Journal of
Computer & Electrical and
Electronics Engineering Sciences

Original Article

DOI: 10.51271/JCEEES-0028

Genetic algorithm-based optimization of PID controller parameters for DC motor speed control

Zafer Civelek, Mustafa Teke
Department of Electrical Electronics Engineering, Faculty of Engineering, Çankırı Karatekin University, Çankırı, Turkiye

Cite this article as: Civelek, Z., & Teke, M. (2025). Genetic algorithm-based optimization of PID controller parameters for DC motor speed control. *J Comp Electr Electron Eng Sci, 3*(2), 47-53.

Received: 03.07.2025 ◆ **Accepted**: 01.09.2025 ◆ **Published**: 03.10.2025

ABSTRACT

This study investigated the optimization of PID controller parameters for DC motor speed control using genetic algorithms, comparing the results with the traditional Ziegler-Nichols tuning method. A comprehensive mathematical model of a DC motor was developed in MATLAB/Script, incorporating realistic operating constraints and dynamic load variations to simulate practical industrial applications. The genetic algorithm was configured with a crossover rate of 90%, mutation rate of 3%, population size of 20 individuals, and single-point crossover method, running for 100 iterations. The fitness function incorporated multiple performance criteria including total error, settling time, and overshoot. The GA-optimized PID controller with parameters kp=95.984, ki=0.250, and kd=13.005 outperformed the Ziegler-Nichols-tuned controller (kp=20, ki=0.5, kd=3) across all performance metrics. Most notably, the overshoot was reduced by approximately 59% (from 4.724% to 1.922%), while maintaining comparable rise time. The controller also demonstrated excellent robustness when subjected to variable load torques of 20 N·m and 10 N·m at different points during simulation.

Keywords: PID controller, genetic algorithm, DC motor, Ziegler-Nichols method, speed control optimization

INTRODUCTION

DC motors have emerged as fundamental components of contemporary industrial control systems due to their versatility, reliability characteristics, and relative simplicity of control mechanisms. These motors are utilized across a broad spectrum of applications including robotics, electric vehicles, aerospace systems, and various manufacturing processes (Ortatepe, 2023). One of the most critical aspects of DC motor control is achieving precise speed regulation necessary for optimal performance and efficiency under dynamic operating conditions. To address this challenge, various control strategies such as proportional-integral-derivative (PID) controllers have emerged as widely preferred solutions due to their robustness and implementation simplicity. The control performance of PID controllers largely depends on the accurate determination of their parameter configurations (Borase et al., 2021). The mathematical modeling of DC motors plays a critical role in the design and optimization of control strategies. A comprehensively characterized DC motor model precisely represents the dynamic behaviors of the motor, including the relationships between armature voltage, current, and rotational velocity (Allaoua et al., n.d.; Tiwari et al., 2018). Researchers have developed various mathematical models over the years, ranging from simple linear approximations to complex nonlinear formulations that incorporate significant factors such as friction, magnetic saturation, and load variations. These models not only provide the foundation for simulation and analysis of motor behavior under various operating conditions but also contribute significantly to the formulation of advanced control techniques. Despite their widespread implementation, PID controllers encounter significant limitations when applied to systems with complex dynamics and time-varying parameters.

The main problem addressed in this work is to ensure reliable tracking of DC motor speed under realistic industrial constraints (time delay, supply voltage limitations, sudden load torque changes) without violating overshoot and settling time limits; classical Ziegler-Nichols tuning often cannot guarantee target performance under these conditions. Traditional parameter tuning methodologies, such as Ziegler-Nichols, frequently prove inadequate in delivering optimal performance across variable operational scenarios (Patel, 2020). To overcome these limitations, researchers have developed various optimization algorithms to enhance PID controller performance. These approaches encompass classical optimization techniques such as gradient descent and pole placement, as well as contemporary metaheuristic methods including particle swarm optimization (PSO), genetic algorithms (GA), and artificial neural networks (ANN) (Gaing, 2004a, 2004b; Pereira & Pinto, 2005). These techniques aim to automate the parameter tuning process and adapt controller parameters to changing system conditions, thereby improving control precision and robustness (Figueiredo et al., 2023). Manuel et al. (2023) studied a DC motor speed model

Corresponding Author: Zafer Civelek, zafercivelek@karatekin.edu.tr

This work is licensed under a Creative Commons Attribution 4.0 International License.

based on MATLAB/Simulink and used the standard motor model as material; optimized PID gains with meta-heuristic methods such as EO, PSO, TLBO, DE, and GA and compared them with FLC; as a result, they reported that optimized PIDs outperformed classical tuning, while FLC provided the lowest overshoot and settling time (Manuel et al., 2023). Huang et al. (2018) used a model that includes PWM/saturation effects as material in BLDC speed control; designed a self-tuning fuzzy PID with anti-windup block as a method and tested it under sudden load and reference jumps; as a result, it showed shorter settling time, lower overshoot, and better disturbance rejection compared to the classical PID (Jigang et al., 2018). Ahangari Sisi et al. (2023) established a materially delayed system in the arm assembly driven by a time-delayed DC motor; as a method, they compensated for the delay with the Smith estimator and adjusted the PID according to the non-delayed part; as a result, they stated that they reduced the delay-induced oscillations and obtained a faster/damped response (Ahangari Sisi et al., 2023). Idir et al. (2018) tested PID and fractional order FOPID with DC motor speed model as material; optimized ITAE criterion with DE and PSO as method; as a result, they showed that FOPID surpassed PID in terms of both tracking and noise immunity (Idir et al., 2018). Saravanan et al. (2025) took the DC motor control system as the material and adjusted the PID gains according to ITAE with Kookaburra and Red Panda optimization algorithms as the method; as a result, they reported significant improvements in rise/settlement times and robustness (Saravanan et al., n.d.). Acharya et al. (2021) worked with an armature-controlled DC motor model in MATLAB/Simulink as a material; adjusted the PID gains according to ITAE with Archimedes Optimization (AOA) and Dispersive Flies Optimization (DFO) as a method and compared them with Ziegler-Nichols and PSO; as a result, they showed that AOA/DFO reduces the rise and settling times and reduces overshoot, and DFO converges faster (Acharya et al., 2021). Sharma et al. (2022) used DC motor speed model as material and compared PSO-based PID tuning with ZN-PID on four performance indices (IAE, ISE, ITAE, ITSE). As a result, they reported that PSO-PID gives superior and better transient regime in all indices (Sharma et al., 2022). Yadav and Gupta (2024) considered a DC motor speed system with a materially delayed dynamics and designed a modified Smith estimator + PID with a direct synthesis approach and tested the servo/regulator conditions and ±30% parameter deviations. As a result, they showed that ISE/IAE is significantly reduced and the immunity to disturbances is increased compared to the classical PID (Yadav & Gupta, 2024).

This study focuses on the mathematical modeling of DC motors and the metaheuristic optimization of PID controllers for speed regulation. The research examines the formulation of mathematical models that characterize the structural parameters, fundamental operating principles, and dynamic behaviors of DC motors. The work systematically analyzes the challenges associated with PID controller parameter tuning and evaluates proposed optimization methodologies to overcome these challenges. Additionally, the impact of sudden load variations and environmental factors on controller performance is comprehensively addressed. Finally, this investigation highlights recent advancements in adaptive and intelligent control techniques that offer promising solutions for overcoming the limitations of conventional PID controllers. This study emphasizes the importance of parameter tuning of PID controllers in DC motor control. It also presents how parameter optimization makes the control system stable, accurate and efficient.

In industrial applications, DC motors are subjected to time-varying load torques, measurement and processing delays, and saturation of the control signal. Under these conditions, classical PID tuning methods such as Ziegler–Nichols may fail to achieve the desired balance between overshoot, settling time, and tracking error, and are sensitive to system parameter uncertainties. This study addresses this tuning problem, where PID gains cannot be determined in closed form and must be optimized under a multi-objective performance metric (total error, settling time, overshoot). As a solution approach, a genetic algorithm (GA)-based PID optimization is proposed using a model that includes realistic constraints such as time delay (~100 ms), supply voltage limit (35 V), and variable load torques applied at specific instants (e.g., 20 and 10 N m at 35 and 65 seconds). This approach is systematically compared with the classical Ziegler-Nichols. The contribution of this study to the literature is as follows:

- Mathematical modeling of DC motors with comprehensive characterization of dynamic behaviors
- Systematic analysis of PID controller parameter tuning challenges
- Evaluation of metaheuristic optimization methodologies for PID controllers
- Assessment of how sudden load variations and environmental factors affect controller performance
- Review of recent advancements in adaptive and intelligent control techniques

Table 1 shows a summary of the literature.

METHODS

Methodology and Material

In this study, optimized PID controller parameters for speed control of DC motor were developed. First, a comprehensive mathematical model of DC motor was created in MATLAB/Script environment and operating constraints and variable load conditions that may be encountered in industrial applications were included in the simulation. Genetic algorithm (GA) approach was used for optimization of PID controller parameters. GA was configured with 90% crossover rate, 3% mutation rate, 20 individual population size and single point crossover method and was run for 100 iterations. In the optimization process, a fitness function was used that considered multiple performance criteria including total error, settling time and overshoot values. First, a study was conducted on the DC motor model.

DC Motor Mathematical Model Expansion

The mathematical model of a DC motor comprises the integration of electrical and mechanical dynamics to fully characterize its operation. This section presents a comprehensive description encompassing the differential equations, state-space representations, transfer functions, and practical considerations employed in the mathematical modeling of DC motors (Ortatepe, 2023a). Equation 1 below the electrical behavior of the armature circuit is derived using Kirchhoff's Voltage Law (KVL):

Table 1. Comparison with the literature

Authors & year	Title	Contributions	Implementation	Performance metrics
(Khettab et al., 2025)	Performances improvement of DC motor using a fractional order adaptive PID controller...	Optimization of Fractional Order Adaptive PID (FAPID) controller using GA; better performance compared to APID	GA used to optimize FAPID parameters (Kp, Ki, Kd, λ, μ).	Rise time: 0.0084s, settling time: 0.0683s, overshoot: 0%, MAE: 0.0032 rad/s
(M. V Patel & Pathak.,2015)	PID tuning using genetic algorithm for DC motor positional control system	GA-optimized PID outperforms Ziegler-Nichols with lower overshoot and faster response time	GA used ITAE, IAE, and ISE objective functions to optimize PID parameters.	Rise time: 0.06s (GA-IAE), settling time: 0.741s, overshoot: 38.7%
(Tiwari et al., 2018b)	Control of DC motor using genetic algorithm based PID controller	GA-optimized PID shows lower overshoot (0.408%) and faster rise time compared to Ziegler-Nichols	MSE and ITAE objective functions used; GA parameter ranges [0-700, 0-8000, 0-5]	Rise time: 0.0202s, settling time: 0.917s, overshoot: 0.408%
(Mahmood et al., 2023)	Design of fractional order PID controller based on genetic algorithm optimization...	GA-optimized FOPID for VTOL system; comparison of ISE, ITSE, and MSE objective functions	GA optimized FOPID parameters (Kp, Ki, Kd, λ, μ); population size 40	Rise time: 0.00259s, settling time: 0.0044s, overshoot: 0.127%
(Jamil & Moghavvemi, 2021)	Optimization of PID controller tuning method using evolutionary algorithms	Comparison of GA and PSO for PID tuning; PSO outperforms GA in convergence speed	GA and PSO used to optimize PID parameters; GA parameters: population=35, iterations=40	Rise time: 0.0048s, settling time: 0.0079s, overshoot: 0%
(Mahfoud et al., 2021)	A new strategy-based PID controller optimized by genetic algorithm for DTC of the doubly fed induction motor	GA-optimized PID for DTC of DFIM; improved speed, torque, and flux ripples	GA optimizes PID parameters (Kp, Ki, Kd) using weighted ISE, IAE, and ITAE	Response time:18.2ms, overshoot: 0%, torque ripples:2.05Nm, THD: 4.8%
(Yan & Zhou, 2020)	Application to optimal control of brushless DC motor with ADRC based on genetic algorithm	Proposed ADRC optimized by GA for BLDCM. Introduced ISE-ITAE fitness function to balance dynamic and static performance. Demonstrated superiority over PID control	Adaptive GA: Variable crossover (Pc*Pc*) and mutation (Pm*Pm*) probabilities. Fitness function: ISE+ITAE. Population size, coding digits, and evolution steps configured	Overshoot: 3.5% reduce, lower torque ripple, improved stability
(Suseno & Ma'Arif, 2021)	Tuning of PID controller parameters with genetic algorithm method on DC motor	Applied GA for PID tuning on DC motors. Compared GA with trial-and-error methods	Population size: 50 Generations: 100 Mutation/crossover effects: Tested varying rates	Overshoot: 2%, Settling time: 13.5s. Rise time: 2.7872s.
(Ortatepe, 2023b)	Genetic algorithm based PID tuning software design and implementation for a DC motor control system	Developed MATLAB-based GA-PID tuning software. Compared GA with conventional methods. Conducted sensitivity analysis	Fitness function: ITAE Selection: Tournament method Crossover: One-point strategy Mutation rate: 0.01 Population size: 50 Generations: 40	Reduced overshoot (e.g., 0% vs. 5% in conventional PID), Minimized steady-state error, Faster settling time (e.g., 0.4s), Robustness to parameter variations.
(Gonzales & Manzano, 2020)	Genetics algorithms based PID tuning using elastic net as model structure in non-parametric system identification	Integrated elastic net (non-parametric) system identification with GA-based PID tuning	GA parameters: 33 bits/ chromosome, mutation factor: 0.7, crossover factor: 0.3, 40 generations, population size: 20	PID GA&EN: Overshoot: 103.69%, peak time: 4.11s, Settling time: 4.79s. PID GA&TF: Settling time: 5.94s
(Ibrahim et al., 2019)	Optimal PID controller of a brushless DC motor using genetic algorithm	- Optimized PID parameters for BLDC motor using GA with ISE/ IAE criteria - Demonstrated superiority over trial-and-error and MATLAB Tuner	GA parameters: Roulette, 40 generations, population size: 20 Objective functions: ISE and IAE. Mutation: 2%, Crossover rate: 90%	Overshoot: 0 Rise time: 4.56×10-84.56×10-8s Settling time: 8.12×10-88.12×10-8s Steady-state error: 0

$$V_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + e_b(t) \tag{1}$$

where:

- **Va(t):** Applied armature voltage (V)
- **Ra:** Armature resistance (Ω)
- **La:** Armature inductance (H)
- **ia(t):** Armature current (A)
- **eb(t):** Back electromotive force (EMF) (V)

Equation 2 below the back EMF is proportional to the motor's angular velocity [ω(t)]:

$$eb(t)=Ke\omega(t) \tag{2}$$

where:

Ke: Back EMF constant (V·s/rad).

Equation 3 below the mechanical subsystem follows Newton's second law for rotation:

$$J\frac{d\omega(t)}{dt} + B\omega(t) = \tau_m(t) - \tau_L(t) \tag{3}$$

where:

- **J:** Moment of inertia (kg·m²)
- **B:** Viscous friction coefficient (N·m·s/rad)
- **τm(t):** Motor torque (N·m)
- **τL(t):** Load torque (N·m)

Equation 4 below the motor torque is proportional to armature current:

$$\tau m(t)=Kt\ \ ia(t) \tag{4}$$

where:

- **Kt:** Torque constant (N·m/A). In SI units, *Kt=Ke*.

Equations 5 and 6 below define the state variables as angular velocity (*ω*) and armature current (*ia*):

$$\frac{d\omega}{dt} = -\frac{B}{J}\omega + \frac{K_t}{J}i_a - \frac{\tau_L}{J} \tag{5}$$

$$\frac{di_a}{dt} = -\frac{K_e}{L_a}\omega - \frac{R_a}{L_a}i_a + \frac{V_a}{L_a} \tag{6}$$

This linearized model is foundational for control system design.

Assuming no load torque (τL=0) and applying Laplace transforms at equation 7 below:

$$G(s) = \frac{\omega(s)}{V_a(s)} = \frac{K_t}{(L_a s+R_a)(Js+B)+K_e K_t} \tag{7}$$

Equation 8 below for simplicity if La=0(common in small DC motors):

$$G(s) = \frac{\omega(s)}{V_a(s)} = \frac{K_t}{(R_a J_s)+(R_a B+K_e K_t)} \tag{8}$$

This first-order model is often used for speed control.

In the light of these equations, the DC motor control block diagram is shown in **Figure 1**.

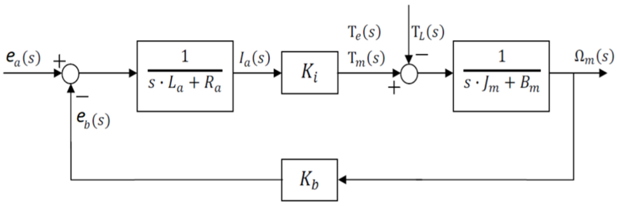

Figure 1. The DC motor control block diagram

PID Controller

The main working principle of the PID (proportional-integral-derivative) controller is based on errors. The principle is to create the difference between the desired value and the actual value, and to produce the required output value of the system by correcting this difference value with proportional, integral, and derivative components (Chauhan et al., 2023). While the proportional component provides a quick response by scaling the current output value with a coefficient when an error occurs, it cannot eliminate the steady-state error. There must be an error with the controller to produce current control output. The magnitude of the proportional coefficient affects the speed of the system's response, meaning a low coefficient can be considered as a low response and a high coefficient as a high response. However, excessively high values cause undesirable overshooting and endless oscillations in the system. The integral component is used to correct the steady-state error and to optimize the integral characteristics of the system. The integral effect of the system is inversely proportional to the time constant and is ready to intervene if the deviation is not corrected. However, a very strong integral effect can cause delays in responses to external system effects. The derivative component detects the changing trend of the error sensitively, intervenes in the system in advance, and comes into play as a correction signal. In this respect, it increases the response speed of the system to external inputs (Zhang et al., 2009). The power of the derivative component not only measures deviations or errors but also predicts changes in deviation, enabling control measures to be applied in advance. This reduces system overshooting, prevents oscillations, and shortens response time. However, if the derivative time constant is too large, the system may become unstable. The general equation of PID controller is given in equation 9.

$$u(t) = Kpe(t) + Ki\int e(t)dt + Kd\frac{de(t)}{dt} \tag{9}$$

Where:

- **u(t):** Control signal (output)
- **e(t):** Error signal (desired value - actual value)
- **Kp:** Proportional gain coefficient
- **Ki:** Integral gain coefficient
- **Kd:** Derivative gain coefficient
- **∫e(t)dt:** Integral of error with respect to time
- **de(t)/dt:** Derivative of error with respect to time

As individual components:

- **Proportional term:** P = Kp·e(t)
- **Integral term:** I = Ki·∫e(t)dt
- **Derivative term:** D = Kd·(de(t)/dt)

Ziegler-Nichols

PID controllers continue to be the predominant control solution for DC motor speed regulation due to their effectiveness, simplicity, and straightforward implementation. However, the performance of a PID controller is largely dependent on appropriate parameter tuning. Among various tuning methodologies, the Ziegler-Nichols method offers a practical approach particularly suitable for DC motor applications, as it can be implemented without detailed knowledge of motor parameters that may vary with operating conditions or aging. By presenting a systematic procedure that accommodates the variability and nonlinearities inherent in electromechanical systems, it remains a robust approach for tuning PID controllers in DC motor applications (Chauhan et al., 2023; Taguchi & Araki, 2000). Standard Ziegler-Nichols's parameters typically require modification for DC motor applications, often reducing Kp to achieve acceptable overshoot. Anti-windup mechanisms are necessary for DC motor control due to supply voltage limitations and inertial effects. In this study, PID parameters were manually obtained using the Ziegler-Nichols method. The parameter acquisition process begins by disabling the integral and derivative actions of the controller. After setting ki and kd values to zero, the proportional gain coefficient kp is increased until sustained oscillations occur. The period (Tu) of the oscillatory signal obtained at the system output is recorded. Under the saturation and delay effects in the system (to satisfy the overshoot and settling time constraints), we gradually weakened the integral effect by applying the standard "ZN initialization + fine-tuning" step; at the end of this process, the final coefficients were obtained. Finally, PID parameters are established using the table recommended by Ziegler-Nichols with the recorded Tu and the final kp value, ku, which produced the oscillation (Patel, 2020). DC motor application values of Ziegler-Nichols parameters are given in **Table 2**.

Table 2. Ziegler-Nichols DC motor parameters

Controller type	Kp	Ki	Kd
P	0.5 Ku	0	0
PI	0.45 Ku	0.54 Ku/Tu	0

Genetic Algorithm (GA)

GAs are robust metaheuristic search techniques inspired by the principles of natural selection, employed to address complex optimization problems. Initially proposed by John Holland in the 1960s and popularized by David E. Goldberg's seminal work, Genetic Algorithms in Search, Optimization, and Machine Learning in 1989, GAs represent one of the most widely utilized forms of evolutionary computation techniques (Goldberg & Deb, 1991). These algorithms aim to solve intricate optimization problems by emulating the biological evolutionary process, which is grounded in Darwin's principles of natural selection and "survival of the fittest." Genetic algorithms offer significant advantages in tackling high-dimensional, nonlinear, and analytically challenging problems (Sivanandam & Deepa, 2008).

A genetic algorithm comprises several key components, including encoding, fitness function, selection, crossover, and mutation. In contemporary applications, various encoding strategies are employed depending on the nature of the problem. Among the most frequently used encoding methods are binary encoding, permutation encoding, value encoding, and tree encoding. Demonstrated that the choice of encoding must align with the problem's characteristics, as inappropriate encoding can significantly degrade the algorithm's performance (Rothlauf, 2003).Genetic algorithm flow chart is shown **Figure 2**.

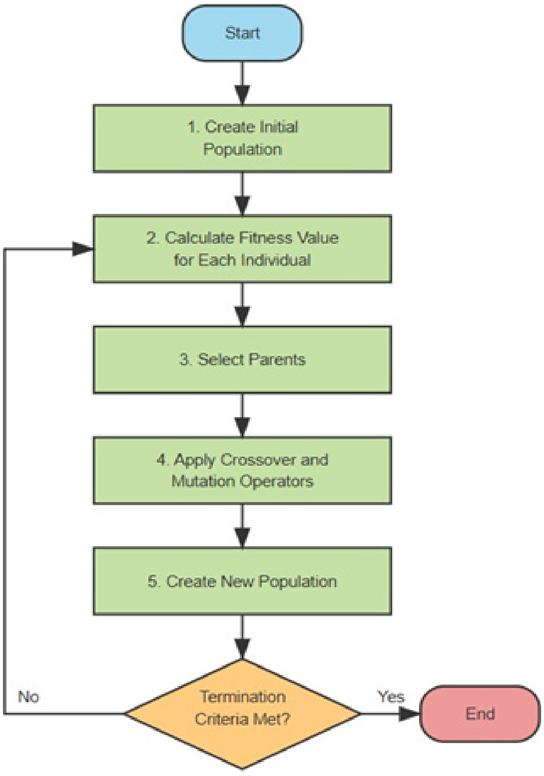

Figure 2. Genetic algorithm flow chart

The fitness function is a mathematical expression that evaluates how close everyone is to solving the problem. The researcher emphasized that the correct design of the fitness function is one of the most critical factors in the success of genetic algorithms. The selection mechanism determines which individuals in the population will have the opportunity to reproduce. Among the most used selection methods in the literature are roulette wheel selection, tournament selection, rank-based selection, and elitism (Jayachitra & Vinodha, 2014).

Crossover is the process of generating new solutions (offspring) from two parent solutions. Researchers investigated the critical role of crossover in the performance of genetic algorithms and explored the effects of different crossover operators. The primary crossover methods used in the literature include single-point crossover, multi-point crossover, uniform crossover and arithmetic crossover (Jaen-Cuellar et al., 2013; Pereira & Pinto, 2005).

Mutation is the process of introducing random changes into the solution set to increase genetic diversity and prevent the solution set from becoming trapped in local optima. Demonstrated that both excessively low and excessively high mutation rates can negatively impact the performance of the algorithm (Zahir et al., 2018; Zhang et al., 2009).

The researcher examined the applications of genetic algorithms in the design of control systems and demonstrated the effectiveness of genetic algorithms in optimizing PID controller parameters (Chauhan et al., 2023; Kasilingam, 2014; Zahir et al., 2018). In this study, the crossover rate of the genetic algorithm was selected as 90%, with a mutation rate of 3%. The population size was determined to be 20 individuals, and a single-point crossover method was implemented. The genetic algorithm was executed for 100 iterations.

RESULTS

The DC motor was modeled in the MATLAB/Script environment, and its angular velocity was controlled using a PID controller. The MATLAB/Script codes for the modeled DC motor are provided in Appendix-1. To make the study more realistic, a time delay of 100 ms was added to the DC motor. Additionally, a more realistic working environment was provided by limiting the DC source voltage to 35 volts. Load torques of 20 N.m at the 35th second and 10 N.m at the 65th second of the simulation were applied to the DC motor. The parameters of the DC motor are presented in **Table 3**.

Table 3. DC motor parameters
r = 0.35; % armature resistance
L = 0.0015; % nominal inductance
j = 0.06; % moment of inertia
b = 0.1; % damping constant
kt = 0.5; % torque constant
ke = 0.5; % voltage constant

The simulation step size was selected as 0.001 and the simulation duration as 100 ms. The PID controller coefficients kp, ki, and kd were optimized using a genetic algorithm. The coefficients obtained because of the optimization are: kp=95.984, ki=0.250, and kd=13.005. The change in the fitness function during the optimization process is shown in **Figure 3**.

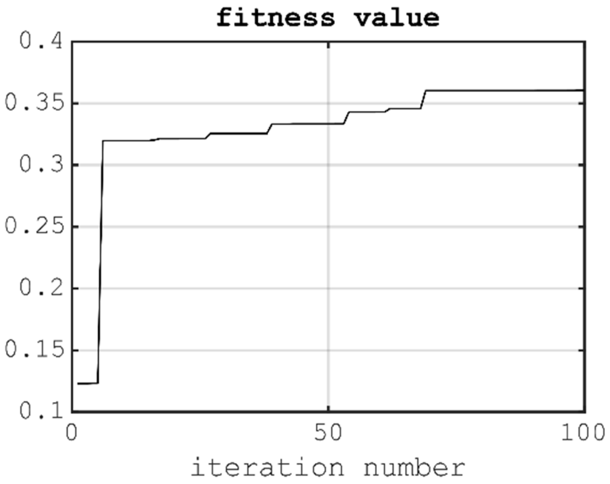

Figure 3. Values obtained by the fitness function of the genetic algorithm

Three criteria were taken into consideration when determining the fitness function of the genetic algorithm. These are the total errors in the step response of the system, settling time, and overshoot amount. The values these parameters assumed during optimization are shown in **Figure 4**.

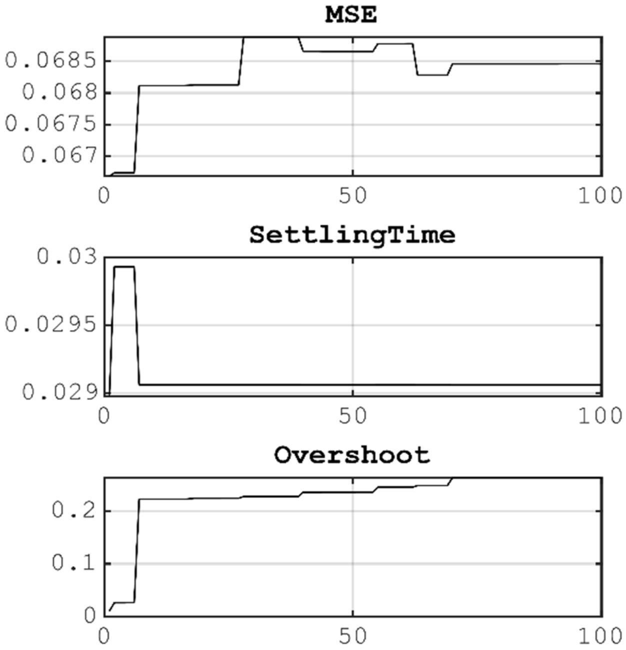

Figure 4. Variation of parameters constituting the fitness function

The PID coefficients obtained using the Ziegler-Nichols method were found to be kp=20, ki=.5, and kd=3. The response of the DC motor as a result of applying both the coefficients obtained with the genetic algorithm and those obtained with the Ziegler-Nichols method to the PID controller against a step reference signal with a set point=30 is presented comparatively in **Figure 5**. As can be seen from **Figure 5**, the genetic algorithm has found coefficients that yield better results.

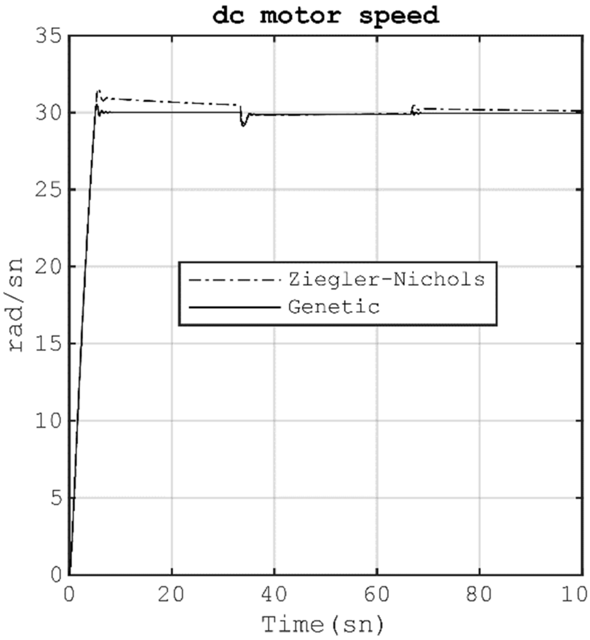

Figure 5. Step response of the DC motor

The results obtained through MATLAB's step info function are summarized in **Table 4**. According to **Table 4**, the genetic algorithm is better than Ziegler-Nichols. The overshoot is 1.992 with coefficients optimized by the genetic algorithm, while it is 3.8 with coefficients determined by the Ziegler-Nichols method. Therefore, the genetic algorithm has yielded better results than the Ziegler-Nichols method in terms of rise time, overshoot, peak, and peak time values.

Table 4. Comparison of DC motor speed results

Parameters	Ziegler-Nichols	Genetic
Rise time	3.800	3.799
Overshoot	4.724	1.922
Peak	31.536	30.533
Peak time	5.601	5.301

When the DC motor simulation is run with optimized coefficients, the changes in control voltage, motor current, angular velocity, derivative of motor current, angular acceleration, and load torque are shown in **Figure 6**. From this figure, it appears that the PID controller with coefficients optimized by the genetic algorithm successfully controls the angular velocity at the output despite changes in load torque.

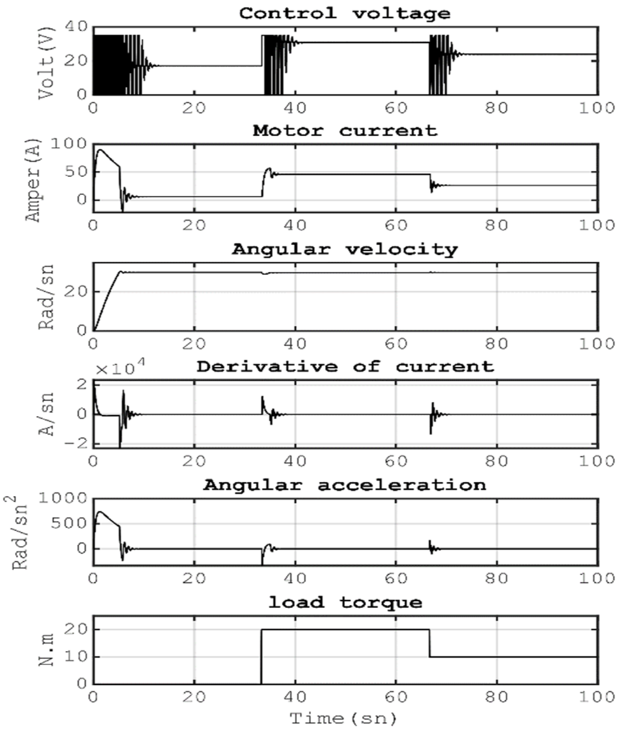

Figure 6. Values of the DC motor during simulation

CONCLUSION

As a result, this study has demonstrated the superior performance of PID controllers with coefficients optimized by genetic algorithms compared to those tuned by the traditional Ziegler-Nichols method for DC motor speed control. The research utilized a comprehensive mathematical model of a DC motor implemented in MATLAB/Script, incorporating realistic operating conditions such as time delay, voltage limitations, and variable load torques to simulate practical applications. The genetic algorithm optimization approach yielded PID coefficients of kp=95.984, ki=0.250, and kd=13.005, which demonstrated significant improvements over the Ziegler-Nichols method (kp=20, ki=0.5, kd=3) across all critical performance metrics. Notably, the GA-optimized controller reduced overshoot from 4.724% to 1.922%, while maintaining comparable rise time. The optimization process incorporated multiple criteria in the fitness function, including total error in step response, settling time, and overshoot magnitude, ensuring a balanced control solution. The robustness of the GA-optimized controller was further evidenced by its excellent disturbance rejection capabilities. When subjected to sudden load torque variations of 20 N·m at 35 seconds and 10 N·m at 65 seconds, the controller maintained stable angular velocity, demonstrating its suitability for real-world applications where load conditions frequently change. This research contributes to the existing literature by providing a systematic comparison between conventional and evolutionary algorithm-based tuning methods for PID controllers in DC motor applications. The findings align with previous studies indicate that metaheuristic optimization techniques can significantly enhance control system performance beyond what traditional methods achieve.

ETHICAL DECLARATIONS

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

REFERENCES

Acharya, B. B., Dhakal, S., Bhattarai, A., & Bhattarai, N. (2021). PID speed control of DC motor using meta-heuristic algorithms. *Int J Power Electr Drive Syst*, *12*(2), 822-831. doi:10.11591/ijpeds.v12.i2.pp822-831

Ahangari Sisi, Z., Mirzaei, M., & Rafatnia, S. (2023). Time delay estimation and PID controller design using smith predictor for lever arm platform. *Iran J Mechan Eng Transact ISME*, *24*(2), 142-156. doi:10.30506/JMEE.2023.2011437.1323

Allaoua, B., Gasbaoui, B., & Mebarki, B. (n.d.). Leonardo Electronic Journal of Practices and Technologies Setting Up PID DC Motor Speed Control Alteration Parameters Using Particle Swarm Optimization Strategy. Retrieved February 21, 2025, from http://lejpt.academicdirect.org

Borase, R. P., Maghade, D. K., Sondkar, S. Y., & Pawar, S. N. (2021). A review of PID control, tuning methods and applications. *Int J Dynam Control*, *9*(2), 818-827. doi:10.1007/S40435-020-00665-4/FIGURES/1

Chauhan, S., Singh, B., Singh, M., & Li, Z. (2023). Review of PID control design and tuning methods. *J Physic Confer Series*, *2649*(1), 012009. doi:10.1088/1742-6596/2649/1/012009

de Figueiredo, R., Toso, B., & Schmith, J. (2023). Auto-Tuning PID Controller Based on Genetic Algorithm. In Disturbance Rejection Control. IntechOpen.

Gaing, Z. L. (2004a). A particle swarm optimization approach for optimum design of PID controller in AVR system. *IEEE Transact Energy Convers*, *19*(2), 384-391. doi:10.1109/TEC.2003.821821

Gaing, Z. L. (2004b). A particle swarm optimization approach for optimum design of PID controller in AVR system. *IEEE Transact Energy Convers*, *19*(2), 384-391. doi:10.1109/TEC.2003.821821

Goldberg, D. E., & Deb, K. (1991). A comparative analysis of selection schemes used in genetic algorithms. In *Foundations of genetic algorithms* (Vol. 1, pp. 69-93). Elsevier.

Idir, A., Kidouche, M., Bensafia, Y., Khettab, K., & Tadjer, S. A. (2018). Speed control of DC motor using PID and FOPID controllers based on differential evolution and PSO. *Int J Intell Eng Systems*, *11*, 4. doi:10.22266/ijies2018.0831.24

Jaen-Cuellar, A. Y., Romero-Troncoso, R. D. J., Morales-Velazquez, L., & Osornio-Rios, R. A. (2013). PID-controller tuning optimization with genetic algorithms in servo systems. *Int J Advan Robotic Systems*, *10*. doi:10.5772/56697/ASSET/IMAGES/LARGE/10.5772_56697-FIG12.JPEG

Jayachitra, A., & Vinodha, R. (2014). Genetic algorithm based PID controller tuning approach for continuous stirred tank reactor. *Advanc Artific Intell*, *2014*, 1-8. doi:10.1155/2014/791230

Jigang, H., Jie, W., & Hui, F. (2018). An anti-windup self-tuning fuzzy PID controller for speed control of brushless DC motor. *Automat J Control, 58*(3), 321-335. doi:10.1080/00051144.2018.1423724

Kasilingam, G. (2014). Particle swarm optimization based PID power system stabilizer for a synchronous machine. *Int J Electr Comput Eng*, *8*(1), 118-123.

Zahir, A. A., Alhady, S. S. N., Othman, W. A. F. W., & Ahmad, M. F. (2018). Genetic algorithm optimization of PID controller for brushed DC motor. *Lecture Note Mechan Eng*, *0*(9789811087875), 427-437. doi:10.1007/978-981-10-8788-2_38

Manuel, N. L., İnanç, N., & Lüy, M. (2023). Control and performance analyses of a DC motor using optimized PIDs and fuzzy logic controller. *Res Control Optimizat*, *13*, 100306. doi:10.1016/J.RICO.2023.100306

Ortatepe, Z. (2023). Genetic algorithm based PID tuning software design and implementation for a DC motor control system. *Gazi Univ J Sci Part A Eng Innovat*, *10*(3), 286-300. doi:10.54287/GUJSA.1342905

Patel, V. V. (2020). Ziegler-Nichols tuning method: understanding the PID controller. *Resonance*, *25*(10), 1385-1397. doi:10.1007/S12045-020-1058-Z

Pereira, D. S., & Pinto, J. O. P. (2005). Genetic algorithm based system identification and PID tuning for optimum adaptive control. *IEEE/ASME Int Confer Advanc Intell Mechatr, AIM*, *1*, 801-806. doi:10.1109/AIM.2005.1511081

Rothlauf, F. (2003). Representations for genetic and evolutionary algorithms. *J Operat Res Society*, *54*(10), 1112.

Saravanan, G., Pazhanimuthu, C., & Naveen, P. (2025). Performance improvement of DC motor control system using PID controller with Kookaburra and Red Panda optimization algorithm. *Sci Rep, 15*(1), 20021. doi:10.1038/s41598-025-87607-2

Sharma, A., Sharma, V., & Rahi, O. P. (2022). PSO tuned PID controller for DC motor speed control. *Lecture Note Electr Eng*, *822*, 79-89. doi:10.1007/978-981-16-7664-2_7

Sivanandam, S. N., & Deepa, S. N. (2008). Genetic algorithm optimization problems. *Introduct Genet Algorit*, 165-209. doi:10.1007/978-3-540-73190-0_7

Tiwari, S., Bhatt, A., Unni, A. C., Singh, J. G., & Ongsakul, W. (2018). Control of DC motor using genetic algorithm based PID controller. *Proceed Confer Industr Commerc Use Energy, ICUE*, 1-16. doi:10.23919/ICUE-GESD.2018.8635662

Yadav, A., & Gupta, M. K. (2024). Design a controller based on smith predictor by direct synthesis method for speed control DC motor. *Int J Elect Eng Comp Sci*, *6*, 86-91. doi:10.37394/232027.2024.6.9

Zhang, J., Zhuang, J., Du, H., & Wang, S. (2009). Self-organizing genetic algorithm based tuning of PID controllers. *Informat Sci, 179*(7), 1007-1018. doi:10.1016/J.INS.2008.11.038