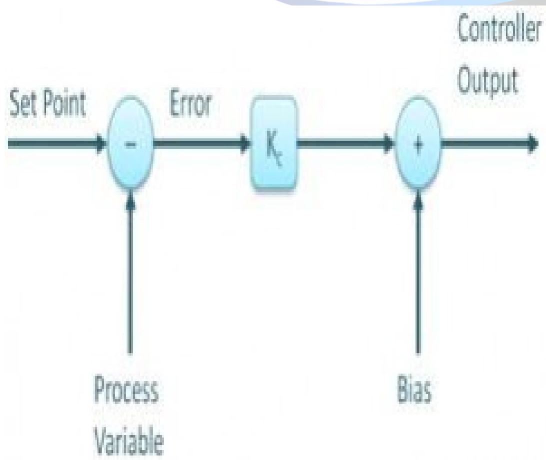

Fig 2. P-controller

This controller needs biasing, or a manual reset when used alone. This is because of it, never extension the steady-state condition. Fig 3. Shows P-controller response. It always maintains the steady-state error in need of a stable operation. The speed of the response is increased when the proportional constant Kc increases.

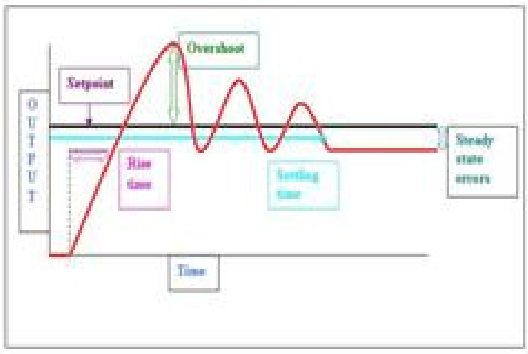

Fig 3. P-Controller Response

Drawback of P-control:

- Too high a value of K_p will lead to the oscillation of PV.
- Also, the P-controller tends to generate an offset value.
- Proportional controllers also increase the maximum overshoot of the system.

B) I-Controller:

Due to te limitation of p-controller where there always exists an offset between the process variable and set point, I-controller is needed, which provides necessary action to eliminate the steady-state error. It confirms the error over a period of time until error value reaches to zero. It holds the value to the final control device at which error becomes zero.

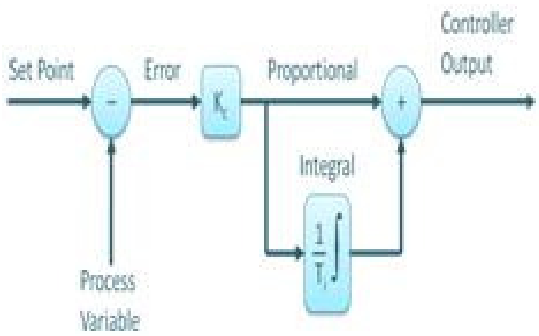

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Fig 4. PI controller

Integral control decreases its output when a negative error takes place. It limits the speed of response and affects the stability of the system. The speed of the response is increased by decreasing integral gain, K_i. Fig 4. Shows PI controller structure. In the fig 5, as the gain of the I-controller declines, steady state error also goes on declining. For most of the cases, the high-speed response is not required in the PI controller.

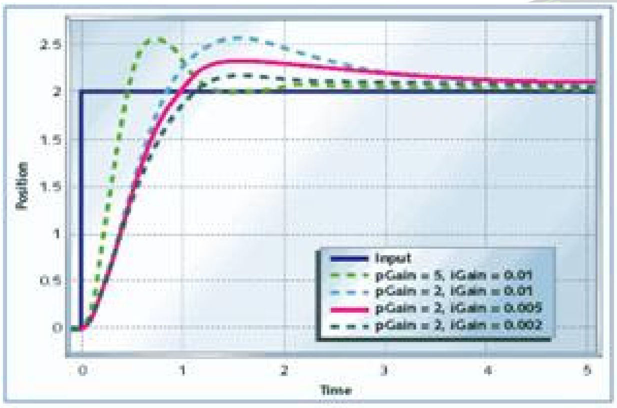

Fig 5. PI Controller Response

While using the PI controller, I-controller output is limited to somewhat range to overcome the integral windup conditions where the integral output goes on increasing even at zero error state, due to nonlinearities in the plant.

C) D-Controller:

The proportional corrects instances of error, the integral corrects accumulation of error, and the derivative corrects present error versus error the last time it was checked. The effect of the derivative is to counteract the overshoot caused by P and I.

When the error is large, the P and the I will push the controller output. Fig shows PID controller structure. This controller response makes error change quickly, which in turn causes the derivative to more aggressively counteract the P and the I.

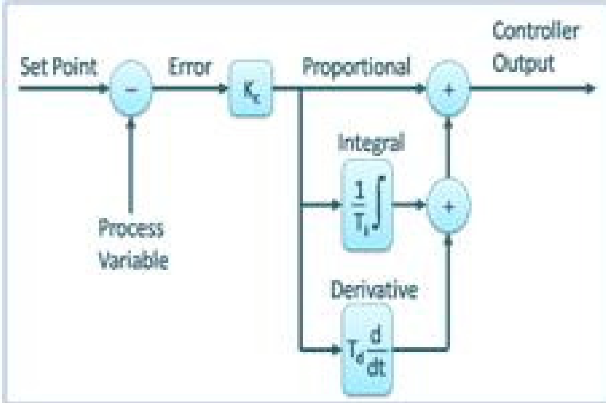

Fig 6. PID controller

I-controller doesn't have the capability to predict the future response of error. So it reacts normally once the set point is changed. D-controller overcomes this problem by anticipating future response of the error. Its output depends on the rate of change of error with respect to time, multiplied by the derivative constant. It gives the make start for the output thereby increasing system response.

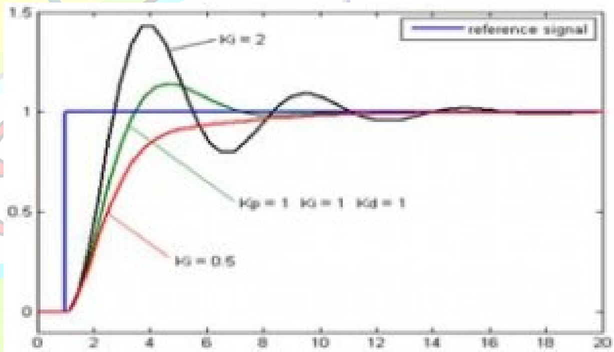

Fig 7. PID Controller Response

In the fig 7. response of D, the controller is more, compared to PI controller and also settling time of output is decreased. It improves the stability of the system by compensating phase lag caused by I-controller. Increasing the derivative gain increases the speed of response.

So finally we observed that by bringing together these three controllers, we can get the desired response for the system. Different manufacturers design different PID algorithms.

III. TUNING METHODS OF PID CONTROLLER

It must be tuned to suit with dynamics of the process to be controlled for before the functioning of PID controller. Designers give the default values for P, I and D terms and these values couldn't give the desired performance and sometimes leads to instability and slow control performances. Different types of tuning methods are refined to tune the PID controllers and require much attention from the operator to select best values of proportional, integral and derivative gains. Some of these are given below.

Trial and Error Method: It is a mild method of PID controller tuning. When system or controller is working, we can tune the controller. In this method, first, we have to set K_i and K_d values to zero and increase proportional term (K_p) until the system reaches to oscillating response. Once it is oscillating, adjust K_i (Integral term) so that oscillations stop and finally adjust D to get a fast response.
PID properties to consider

- Rise time, Overshoot , Settling time, Steady-state error and Stability.

Process reaction curve technique: It is purely open loop tuning technique. It outcomes the response as a step input is enforced to the system. Initially, we have to record response curve and to apply some control output to the system manually.

After that, we need to calculate a slope, dead time, a rise time of the curve and finally substitute these values in P, I and D equations to get the gain values of PID terms.

IV.ZIEGLER-NICHOLS METHOD

Ziegler-Nichols considered closed loop methods for tuning the PID controller. They are continuous cycling method and damped oscillation method. Procedures for both methods are same but oscillation performance is different. In this first, we have to set the p-controller constant K_p to an appropriate value while K_i and K_d values are zero. Proportional gain is increased till system oscillates at a constant amplitude.

Gain at this system produces constant oscillations is called ultimate gain (Ku) and period of oscillations is called ultimate period (Pc).Table 1 shows a Ziegler-Nichols tuning using the oscillation method. Once it is reached, we can arrive the values of P, I and D in PID controller by Zeigler-Nichols table depends on the controller used like P, PI or PID, as shown in the table.

Table 1. Ziegler-Nichols tuning, using the oscillation method.

Controller	**P**	**T_i**	**T_d**
P	**$0.5K_c$**	**-**	**-**
PI	**$0.45K_c$**	**$P_c/1.2$**	**-**
PID	**$0.60K_c$**	**$0.5P_c$**	**$P_c/8$**

Too High KP will lead to oscillation in values and will tend to generate an offset KI will counteract the offset. Higher Value of KI implies that the Set point will reach the PV too fast If this action is very fast, the process variable is prone to be unsteady. KD keeps this under control.

V.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:

1.*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.

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There are some classical optimization techniques:

- Calculus Methods
- Linear Programming
- Dynamic Programming
- Stochastic Programming

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

2.*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].

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.

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]. 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

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

Teaching Learning Based Optimization. This method was introduced by Rao et al. 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. One degree of freedom and two degree of freedom PID controller design is implemented on automatic voltage regulator system using teaching learning based algorithm.

VI. CONCLUSION

This paper presents a brief review of basic of PID control and their techniques for optimizing the output of PID control system. 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.

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