Parameter Tuning of DC Motor Using Teaching Learning Based Optimization Algorithm

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Abstract- *Most of the industrial controllers in use today utilize PID controllers. The tuning of PID controller parameters is the very difficult task. PID controllers are widely used as a means of controlling system outputs. Properly tuning the PID controller, i.e., setting its parameter values based on characteristics of the process it controls together with robustness criteria is commonly both timely and costly. The main focus of this paper is to apply TLBO algorithm parameter tuning of DC motor using PID controller to get an output with better dynamic and static performance.*

Keywords- control system, PID controller, TLBO algorithm

I. INTRODUCTION

The PID controller is the most common controller in control systems. For example, in the mid 1990's the PID controller was used in over 95 % of the control loops in process control [1]. The PID controller contains three different parameters and hence it is also called three term control system which can also be written as proportional, integral and derivative. These terms are defined as variables of time as P defined as present Difference (error), I defined as an integration of past differences (errors) and D is defined as prediction of future differences (errors). These three elements control all the processes in the process industries.

PID controller is the best controller in the absence of any information regarding the process. After tuning the PID controller, the controller can be used for different control action for any process requirement. The error can be defined by the process of the controller, but it does not the guarantee about the optimal control of the system.

Within process industry, and in many other areas, the PID controller is responsible for handling regulatory control. An educated guess is that the number of executing PID control loops lies in the billions (2011) and there are no signs indicating a decrease of this number.

Properly tuning the PID controller, i.e., setting its parameter values based on characteristics of the process it controls together with robustness criteria is commonly both timely and costly. Hence, the tuning is often overseen, resulting in numerous poorly tuned loops. These result in unnecessary lack of performance, which might be both hazardous and uneconomic.

If a linear time invariant model of the process is given, there exist numerous feasible tuning methods. However, automatically obtaining even a low complexity model is far from trivial in the absence of a priori process information.

II. LITERATURE SURVEY

Some of the technique / approaches used to Tuning for PID controller by various researchers have been summarized here.

Hohenbichler et al. [3] has been offered A technique to compute the entire set of stabilizing PID controller parameters for a random (including unstable) linear time delay system. To handle the countless number of stability boundaries in the plane for a permanent proportional gain Kp was the most important contribution. It was illustrated that the steady area of the plane contains convex polygons for retarded open loops. A phenomenon was initiated concerning neutral loops. For definite systems and certain kp, the precise, steady area in the plane could be explained by the limit of a sequence of polygons with an endless number of vertices. This cycle might be fined fairly accurate by convex polygons. Moreover, they explained a needed condition for kp-intervals potentially containing a stable area in the plane. As a result, after gridding kp in these intervals, the set of stabilizing controller parameters could be planned.

Liang et al. [4] has been presented A partial order PID controller of robust constancy areas for interval plant with time delay. They have explored the problem of computing the robust constancy area for interval plant with time delay. The partial order interval quasi-polynomial was crumbling into a number of vertex attribute quasi-polynomials by the lower and upper bounds. To explain the constancy boundaries of every vertex attributes quasi-polynomial in the space of controller parameters, the D-decomposition method was employed. By overlapping the constancy area of each quasi polynomial, the constancy area of interval attribute quasi polynomial was found out. By choosing the control parameters from the constancy area, the parameters of their suggested controller were attained. The vigorous constancy was checked by means of the value set together with the zero elimination principle. Their suggested algorithm was constructive in examining and planning the robust PIkDl controller for interval plant.

Suji Prasad et al. [5] proposed a particle swarm optimized PID controller of Second Order Time Delayed System. Optimization was based on the presentation indices like settling time, rise time, peak overshoot, ISE (integral square error) and IAE (integral absolute error). PID controllers and its alternatives are most commonly used, although there are important improvements in the control systems in industrial processes. If the parameter of controller was not appropriately planned, next needed control output may not succeed. Compared with Ziegler Nichols and Arvanitis tuning, they have confirmed that their simulation results with optimized I-PD controller to be specified enhanced presentations.

Rama Reddy et al. [6] has been explained a PID controller for time delay systems. Their suggested technique precise the stable areas of PID and a novel PID with cycle leading correction (SLC) for network control systems with time delay. The latest PID controller has a modification parameter 'b'. They have obtained that relation of the parameters of the system. The outcome of plant parameters on constancy areas of PID controllers and SLC-PID controllers in first-order and second-order systems with time delay is moreover précised. Finally, an open-loop zero was introduced into the plant unstable second order system with time delay so that the constancy areas of PID and SLC-PID controllers get competently made bigger.

Luo et al. [7] have suggested a part encloses in selecting two feasible or achievable patterns, and a FOPI/IOPID controller synthesis was applied for all the steady FOPTD systems. The entire possible area of two patterns can be attained and pictured in the plane by means of their suggested plan. Every mixture of two patterns can be confirmed before the controller design, with those areas as the previous knowledge In particular, it was fascinating to compare the regions of these two possible areas for the IOPID and FOPI controllers. A simulation picture demonstrates that their suggested plan has resulted and their presentation of the designed FOPI controller is compared to the optimized integer order PI controller and the planned IOPID controller.

Bouallegue et al. [8] have suggested to a novel PID-type fuzzy logic controller (FLC) tuning approaches from a particle swarm optimization (PSO) strategy. Two self-tuning methods were inserted so as to develop more the presentation and toughness properties of the suggested PID-fuzzy strategy. The scaling features tuning problem of these PID-type FLC configurations was created and steadily determined, by means of a suggested limited PSO algorithm. To show the competence and the supremacy of the suggested PSO-based fuzzy control strategies, the case of an electrical DC drive benchmark was explored, inside an improved real-time framework.

Shabib et al. [9] have explained about the power system nonlinear with frequent changes in operating areas. In excitation control of power systems, Analog proportional integral copied PID controllers were extensively employed. Fuzzy logic control was frequently out looked as a structure of nonlinear PD, PI or PID control. They moreover explained the design principle, tracking presentation of a fuzzy proportional integral PI plus derivative D controller. To integrate a fuzzy logic control mechanism into the alterations of the PID structure, this controller was improved by first explaining discrete time linear PID control law and subsequently more and more obtaining the steps required. The bilinear transform (Tustin's) was applied to discretize the conventional PID controller. In that some presentations criteria were employed for comparison between other PID controllers, such as settling times, overshoots and the amount of positive damping.

Ozbay et al. [10] possess created some sort of traditional appropriate PID controllers with regard to linear time period invariant facilities whoever transfer operates were logical operates connected with Sa, exactly where $0< a< 1$, and s is the Laplace transform variable. Effect connected with input– output time period delay about the range of allowed controller details has been perused. This allowed PID controller details were identified from a small acquire style of argument utilized sooner with regard to specific dimensional facilities.

Zhao et al. [11] proposed an Integral of Time Absolute Error (ITAE) zero-position-error optimal tuning and noise effect minimizing method for tuning two parameters in MD TDOF PID control system to own sought after regulatory as well as disturbance rejection overall performance. Your contrast together with Two-Degree-of-Freedom control program by modified smith predictor (TDOF CS MSP) and also the made MD TDOF PID tuned by the IMC tuning approach demonstrates the potency of the particular described tuning approach.

Feliu-Batlle et al. [12] proposed the latest technique for the control of water distribution in an irrigation main canal pool seen as substantial time-varying time delays. Time delays may perhaps adjust greatly in an irrigation main canal pool as a result of versions inside its hydraulic operations program. A classic system got its start to development fractional buy PI controllers coupled with Smith predictors that produce control systems which can be robust for the modifications in the process time delay. The system was given to fix the situation regarding powerful water submission control in an irrigation main canal pool.

Sahu et al. [13] have outlined around the design and style as well as effectiveness evaluation regarding Differential Evolution (DE) algorithm based parallel 2-Degree Freedom of Proportional-Integral-Derivative (2-DOF PID) controller for Load Frequency Control (LFC) of interconnected power system process. The planning issue has been formulated as an optimization issue and DE has been currently employed to look for optimal controller parameters. Standard as well as improved aim features have been used for the planning goal. Standard aim features currently employed, which were Integral of Time multiplied by Squared Error (ITSE) and Integral of Squared Error (ISE). To be able to additionally raise the effectiveness in the controller, some sort of improved aim operate is derived making use of Integral Time multiply Absolute Error (ITAE), damping ratio of dominant eigenvalues, settling times of frequency and peak overshoots with appropriate weight coefficients. The particular fineness in the recommended technique has become confirmed by simply contrasting the results with a lately published strategy, i.e. Craziness based Particle Swarm Optimization (CPSO) for the similar interconnected electric power process. Further, level of sensitivity evaluation has been executed by simply varying the machine details as well as managing load conditions off their nominal valuations. It is really observed which the recommended controllers are quite powerful for many the system parameters as well as managing load conditions off their nominal valuations.

Debbarma et al. [14] have suggested a new two-Degree-of- Freedom-Fractional Order PID (2-DOF-FOPID) controller ended up being suggested intended for automatic generation control (AGC) involving power systems. The controller ended up being screened intended for the first time using three unequal area thermal systems considering reheat turbines and appropriate generation rate constraints (GRCs). The simultaneous optimization of several parameters as well as speed regulation parameter (R) in the governors ended up being accomplished by the way of recently produced meta-heuristic nature-inspired criteria known as Firefly Algorithm (FA). Study plainly reveals your fineness in the 2-DOFFOPID controller regarding negotiating moment as well as lowered oscillations. Found function furthermore explores the effectiveness of your Firefly criteria primarily based marketing technique in locating the perfect guidelines in the controller as well as selection of R parameter. Moreover, the convergence attributes in the FA are generally justified when compared with its efficiency along with other more developed marketing technique such as PSO, BFO and ABC. Sensitivity analysis realizes your robustness in the 2-DOF-FOPID controller intended for distinct loading conditions as well as large improvements in inertia constant (H) parameter. Additionally, the functionality involving suggested controller will be screened next to better quantity perturbation as well as randomly load pattern.

III. DC MOTOR MODEL

The DC motor transfer function in Eq.1, is used as the transfer function of our plant (GP) [15]. However any system with a transfer function can be used as a process to be controlled.

$$GP = \frac{K_T}{(J*s+B)(L*s+R)+K_T*K_b} \quad (1)$$

Where,
J = Equivalent moment of inertia of motor shaft & load referred to the motor.
B = Equivalent Coefficient of friction of motor shaft & load referred to the motor.
KT = motor toque constant
Kb = back EMF constant
R = Armature Resistance
L = Armature self-inductance

For all analysis on this system the values of parameter are as follows:

J = 0.01, B = 0.1, K_T = 0.01, R = 1, L = 0.5, K_b= 0.01

IV. PID CONTROLLER DESIGN

A PID control of a plant as shown in Figure 1, is necessarily required a mathematical model of a plant. The process of selecting controller parameters to meet the optimized plant performance with optimal plant parameters is known as controller tuning.

This work assumes to have a plant mathematical model (DC motor transfer function) is available and the controllers design is carried out by the given formula. We will start with The Empirical Ziegler-Nichols Tuning algorithm followed by some modified tuning algorithms based on Ziegler-Nichols's Step Response tuning Algorithm and teaching learning based optimization algorithm used to optimize the plant performance.

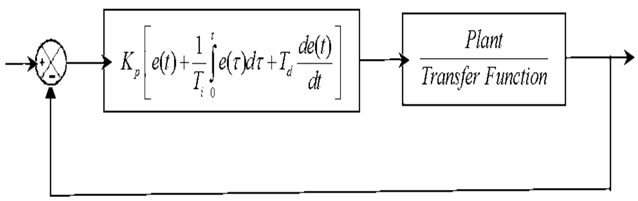

Figure 1: PID Control of a Plant

V. TEACHING LEARNING BASED OPTIMIZATION

Teaching learning based optimization (TLBO), is a new nature inspired meta-heuristic algorithm which is based on the teaching-learning process. The TLBO has been developed by Rao and colleagues. In contrast with the other optimization algorithm, TLBO does not require any algorithm-specific parameters [16]. The behavior of the students in the class, and the way of acquiring knowledge from the teacher and fellow students to improve their performance is used in the proposed algorithm. For solving a problem by using any type of algorithm the input parameter adjustment plays a crucial role. However, for tuning process TLBO requires very few inputs control parameters and such controlling parameters are number of generations and population size for its operation. In the proposed algorithm, the string of variables is assigned for each candidate solution, which represents the grade point scored by a student on different subjects. The two basic operations, namely teaching and learning phase governs the TLBO algorithm. Brief descriptions of these steps of TLBO algorithm are given below [17-18]:

4.1.1 Teaching phase

This operator plays a crucial role for global searching of the proposed algorithm. The academic performance of the students was improved by the teacher, who is the most knowledgeable person in the class, always motivates the students to acquire supreme knowledge. To improve the average result of the classroom from an initial level to his own level is the main goal of the teacher. But the teacher cannot improve the results of the whole class because it largely depends on the students own quality so the teacher can only improve the average grade of the class to some extent.

Using the above concept, the grade point of subject j of student i may be modified as follows

$$G_{i,j}^{k+1} = G_{i,j}^{k} + \lambda_j^k \quad (2)$$

Where λ_j^k is the difference between the existing and new mean of subject j at iteration k which may be formulated as

$$\lambda_j^k = rand \times \left(M_{new_j}^k - t_f M_j^k\right) \quad (3)$$

Where $M_{new_j}^k$ is the mean grade point of subject j at iteration k; t_f is the teaching factor which is evaluated randomly using:

$$t_f = round[1 + rand(0,1)] \quad (4)$$

4.1.2 Learner phase

This phase is mainly performed local search of the algorithm. In this step, the students randomly choose each student having better knowledge than him for mutual interaction and learn new things to improve their results improve their results. It may mathematically be expressed as follows:

$$G_{i,j}^{k+1} = G_{i,j}^{k} + rand \times \left(G_{i,j}^{k} - G_{l,j}^{k}\right) \; if \quad f(OG_i) < f(OG_l)$$
(5)

$$G_{i,j}^{k+1} = G_{i,j}^{k} + rand \times \left(G_{l,j}^{k} - G_{i,j}^{k}\right) \; if \quad f(OG_i) > f(OG_l)$$
(6)

Where, , $OG_l = G_{l,1}, G_{l,2}, \dots \dots, G_{l,j}, \dots . G_{l,d}$ and $f(OG_l)$ is the overall grade point of student l.

A brief description of different steps of TLBO algorithm is given below [19]:

Step 1: Initialize the grade point of each subject of all the students randomly within the given search interval as below:

$$OG_i = \left(G_1^i, G_2^i \dots \dots, G_j^i, \dots . . G_S^i\right) \quad i = 1,2 \dots . N_S \quad (7)$$

Where, N_S is the number of students and S is the number of subjects offered and G_j^i represents the grade point of subject j of student i and is given by:

$$G_j^i = G_j^{min} + rand\left(G_j^{max} - G_j^{min}\right) \quad (8)$$

Step 2: Compute the overall grade point (fitness value) for all the students of the class.

Step 3: The grade points of the students of the entire class are arranged in descending order .As the teacher is the most knowledgeable person in the class, if he appears in the examination, best grade point of each individual subject would become the grade point of the teacher. Therefore, the grade point of the j-th subject of the teacher would mathematically be expressed as:

$$G_j^{teacher} = G_j^{best} \quad j = 1,2 \dots \dots s \quad (9)$$

Where G_j^bestis the best grade point of subject j.

Step 4: Update the grade point of each subject of the individual student using learning concept from the teacher as explain in section 3. Modified grade point of the jth subject of the ith student is given by:

$$G_j^{inew} = G_j^{iold} + r1 \text{ x } [G_j^{teacher} - round\ (1 + r2) \text{ x } M_j] \quad (10)$$

Where, r1 and r2 are the random numbers uniformly distributed between (0, 1) and M_j is the average grade point of subject j and is given by:

$$M_j = G_j^1, G_j^2, \ldots \ldots G_j^i, \ldots \ldots G_j^{N_s} \quad (11)$$

Step 5: In order to improvement the result further, every student exchange his/her knowledge with the other students. The modified grade point of the j-th subject of the ith student is given by

$$G_j^{inew} = G_j^{iold} + rand \text{ x } (G_j^i - G_j^l) \quad if\ f(OG^i) < f(OG^l) \quad (12)$$

$$G_j^{inew} = G_j^{iold} + rand \text{ x } (G_j^l - G_j^i) \quad if\ f(OG^i) > f(OG^l) \quad (13)$$

Where, $OG^i = [G_1^i, G_2^i \ldots \ldots, G_j^i, \ldots\ldots G_s^i]$ (14)

Step 6: The optimization process is repeated for several iterations. This allows individuals to improve their fitness while exploring the solution space for optimal values. The iterative process of teaching phase and learning phase are continued until a user-specified stopping criterion, normally, the maximum number of iterations is met.

4.2 Ziegler and Nichols Methods

Ziegler and Nichols were proposed PID controller tuning methods in 1942 and have been widely utilized either in the original form or in modified forms. Different types of PID controller tuning methods discuss detailed in below [20]

4.2.1 Step Response (Open Loop) Method

The Ziegler-Nichols step response method is the classical tuning methods for PID controllers. They were presented already in 1942, but they are still widely used in the process industry as the basis for controller tuning [21]. The step response method is based on an open-loop step response test of the process, hence requiring the process to be stable. The unit step response of the process is characterized by two parameters, L and T. These are determined by drawing a tangent line at the inflexion point, where the slope of the step response has its maximum value. The intersections of the tangent and the coordinate axes give the process parameters as shown in Figure 2, and these are used in calculating the controller parameters. The parameters for P, PI and PID controllers obtained from the Ziegler-Nichols step response method are shown in Table 1.

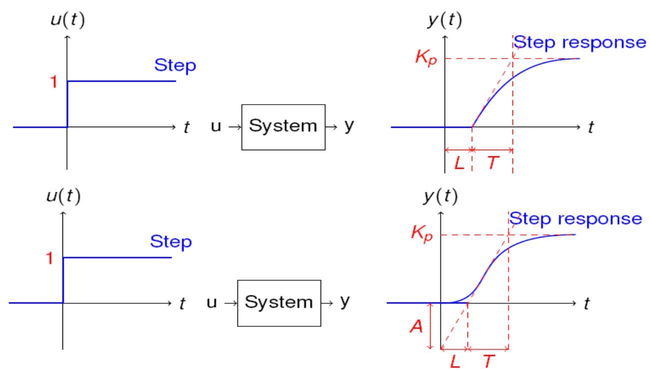

Figure 2: S Shaped Response Curve for Ziegler-Nichols Tuning Algorithm

Table 1: Ziegler–Nichols tuning formulae– Step Response Method

Controller Type	K_p	T_i	T_d
P	T/L		
PI	0.9 T/L	L /0.3	
PID	1.2 T/L	2L	0.5L

3.2 The Cohen-Coon Tuning Algorithm

Another Ziegler–Nichols type tuning algorithm is the Cohen–Coon tuning formula. Referring to the Experiments performed in Ziegler–Nichols Step response Method and denoting [22], a = KL / T and τ = L / (L+T), the different controllers can be designed by the using of Table 2.

Table 2: The Cohen-Coon Tuning Algorithm formulae

Controller type	K_p	T_i	T_d
PID	{(0.7303 + 0.5307 T/L)(T + .5 L)}/K(T + L)	(T + 0.5 L)	0.5LT/(T + 0.5 L)

3.3 The Wang–Juang–Chan Tuning Algorithm

Based on the optimum ITAE criterion, the tuning algorithm proposed by Wang -Juang and Chan, is a simple and efficient method for selecting the PID parameters. If the K,L,T parameter soft he plant model is known from the Experiments performed in Ziegler–Nichols Step response Method, the controller parameters are given Table 3.

Table 3: Wang–Juang–Chan Tuning Formulae

Controller Type	K_p	T_i	T_d
P	1/a { (1+ 0.35 τ) / (1- τ) }		
PI	0.9/a{ (1 + 0.92 τ) /(1- τ)}	{(3.3- 3τ) / (1 + 1.2τ)} L	
PID	1/a { (1+ 0.18 τ) / (1- τ) }	{(2.5 - 2τ) / (1 + 0.39τ)} L	{(3.7- 3.7τ) / (1 + .81τ)} L

VI. NUMERICAL RESULT AND DISCUSSION

In our case, we cast the PID controller design for parameter tuning of DC motor problem in Ziegler-Nichols Tuning Algorithm and TLBO framework as given. We consider the three dimensional search spaces. KP, KI and KD are the three dimensions. We consider the fitness function based on time domain characteristics for adaptation. We set the number of adaptation iterations based on expected parameters and time of computation.

To demonstrate the effectiveness of the proposed algorithm, the DC motor transfer function (Plant) is used as discussed in Eq.15. The results listed in this paper are the following values of key parameters. GEN. =100 and Population size =20.

Fitness function of the closed loop transfer function of the plant (GP)

$$GP = \frac{K_T}{(J*s+B)(L*s+R)+K_T*K_b} \tag{15}$$

CASE A: EMPIRICAL ZIEGLER-NICHOLS TUNING ALGORITHM

To Study the Empirical Ziegler-Nichols Tuning Algorithm [23] and designing the P, I and D parameter for the Plant described as in Eq. 15.

1. Step Response ('S' Shaped) Curve/Process Reaction Curve Method:

As described the procedure and shown in Figure 2, the Parameter for evaluating the values of the PID Controller as given in Table 1, can be obtained from Figure 3. The obtained parameters are: K= 0.098, L= 0.1 and T =0.6 Sec and System Response of P, PI & PID Controller tuned with Process Reaction Curve Method is shown in Figure 4.

2. Cohen-Coon PID Controller Tuning Algorithm:

Taking the values of K= 0.098, L= 0.1 and T =0.6 Sec. and using the Table 2 for tuning the PID Controller, we performed the closed loop response of the system shown in Figure 5.

3. Wang–Juang–Chan Tuning Algorithm

Using the values of K= 0.098, L= 0.1 and T =0.6 Sec., using the Table 3 for wang-jung-chan tuning method of PID Controller, we performed the closed loop response of the system shown in Figure 6.

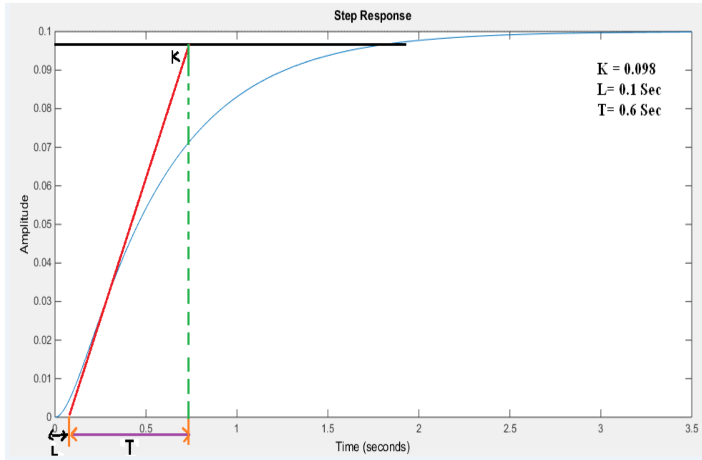

Figure 3: K, L and T from 'S' Shaped Step response Curve

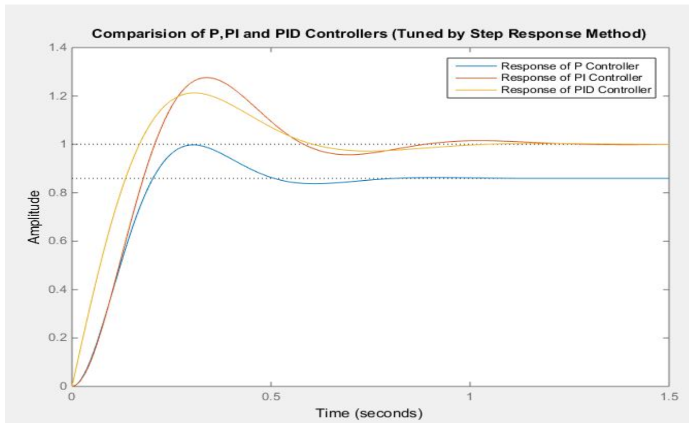

Figure 4: System Response of P, PI & PID Controller tuned with Process Reaction Curve Method

Table 4: Step Response based parameter tuning of DC motor method result

S.No	Rise time	Settling time	Peak Response		
			Peak amplitude	Overshoot (%)	Time (Sec)
1	0.13	0.848	1.21	21.3	3.05

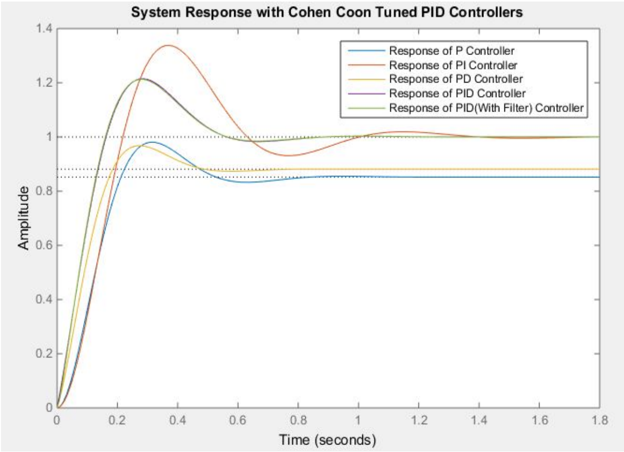

Figure 5: Cohen Coon Tuned PID Controller response of a system with derivative filter Controllers

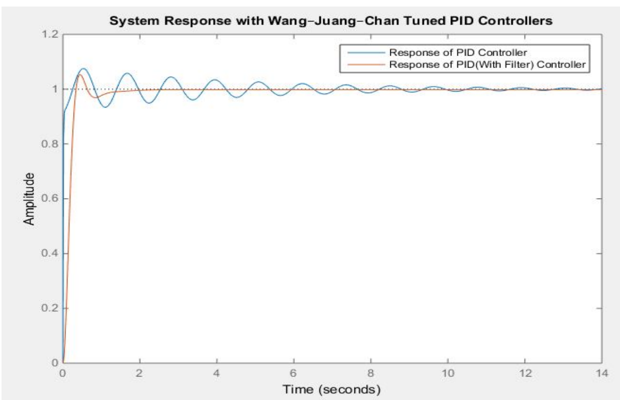

Figure 6: Wang-Jung-Chan Tuned PID Controller response of a system with derivative filter

CASE B: Teaching Learning Based Optimization

To demonstrate the effectiveness of the proposed algorithm, the DC motor transfer function (Plant) is used as discussed in before. The results listed in this paper are the following values of key parameters. GEN. =100 and Population size =20.

Table 5: Comparison of Cohen Coon technique and Wang Juang–Chan Tuning Algorithm based parameter tuning of DC motor method result

S.No	Method	Rise time (Sec)	Settling time (Sec)	Peak Response		
				Peak amplitude	Overshoot (%)	Time (Sec)
1	Cohen Coon Algorithm	0.124	0.522	1.21	21.5	0.282
2	Wang Juang–Chan Tuning Algorithm	0.029	6.25	1.08	7.53	0.532
3	TLBO algorithm	0.11	0.509	1.02	0.8	0.2

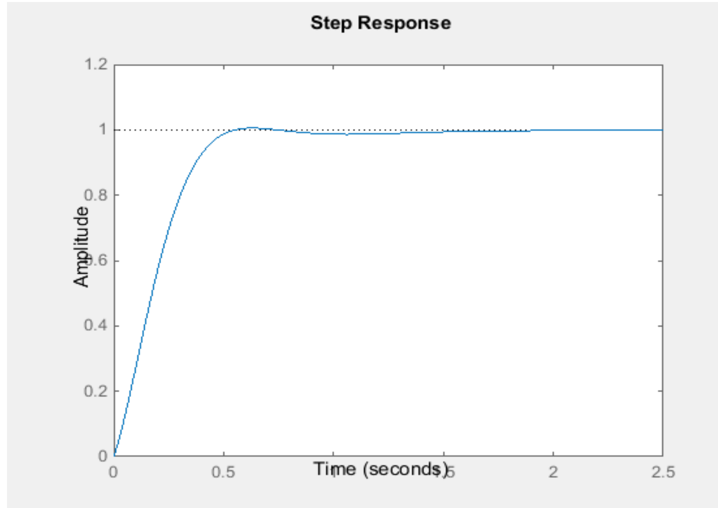

Figure 7: TLBO algorithm parameter tuning of DC motor using PID Controller

VII. CONCLUSION

In this paper, we studied the parameter tuning methods of DC motor using TLBO algorithm. A DC motor transfer function was taken as the control object. Numerical result was carried out using MATLAB to get the output response of the system to a step input.

In this paper is TLBO method proposed, and successfully applied to parameter tuning DC motor with help of PID controller. The proposed approach is improving the system response, improve the steady state error and decrease the peak over shoot of system. The main advantage of purposed method is often, for tuning process TLBO requires very few inputs control parameters and such controlling parameters are number of generations and population size for its operation.

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