Implementing optimization of PID controller for DC motor speed control

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ABSTRACT

The point of this paper presents an optimization technique which is flexible and quick tuning by using a genetic algorithm (GA) to obtain the optimum proportional-integral-derivative (PID) parameters for speed control of a separately excited DC motor as a benchmark for performance analysis. The optimization method is used for searching for the proper value of PID parameters. The speed controller of DC motor using PID tuning methods includes three types: MATALB PID tunner app., modified Ziegler-Nichols method and genetic algorithm (GA). PID controller parameters (Kp, Ki *and* Kd) will be obtained by GA to produce optimal performance for the DC motor control system. Simulation results indicate that the tuning method of PID by using a genetic algorithm is shown to create the finest result in system performance such as settling time, rise time, percentage of overshoot and steady state error. The MATLAB/Simulink software is used to model and simulate the proposed DC motor controller system.

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1. INTRODUCTION

DC Motor is broadly used in industrial applications such as steel rolling mills, electric cranes, robotic manipulators and electric vehicles, because of its precise, low cost, wide, simple and easiest to control [1], [2]. Generally, DC motor control system must have high performance such as load regulation response and good dynamic speed command tracking. To achieve high performance for a DC motor control system, optimal PID controller parameters are required, which traditional PID cannot provide, soft computation has been used widely in the last two decades. El-Deen, Mahmoud, and El-Sawi [3] present a soft computing technique that uses a genetic algorithm (GA) to decide the optimal parameters of PID controllers for a DC motor as a benchmark for performance evaluation. The proposed genetic algorithm (GA) is compared to the active set optimization algorithm (ASOA) in this paper. Agarwal *et al*. [4], compares and analyzes the robustness of as gray wolf-optimized, a FOPID scheme is applied to a fractional-order proportional-integral-derivative (FOPID) on PID controller for dc motor speed control. Based on the genetic algorithm [5], generates an optimally engineered brushless DC motor speed control controller (GA). A PID controller for BLDC motor control device employs the integral squared error (ISE) and integral absolute error (IAE) error criterion. In this paper, a genetic algorithm (GA) optimization strategy for adjusting PID tuning parameters for a separately excited DC motor speed control is proposed. It is critical to obtain the best solution so that the controller has the fastest and most stable response time.Some important advantages of using a PID-genetic algorithm can be generalized as faster response time, smaller overshoot, reduced steady state error, reduced oscillations and improved output disturbance rejection [6]-[8]. To achieve the results obtained by the PID-genetic algorithm, compared it with the MATALB PID tunner app. and the modified Ziegler-Nichols (MZN) method. The main goal of this work is to reduce settling time, overshoot, steady-state error, and velocity gain by using a PID controller, which is a generic feedback controller.

2. DC MOTOR MATHEMATICAL MODEL

The DC motor that will be studied in this paper is of the separately excited (SEDC) type, and focusing on speed control of DC motor. The schematic of the SEDC motor is shown in Figure 1 [9]-[11].

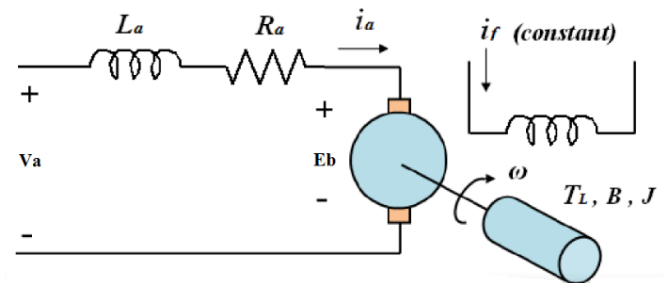

Figure 1. The schematic diagram of SEDC motor

Using the Kirchhoff's law, we can get the following equation obtained:

$$V_a = I_a R_a + L_a \frac{dI_a}{dt} + E_b \quad (1)$$

$$E_b = K_b \, \omega I_f \quad (2)$$

$$T = K_t \, I_a \, I_f \quad (3)$$

$$T = J\frac{d\omega}{dt} + B_\omega + T_L \quad (4)$$

where:
L_a = armature inductance (H)
R_a = armature resistance (Ω)
V_a = armature voltage (V)
E_b = back electromotive force (e.m.f.) (V)
ia = armature current (A)
T_L = Load torque (Nm)
B_m = Viscous friction coefficient (Nms/rad)
if = Field current (A)
J = Rotor inertia (kgm^2)
K_t = Torque constant (Nm-s/rad)
K_b = Back emf constant (Vs/rad)

The Transfer function T.F of the armature-controlled DC motor given by (5). Block diagram expressed in (6) is following in Figure 2. The DC motor test model parameters for this study are given in Table 1. now, the D.C. motor can be represented by T.F shown in (6).

$$\frac{\omega(s)}{V_a(s)} = \frac{K_t}{(Js+B_m)(R_a+L_a\,s)+K_t\,K_b} \quad (5)$$

$$\frac{\omega(s)}{V_a(s)} = \frac{K_t}{(L_a\,J)s^2+(R_a\,J+L_a\,B_m)\,s+(R_a\,B_m+K_t\,K_b)} \quad (6)$$

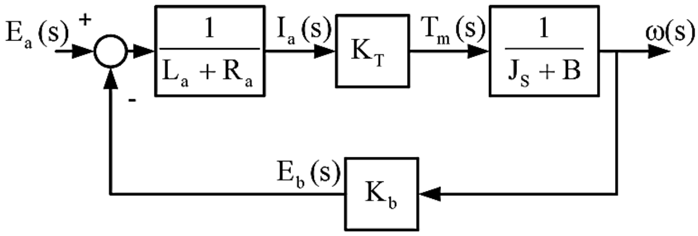

Figure 2. DC Motor Block Diagram

Table 1. Implementation parameters of DC motor [12]

Parameters	Value
Armature inductance (Henry)	L = 0.1215H
Armature resistance (ohm)	R = 11.2 Ω
Rotor inertia (kg m^2)	J_m =0.02215 kg-m^2
Viscous friction coefficient (N_m s/rad)	B_m = 0.002953 N_m-s/rad
Motor torque constant (Nm/A)	K_t =1.28 Nm/A
Back emf constant (V s/rad)	K_b =1.28 V s/rad
Speed	1500 rpm

Thus, the final of T.F is shown in (7).

$$\frac{w(s)}{V_a(s)} = \frac{1.28}{0.0027s^2+0.2481s+1.671} \quad (7)$$

3. PID CONTROLLER

The proportional-integral-derivative (PID) controller is simple to use and set up, and it is widely used in industrial applications for speed control of dc motors due to its proper control performance and lack of complexity in design [8], [13], [14]. The PID controller form is shown in (8).

$$G(s) = K_p+\frac{K_i}{s} + K_d s \quad (8)$$

Where G(s) is the transfer function of PID, K_p, K_i and K_d indicate parameter gainof PID. To improve the performance of any system, there must be proper controller tuning. The setting of the proper parameter value of a controller indicates tuning it. The response of the system becomes unstable and poor, if improper value of gain parameters of a controller is used [15], [16]. Therefore, implementation of PID Tuning is critical to the controller tuning suitable to induce the favored response. Figure 3 illustrates the speed control system for DC motor using a PID controller. Tuning of PID control can be done by many methods. This paper discusses three methods that will be used:

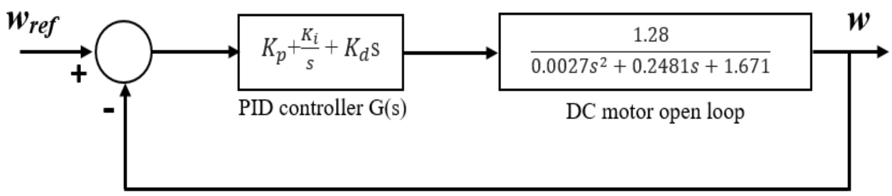

Figure 3. A PID control DC motor speed system

3.1. MATALB PID tunner app

By utilizing PID Tuner Application in MATALB R2018a software will obtain gain parameters of PID controller Kp= 7.632, Ki= 95.733, Kd= 0.0383 and N= 382.998. Figure 4 depicts the response of the DC moror trail and error, as well as the time characteristics. [17]-[19].

3.2. Modified Ziegler-Nichols method

Depending on the chien - hrones - reswick (CHR) algorithm has been obtained. The modified Ziegler-Nichols (MZN) tuning focuses on disturbance rejection. In addition, response and overshoot can accommodate one of the qualitative specifications The MZN method is more powerful compared to the classical Ziegler-Nichols tuning, the time constant T of the plant will be used. The MZN tuning formulas are given in Table 2 [20]-[21]. From response curve of T.F in (7) as shown in Figure 5 can be obtained the parameters a, L and T, a= 0.0343, L= 0.0077, T= 0.2259. We will get: K_p= 27.7, K_i=K_p/T_i =87.586 and K_d=K_p*T_d =0.1002.

Table 2. MZN tuning formulas [19]

Controller Type	K_p	T_i	T_d
P	0.7/a		
PI	0.6/a	T	
PID	0.95/a	1.4T	0.47L

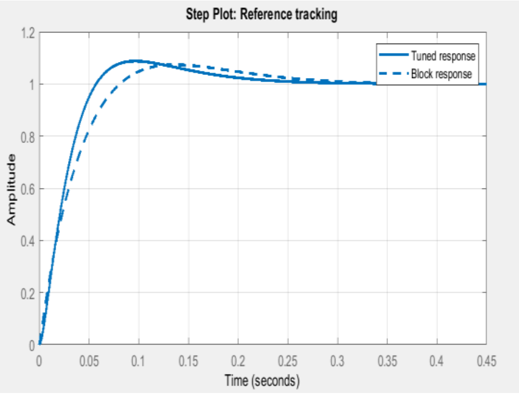

Figure 4. Response of PID tunner app.for DC motor

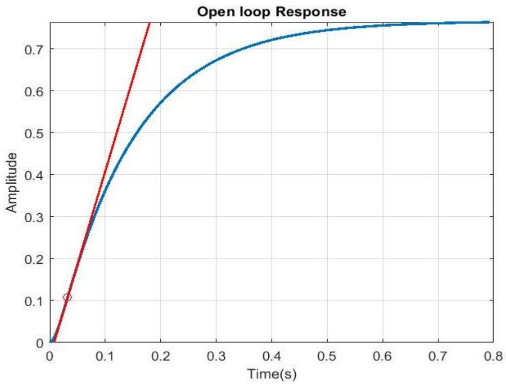

Figure 5. Response curve for MZN

3.3. Genetic algorithm for PID tuning

A genetic algorithm is an optimization technique which is an offshoot of natural selection applied to the effect of creating diversity [3]. The starting population contains the number of chromosomes, which are used as problem-solving tools, which are then tested according to their ability to execute the solution. Depending on the fitness of each person, three common processes are performed: selection, crossover, and mutation [22], [23]. Once these three simple operations are applied, new individuals can result in better solutions.

The parameters of population size, crossover rate (Pc), mutation rate (Pm) and the number of generations are the starting points for GA. By sequentially setting the PID parameters, kp, ki, and kd, the population is encoded in binary strings defined as the way that it is The fitness of each chromosome is calculated by taking its two-dimensional strings and transforming them into real values, and replacing them with objective (fitness) function. In this study, we will be using an optimization tool in MATLAB [24], [25]. The GA parameters in this study are shown in Table 3. As illustrated in Figure 6, the GA Step Flowchart shows.

Table 3. Parameter setting of genetic algorithm

Parameter	Value
Lower bound [Kp Ki Kd]	[0 0 0]
Upper bound [Kp Ki Kd]	[100 50 5]
Populations	20
Generations G	80
Population type	Double vector
Crossover rate Pc	0.8
Mutation rate P_m	0.01
Elite count	5
Selection function	Stochastic uniform

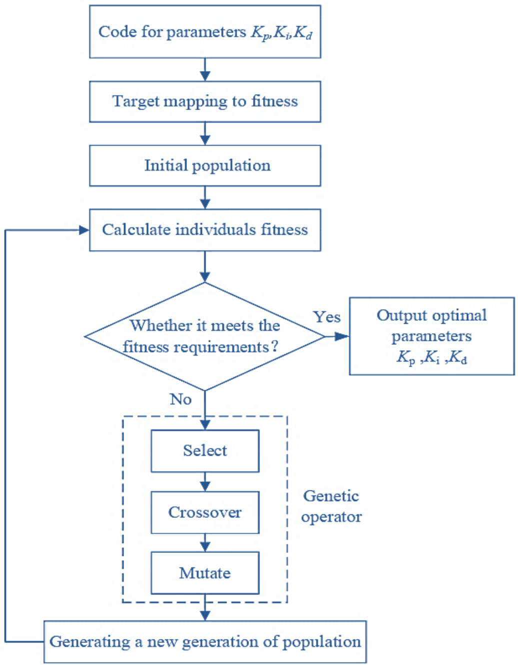

Figure 6. Flowchart for optimal PID tuning based on genetic algorithm [25]

4. SIMULATION RESULTS

Figure 7 shows speed control of the DC motor system in Matlab Simulink for various PID tuning methods. In this simulation takes various cases: case i): no-load operation. (at t= 1s); case ii): full-load operation (at t=3s) TL=300 Nm; case iii): change rotation speed.(at t=5s). As shown in Figures 8 (MATALB PID tunner app.) and 9 (MZN), compared to Figure 10 (PID-genetic algorithm) tuning method control with conventional PID methods within the desired speed of N=1500 rpm, At t=1s, the motor's speed response curve reaches a steady state in a short period of time with no overshoot; at t=3s, when the motor is running at full load, the speed response curve decreases slightly and returns to the desired speed more quickly.The system shows great dynamic characteristics and the robustness is greatly improved. Figure 11 shows the comparison of the speed response curve of a motor by using various tuning methods of PID controller, as it can be seen that the performance of each method is different in settling time Ts, rise time Tr and peak overshoot Mp. PID tuning produces a slower response but has a lower percentage of overshoot than modified Ziegler-Nichols tuning.The genetic algorithm tuning method provides better response compared with conventional methods. In Table 4 shows the performance of each method.

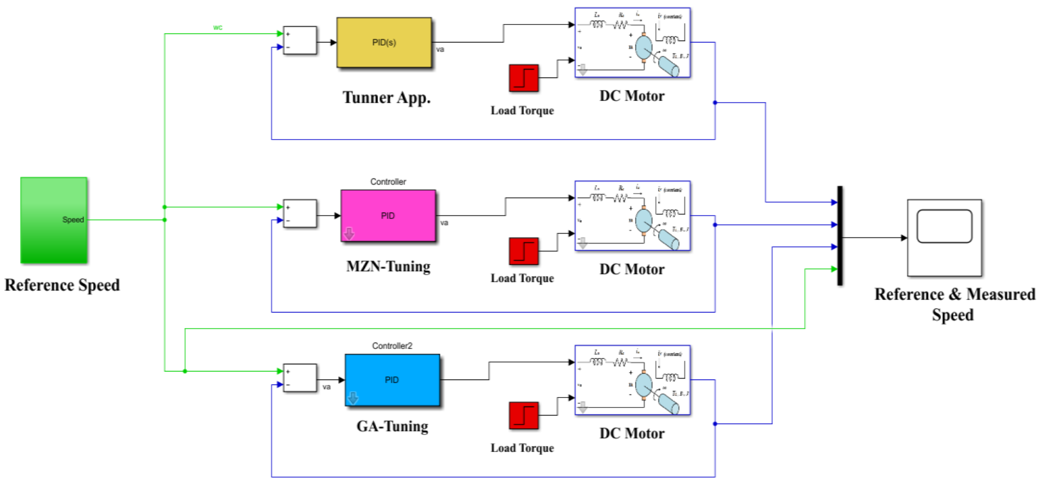

Figure 7. Simulink model of various PID tuning methods

Table 4. Comparison between the performance of various PID tuning methods

Tuning method	M_p %	T_r (s)	T_s (s)	Steady state error
Tuner Adds	18.37	0.15	1.43	0
MZN	9.65	0.12	1.26	0
GA	0	0.056	1.12	0

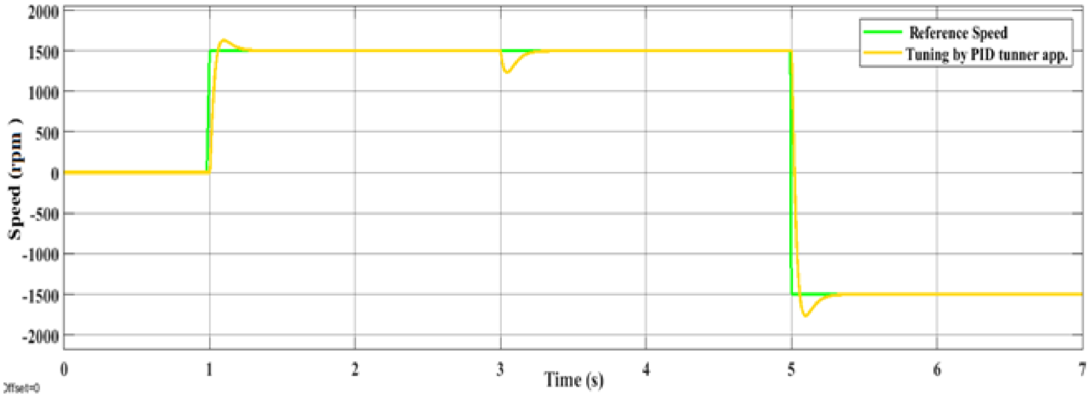

Figure 8. Speed versus time with reference speed of PID controller based on PID tunner app

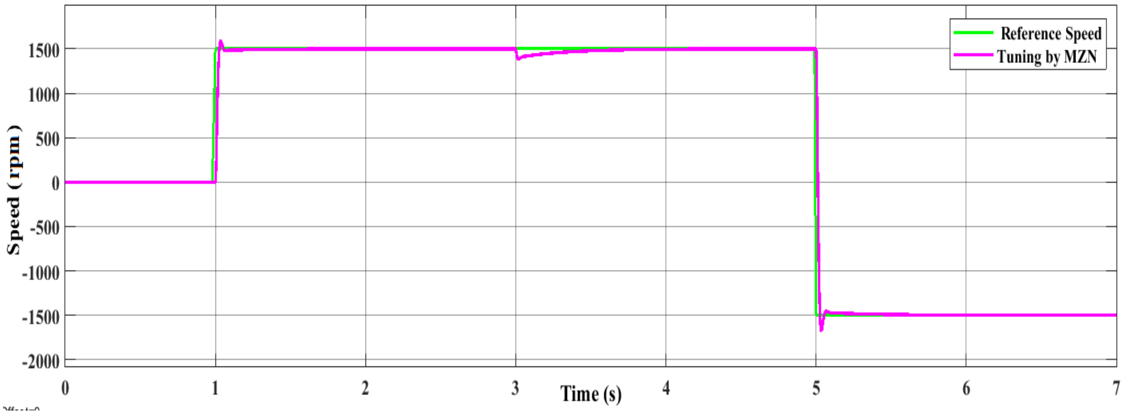

Figure 9. Speed versus time with reference speed of PID controller based on MZN

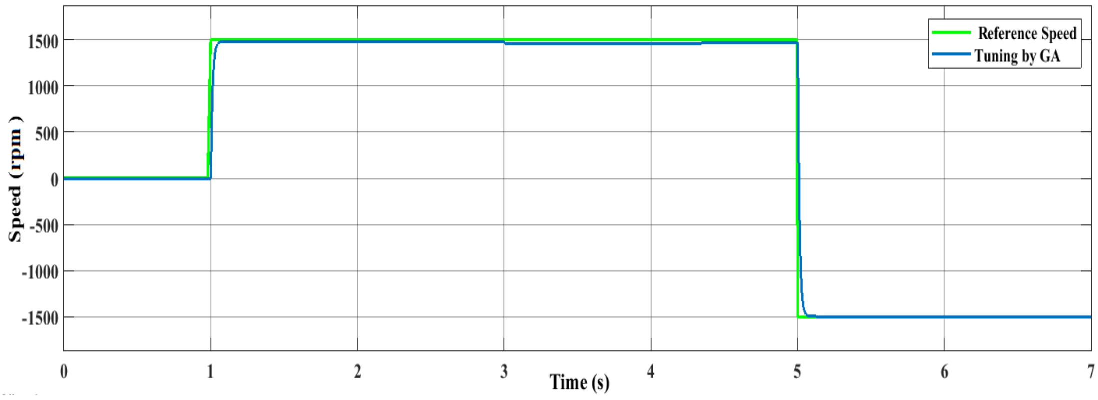

Figure 10. Speed versus time with reference speed of PID controller based on GA

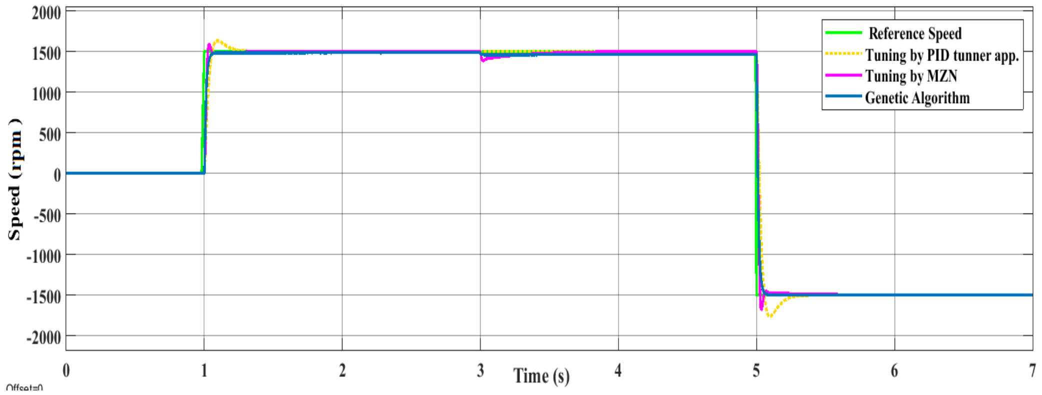

Figure 11. Speed versus time with reference speed of PID controller based on Z-N, tunner app. and GA

5. CONCLUSION

A DC motor speed control using genetic algorithm optimization to determine the proper value gain of PID parameter is presented in this paper. As well, compares its performance with conventional methods MATALB PID tunner app. and Modified Ziegler-Nichols. The results obtained by PID-genetic algorithm compared to other methods, show a high-performance response for DC motor such as less settling time, less rise time, reduced steady state error and no overshoot rate. The PID-GA tuning method as a speed controller for the DC motor is a very effective method. The proposed system's performance is improved and reaches the required requirements.

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