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A Design of Intelligent Controller for Direct Current Motor

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ABSTRACT

A Direct Current motor is commonly employed for many industrial applications due to its high torque and efficiency. This article expresses an optimally designed controller of Direct Current motor speed control depending on the genetic algorithm (GA). The optimization method is used for searching for the ideal Proportional Integral Derivative (PID) factors. The DC motor controller design methods include three kinds: trial and error PID design, auto-tuning PID design, and GA-based controller design. A GA-PID controller is designed to enhance the system performance using GA. PID controller coefficients (K_p, K_i *and* K_d) are calculated by GA to produce optimal PID as a hybrid PID with a GA controller. The suggested controller GA-PID is planned, modeled and simulated by the MATLAB software program. A comparison output system performance is monitored for every controller scheme. The results display the time characteristics performance of GA-PID controller-based.

Keywords: Intelligent Controller, Direct Current (DC), Genetic Algorithm, PID Controller, MATLAB.

1 INTRODUCTION

The direct current (DC) motor, converts electrical energy into mechanical energy. DC motors are the simplest type of motor and are used in household appliances, such as electric razors, and electric windows in cars. Motor speed control keeps the motor's rotation at the preset speed and drives a system at the demanded speed. In a mechanical system, speed varies with several tasks so speed control is necessary to do mechanical work properly and it makes the motor operate easily. The speed control mechanism is applicable in many cases like controlling the movement of robotic vehicles, movement of motors in paper mills, and the movement of motors in elevators where different types of DC motors are used. The speed of the DC motor can be adjusted to a great extent to provide controllability ease and high performance [1, 2]. This paper aims to design a position controller of a DC motor by selecting PID parameters using a genetic algorithm. The model of a DC motor is considered a second-order system. And this paper compares two kinds of tuning methods of parameters for PID controllers. One is the controller design by the genetic algorithm, second is the controller design by the Ziegler and Nichols method. It was found that the proposed PID parameters adjustment by the genetic algorithm is better than the Ziegler & Nichols' method. The proposed method could be applied to the higher-order system also. PID Controller was first published officially by Minor sky in the early 19th century with his theory of three-term control. It is the most used controller in the industrial and robotics world until now [3, 4]. Some advantages of PID Controller are easy to understand, easy to be implemented, and able to provide good system stability [5]. Many systems can be stabilized, from non-linear to linear systems [6]. The tuning parameter of PID is important because it can guarantee controller efficiency [7].

Due to its excellent speed control characteristics, the DC motor has been widely used in industry even though its maintenance costs are higher than the induction motor. As a result, DC motor has attracted considerable research and several methods have evolved. Proportional Integral Derivative (PID) controllers have been widely used for speed and position control of DC motors. This paper endeavors to design a system using a Genetic Algorithm. Genetic Algorithm or in short GA is a stochastic algorithm based on principles of natural selection and genetics. Genetic Algorithms are a stochastic global search method that mimics the process of natural evolution. Using genetic algorithms to perform the tuning of the controller will result in the optimum controller being evaluated for the system every time. The objective of this paper is to show that by employing the GA method of tuning a system, optimization can be achieved. This can be seen by comparing the result of the GA optimized system against the classically tuned system.

The algorithm itself has many variations due to which natural phenomena in the world. Some of them are Genetic Algorithm (GA) [7, 8], Particle Swarm Optimization (PSO) [9], and Differential Evolution (DE) [10, 11]. They are the most commonly used algorithm in Intelligent Search Algorithm. To test the algorithm, it is applied to the PID Controller of the DC Motor System. The performance of the system along with several iterations and iteration times will be observed and analyzed. DC Motor is chosen due to its being commonly used in the industrial [10] and robotics world. Electric motors were developed in the late 1800s. By 1887, the electric motor was installed on the first electric trolley system in Richmond, Virginia. By 1892, the electric elevator and control system was invented. Thomas Edison promoted DC power and built electric power transmission systems to power DC motors. 1 hp to 100,000 hp electric motors are available to meet any industrial need. Asynchronous and synchronous motors and generators are available to suit specialized functions. The NEMA Frame is especially suited for challenging environments. Also, the motors can be vertical with high torque availability for additional power. Of course, they can operate on AC or DC power.

The work has been done on the analysis of genetic algorithm rules and membership function parameters [12]. In 1960, Prof. Holland introduced genetic algorithms [13, 14]. Genetic algorithms are applied to search for the globally optimal solution to problems [15]. The evolution process of genetic algorithms is based on natural selection. Examples of applications include industrial fans, blowers, pumps, machine tools, power tools, turbines, compressors, alternators, ships, rolling mills, paper mills, movers, and other special applications. Some systems can work in highly corrosive environments such as nuclear power stations and highly aggressive environments such as corrosive chemicals and gases. DC series motor is suitable for both high and low power drives, for fixed and variable speed electric drives. Because of its high starting torque, this motor uses in cheap toys and automotive applications such as Cranes, Air compressors, Lifts, Elevators, winching systems, Electric traction, Hair drier, Vacuum cleaner and speed regulation application, power tools, Sewing machines, Electric footing. The benefits of using a controller are electrical protection of the motor and subsequently, the mechanics, maintain a constant speed, even when loads are changing, dynamic response to changing system demands, even in a braking condition with four-quadrant drive, monitoring to evaluate machine performance, energy-saving and accurate speed control.

1.1 Objectives

a) To develop a robust control platform with optimization methods.
b) To improve the performance of DC motor speed control/ position control.
c) To add adaptation/ intelligence in our control architecture.

1.2 Methodology

The step response is the reference signal, DC motor which is a plant, scope where we see the output response and this is controller where we will see the performance by applying different approaches. Firstly, we apply the PID controller. PID controller is a combination of proportional, integral and derivative actions. PID Controller is the most common control algorithm used in industrial automation. PID controllers show poor control performances for an integrating process and a large time delay process “Figure 1”. then apply intelligent controller which is a class of control techniques that use various artificial intelligence computing approaches like neural networks, fuzzy logic, machine learning and genetic algorithms.

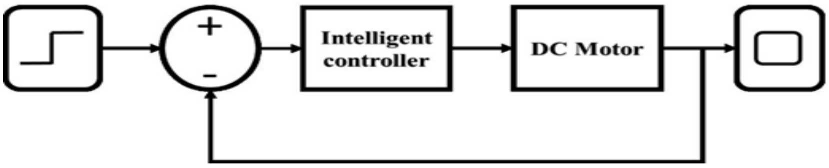

Figure 1: *Methodology of design of intelligent controller for direct current (dc) motor.*

2 INTELLIGENT CONTROLLERS

Intelligent control is a class of control techniques that use various artificial intelligence computing approaches like neural networks, Bayesian probability, fuzzy logic, machine learning, reinforcement learning, evolutionary computation and genetic algorithms.

2.1 Proportional Integral Derivative (PID) Controller

Intelligent PID controllers, are PID controllers where the unknown parts of the plant, which might be highly nonlinear and/or time-varying, are taken into account without any modeling procedure. Our main tool is an online numerical differentiator, which is based on easily implementable fast estimation and identification techniques. Several numerical experiments demonstrate the efficiency of our method when compared to more classic PID regulators.

The working principle behind a PID controller is that the proportional, integral and derivative terms must be individually adjusted or "tuned." Based on the difference between these values a correction factor is calculated and applied to the input. For example, if an oven is cooler than required, the heat will be increased “Figure 2”. Here are the three steps:

Proportional tuning (K_p) involves correcting a target proportional to the difference. Thus, the target value is never achieved because as the difference approaches zero, so too does the applied correction.

Integral tuning (K_i) attempts to remedy this by effectively cumulating the error result from the "P" action to increase the correction factor. For example, if the oven remained below temperature, “I” would act to increase the head delivered. However, rather than stop heating when the target is reached, "I" attempts to drive the cumulative error to zero, resulting in an overshoot.

Derivative tuning (K_d) attempts to minimize this overshoot by slowing the correction factor applied as the target is approached.

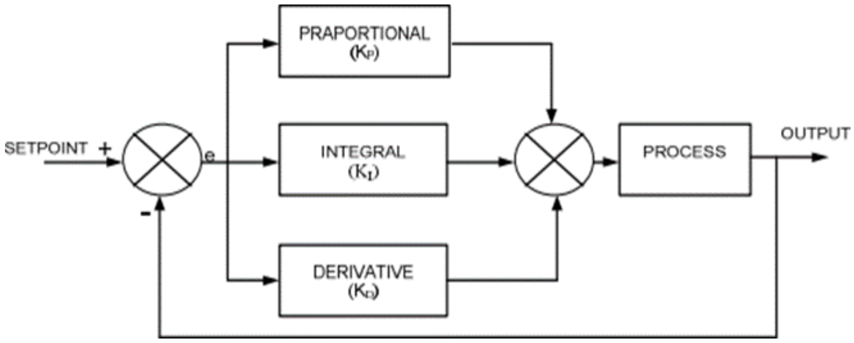

Figure 2: *Proportional integral derivative (PID) controller system.*

The controller attempts to minimize the error by adjusting the process control input. The PID controller calculation (algorithm) involves three constant parameters called the proportional (P), integral (I) and derivative (D) values, these values can be interpreted in terms of time. P depends on the present error, I on the accumulation of past error, and D is a prediction of future error, based on the current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, or power supplied to a heating element.

2.2 Genetic Algorithm (GA) Controller

A genetic algorithm is an evolutionary optimization technique. This optimization is inspired by genetic evolution in the animal world. It can minimize or maximize an objective function given “Figure 3”.

It has four steps in the process:

(1) Selection.
(2) Crossover.
(3) Mutation.
(4) Replace population with better fitness.

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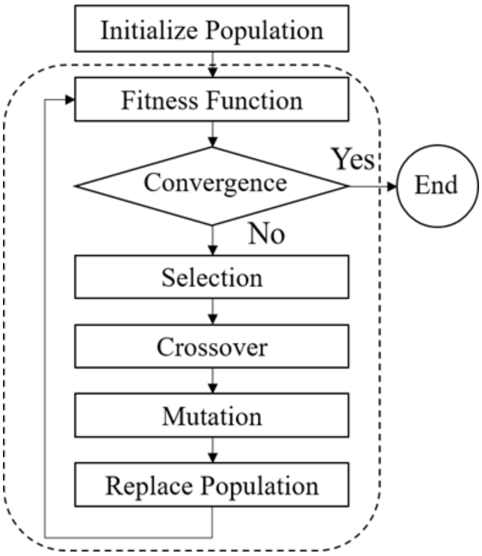

Figure 3: *Genetic algorithm (GA) controller flow chart.*

3 DIRECT CURRENT (DC) MOTOR

A DC motor is an electrical machine that converts electrical energy into mechanical energy. In a DC motor, the input electrical energy is the direct current which is transformed into the mechanical rotation "Figure 4".

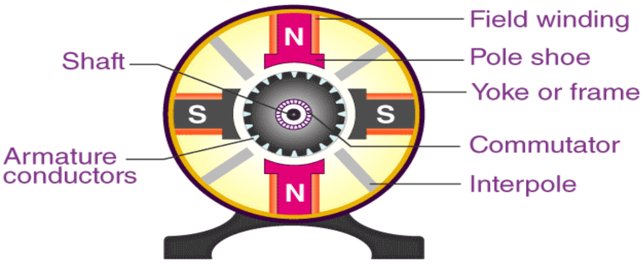

Figure 4: *Parts of a direct current (DC) motor [16].*

3.1 Types of Direct Current (DC) Motor

There are different types of DC motors available. They are listed below:

1. PMDC (Permanent Magnet DC Motor) type.
2. Separately excited.
3. Self-excited.

The classification of self-excited can be done like the following.

1. Shunt-wound.
2. Series wound.
3. Compound wound type.

The compound type can be classified into two types namely long shunt as well as the short shunt. The long shunt is further classified as cumulative and differential types. Similarly, the short shunt types are further classified as cumulative and differential types. The separately excited and series types are commonly preferred for industrial purposes "Figure 5". The DC motors classification figure is shown below.

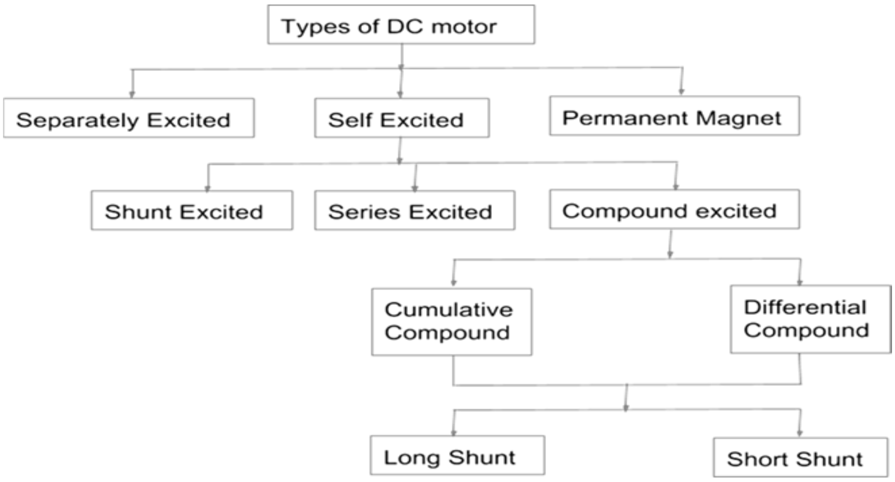

Figure 5: *Types of direct current (DC) motor.*

3.2 Direct Current (DC) Motor Controller

DC motor controller manipulates the position, speed, or torque of a DC-powered motor and easily reverses, so the DC runs in the opposite direction. Enjoy higher starting torque, quick starting and stopping, reversing, variable speeds with voltage input and more.

There are two major types of DC motor - the common DC motor with brushes, and the brushless DC motor. Both types have a non-moving source of magnetic fields, known as a stator, and a rotating source of magnetic fields, known as the rotor.

The intended use of a motor controller is to manage the performance of an electrical motor. Irrespective of the motor type, this electronic device can fulfill the following functions:

(1) Start/stop the motor.
(2) Change the rotation direction.
(3) Control the speed and torque.
(4) Provide overload protection.
(5) Prevent electrical faults.

4 CONTROLLER DESIGN

4.1 Direct Current (DC) Motor: Proportional Integral Derivative (PID)

Direct-current motors find applications in electrical equipment, computer peripherals, robotic manipulators etc. due to their excellent speed control characteristics. Therefore, the speed control of DC motor attracts the attention of researchers to date as a notable task [17]. For many years, the conventional proportional-integral-derivative (PID) controllers had been used as a control strategy for various industrial processes and motor control applications. The steps for obtaining the optimized PID gains using the LQR technique are presented in [18]. Long time and effort are required to tune controller parameters using the Ziegler Nichols frequency response method. Ziegler Nichols considers the system in an oscillation mode to realize the tuning procedure, which is not physically realizable [19].

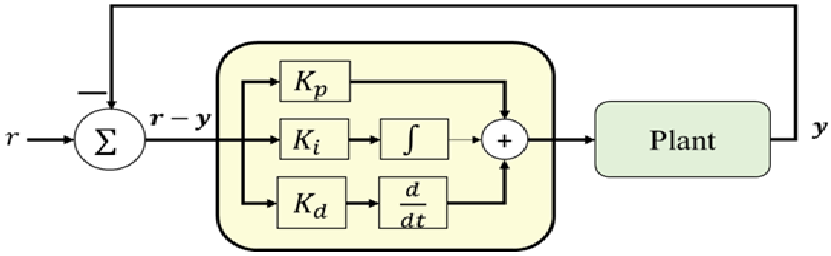

Figure 6: *Conventional proportional integral derivative (PID)control structure.*

$$C(s) = Kp + \frac{Ki}{s} + Kd \times s \qquad (i)$$

PID is a very simple but very effective controller.
It has three gains K_P proportional gain, $K_i$integral gain, $K_d$derivative gain.

The choice of the gains of PID is a challenge that has been solved using different tuning rules for PID control.

The gain parameters can be defined by conventional tuning rules e.g.

- Ziegler Nichols (ZN).

- Modified ZN (MZN).
- Cohen Coon (CC).
- Chien Hrones Reswick (CHR) etc.

There are also many more tuning rules to determine the K_p, K_i, K_d values of PID. But these rules have some limitations. They assumed the system to be a first-order pulse dead time model. Depending on the reaction curve of the open-loop system, they select the value of k_p, k_i, k_d. If the model of the system is wrong the value of k_p, k_i, k_d will be wrong "Figure 6". Therefore, these systems are not always effective.

Without depending on the reaction curve of the system and use modern optimization techniques that will automatically work with system errors and automatically update the gain. Then this problem can be fixed.

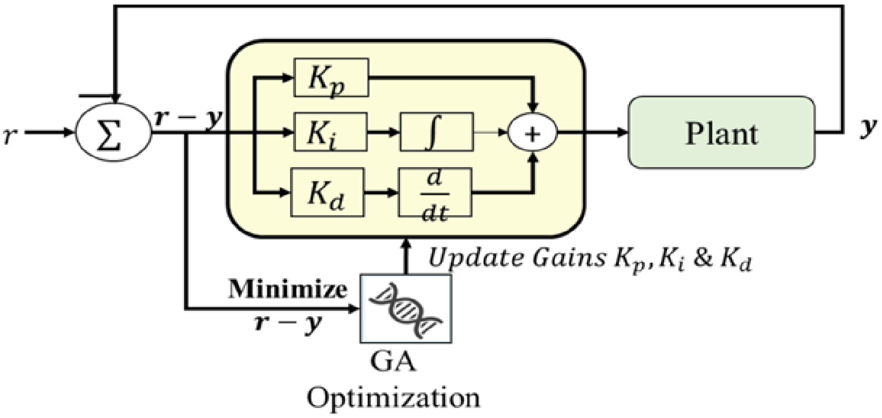

Figure 7: *Genetic algorithm based on proportional integral derivative (PID).*

In this block here added optimization block which is an additional block. A genetic algorithm can optimize a given error function to find the best suitable sets of gains for the PID controller. This cause minimizes errors. Which is on the basis of objective function (TTSE).

First order plus Dead time (FOLDT) model: $G_m(s) = \frac{K_m e^{-sT_m}}{1+sT_m}$ *(ii)*

Table1: *Conventional tuning rule.*

Rule Name	K_p	T_i	T_d
ZN	$1.2\frac{T}{L}$	2L	0.5L
Modified ZN	$0.95\frac{T}{L}$	1.4T	0.47T

4.2 Proportional Integral Derivative (PID) +Genetic Algorithm (GA)

Genetic algorithm is the major category of evolutionary algorithms (EA) that creates resolutions to optimization difficulties by retaining methods stimulated by usual developments such as; selection, inheritance, mutation and crossing. GA is operated to decide on optimizing the rates of PID controller gains for the selected BLDC motor system. The controller is proposed to reduce the error decrease of the output response with regard to the orientation signal. The error is computed equally in the performance table, achieved by reducing the error among the unit step of input response. The physiognomies for the wanted performance are typically stated in relation to time field amounts. The performance of the control system is measured equally to the optimum "Figure 7". If the parameters values of the PID controller are selected the performance table is the lowest. Integral squared error (ISE) and integral absolute.

Genetic algorithms can optimize a given error function to find the best suitable sets of gains for the PID controller. Objective Functions/ performance indices used here is:

Integral of Time times the Squared Error, ITSE = $\int_0^{\infty} te(t)^2\, dt$. *(iii)*

It gives robustness to the controller as it does not depend on the system model. Genetic algorithm is an evolutionary optimization technique. This optimization is inspired by genetic evolution in animal world. It can minimize or maximize any objective function given.

4.3 Motor Models

Here DC motor model transfer function that has been collected from various references.

Motor Model 1: $t\int 1\,(s) = \frac{0.01}{0.005s^2+0.06S+0.1001}$

Motor Model 2: $t\int 2\,(s) = \frac{0.02}{0.008s^2+0.12S+0.004}$

Motor Model 3: $t\int 3\,(s) = \frac{0.972}{0.001488\ s^2+0.2832\ S+0.78341}$

Motor Model 4: $t\int 4\,(s) = \frac{0.067}{0.00113\ s^2+0.0078854\ S+0.0171}$

These are the transfer function of our four motor models.

4.4 Step Response and Comparison between ZN vs GA+PID

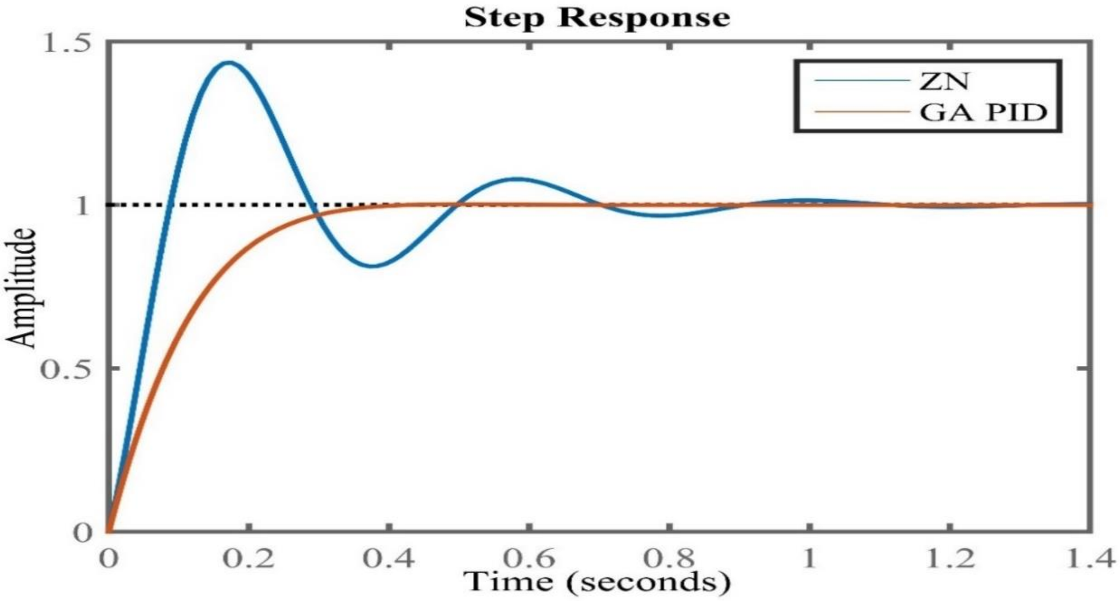

Figure 8: *Comparison between ZN vs GA+PID for motor model-1.*

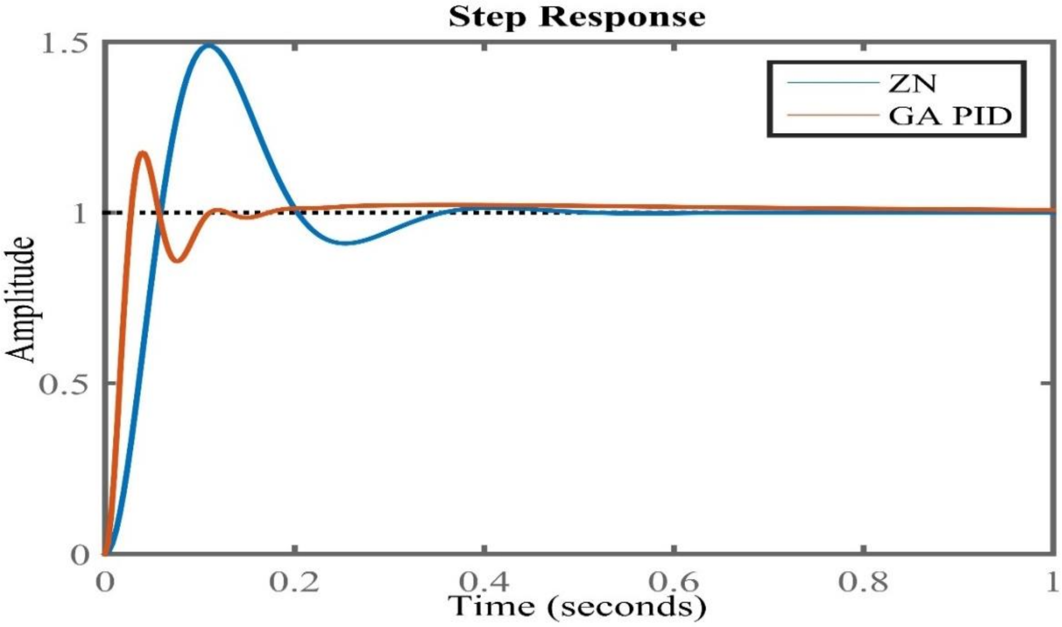

Figure 9: *Comparison between ZN vs GA+PID for motor model-2.*

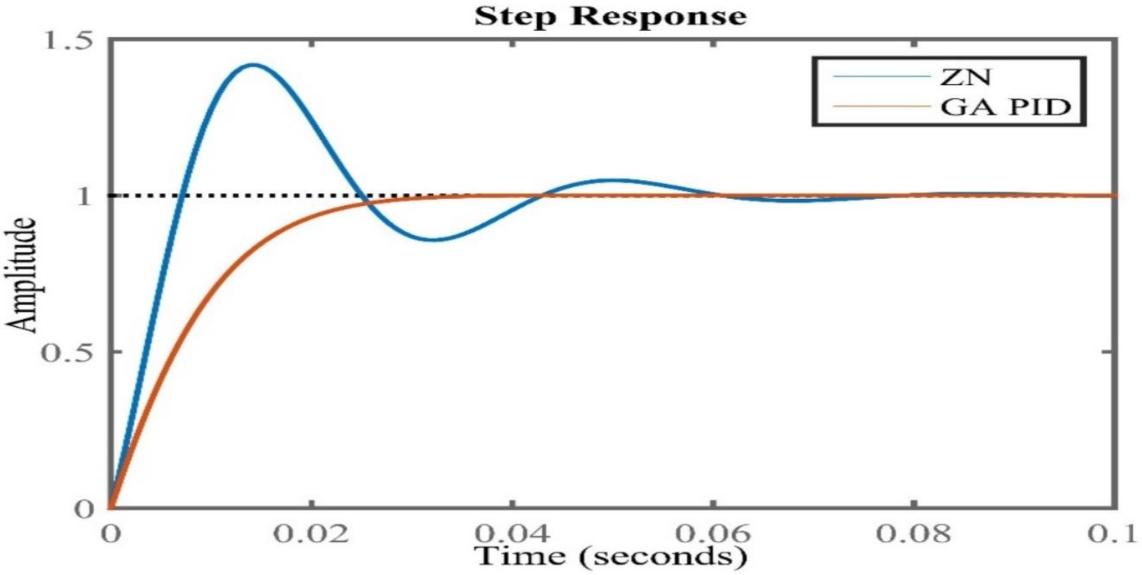

Figure 10: *Comparison between ZN vs. GA+PID for motor model-3.*

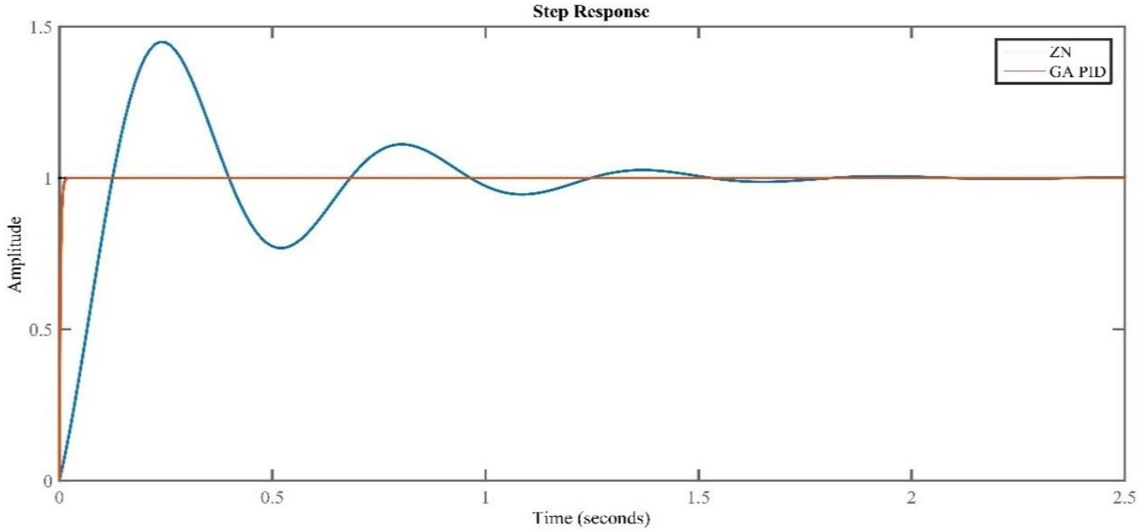

Figure 11: *Comparison between ZN vs. GA+PID for motor model-4.*

5 RESULTS AND DISCUSSION

5.1 Proportional Integral Derivative (PID)+ Ziegler Nichols (ZN) Vs. Proportional Integral Derivative (PID) + Genetic Algorithm (GA)

- The extent of K_p, K_i and K_d are picked between (0-100) separately.
- Estimations of K_p, K_i and K_d are plotted through the objective function demonstrates the variety of the wellness of the best arrangement with era, where best arrangement is characterized as the one which gives least rise time, settling time, zero overshoot and almost zero consistent zero steady state error.

For Motor Model 1: $t \int 1\,(s) = \frac{0.01}{0.005s^2+0.06S+0.1001}$

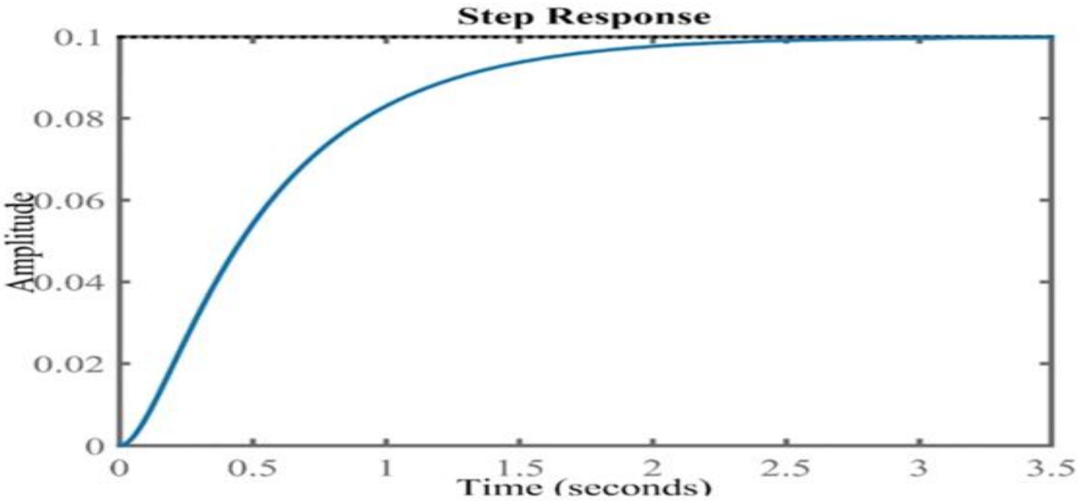

Figure 12: *Open loop step response for motor model-1.*

5.2 Comparison between PID+ZN vs. GA+PID

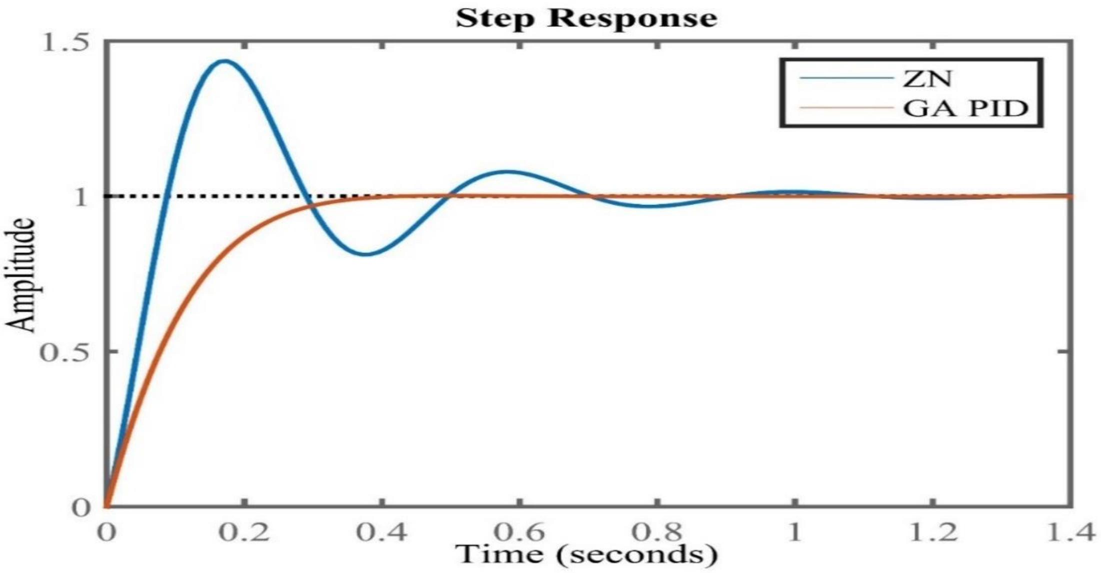

Figure 13: *Comparison between ZN vs GA+PID for motor model-1.*

Table2: *Step response for motor model-1.*

Step response	Motor 1	
	ZN+PID	**GA+ PID**
Settling Time	0.8520	0.323
Overshoot	43.55%	0.00 %

In this graph, the system is getting stable after almost 2.5s and it takes 2.5s to settle. In this comparison if added a PID controller structure with this, then see a close loop response comparison.
Here blue curve is PID controller and red curve is GA+PID controller (proposed controller).

For Motor Model 2: $t\int 2\,(s) = \frac{0.02}{0.008s^2+0.12S+0.004}$

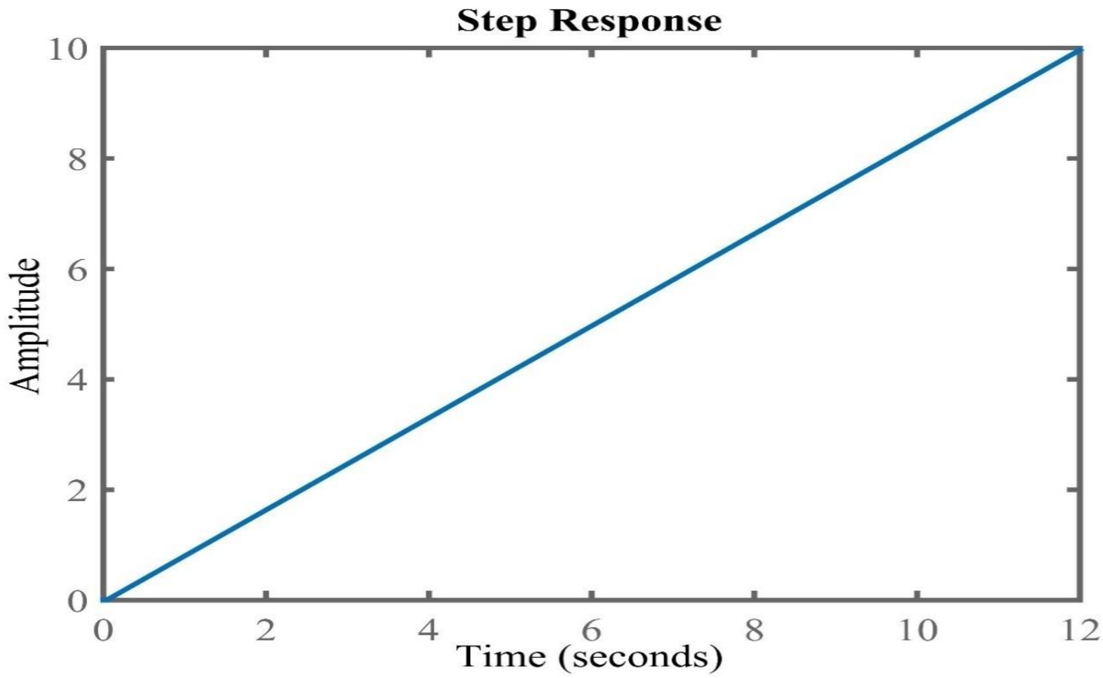

Figure 14: *Open loop step response for motor model-2.*

5.3 Comparison between PID+ZN vs. GA+PID

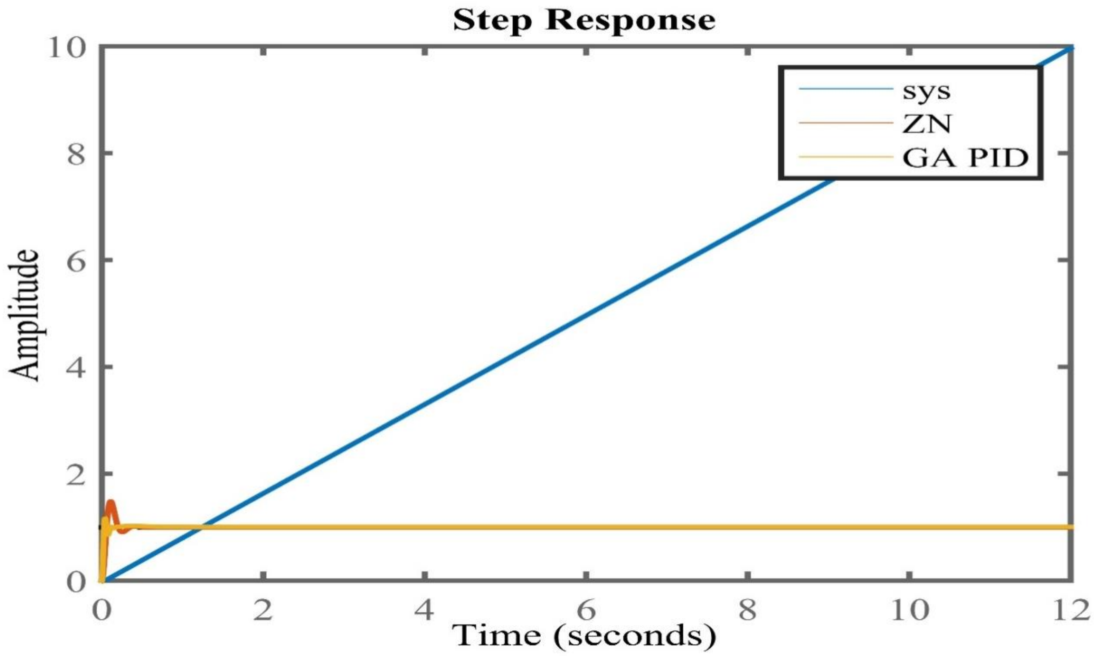

Figure 15: *Comparison between ZN vs GA+PID for motor model-2.*

Table 3: *Step response for motor model-2.*

Step response	**Motor 2**	
	ZN+PID	**GA+ PID**
Rise Time	0.0396	0.0185
Overshoot	48.9026	17.603

In this graph, the system is unstable and if added a PID controller structure with this, then see a close loop response comparison.

Here blue curve is PID controller and red curve is GA+PID controller (proposed controller).

For Motor Model 3: $t\int 3\,(s) = \frac{0.972}{0.001488\,s^2+0.2832\,S+0.78341}$

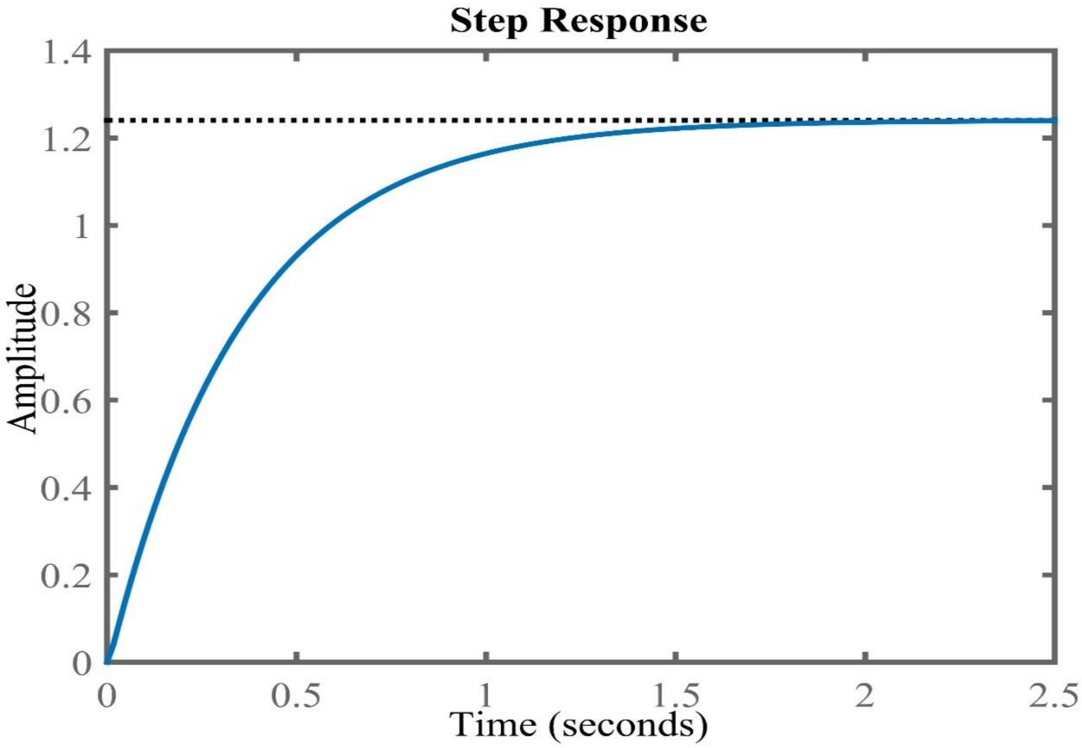

Figure 16: *Open loop step response for motor model-3.*

5.4 Comparison between PID+ZN vs. GA+PID

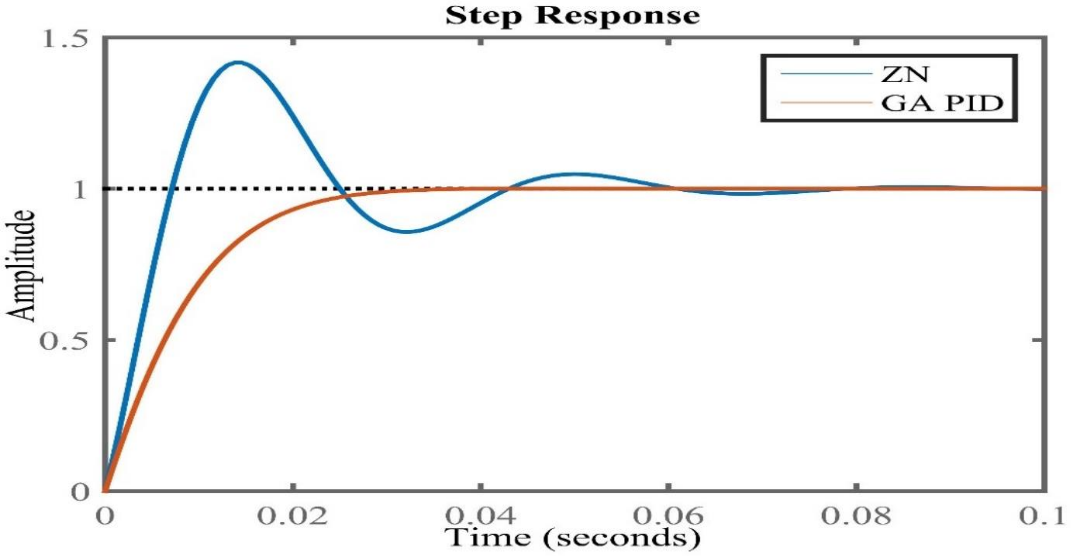

Figure 17: *Comparison between ZN vs GA+PID for motor model-3.*

Table 4: *Step response for motor model-3.*

Step response	Motor 3	
	ZN+PID	**GA+ PID**
Settling Time	0.0572	0.0267
Over shoot	41.7377	0.0693
S-S Error	24.8%	0.00%
Bandwidth	2.8004 Hz	129.176 Hz

In this graph, getting output is 1 but the model is giving 1.2 which means there is an error in the system and it takes time to settle 1.5s.
Here blue curve is PID controller and red curve is GA+PID controller (proposed controller).

For Motor Model 4: $\mathrm{t}\int 4\,(\mathrm{s}) = \frac{0.067}{0.00113\ \mathrm{s}^2+0.0078854\ \mathrm{S}+0.0171}$

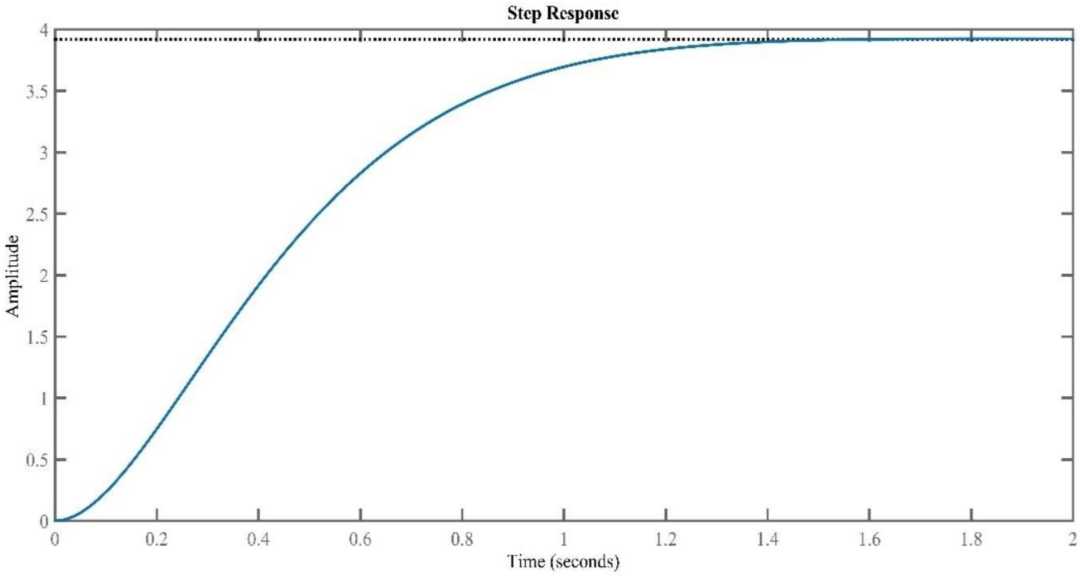

Figure 18: *Open loop step response for motor model-4.*

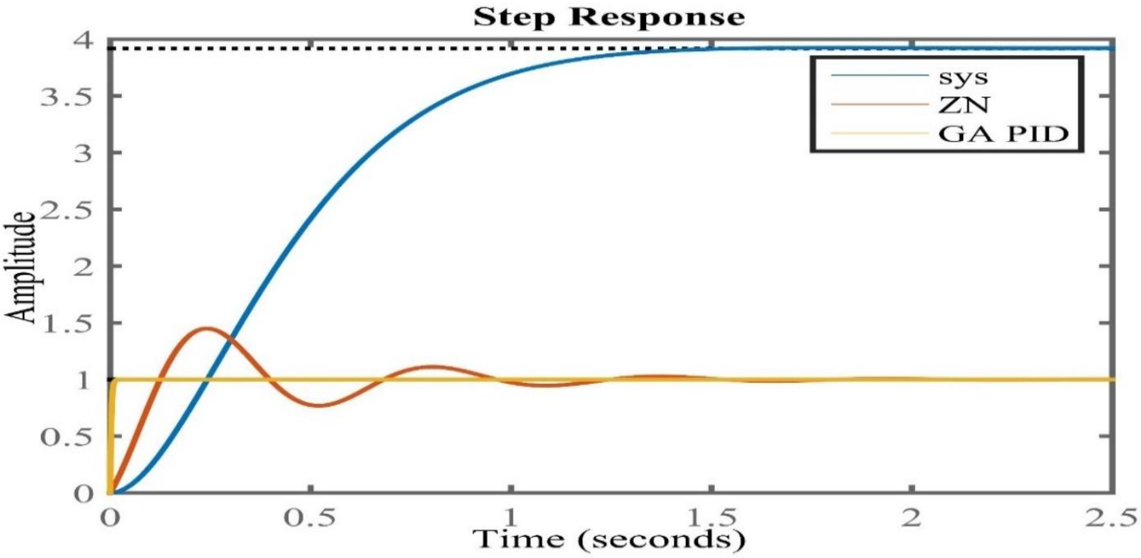

Figure 19: *Comparison between ZN vs GA+PID for motor model-4.*

Table 5: *Step response for motor model-4.*

Step response	Motor 4	
	ZN + PID	**GA + PID**
Rise Time	0.0965	0.0060
Settling Time	1.4338	0.0108
Overshoot	44.9641	0.00
S-S Error	78.4%	0.00%
Bandwidth	2.9107 Hz	362.905 Hz

In this graph, the systems getting output is 1 but model is giving almost 4 which mean there is a huge error in this system and it takes time to settle almost 1.4s.
Here blue curve is PID controller and red curve is GA+PID controller (proposed controller).

5.5 Bode Diagram for Motor Model One

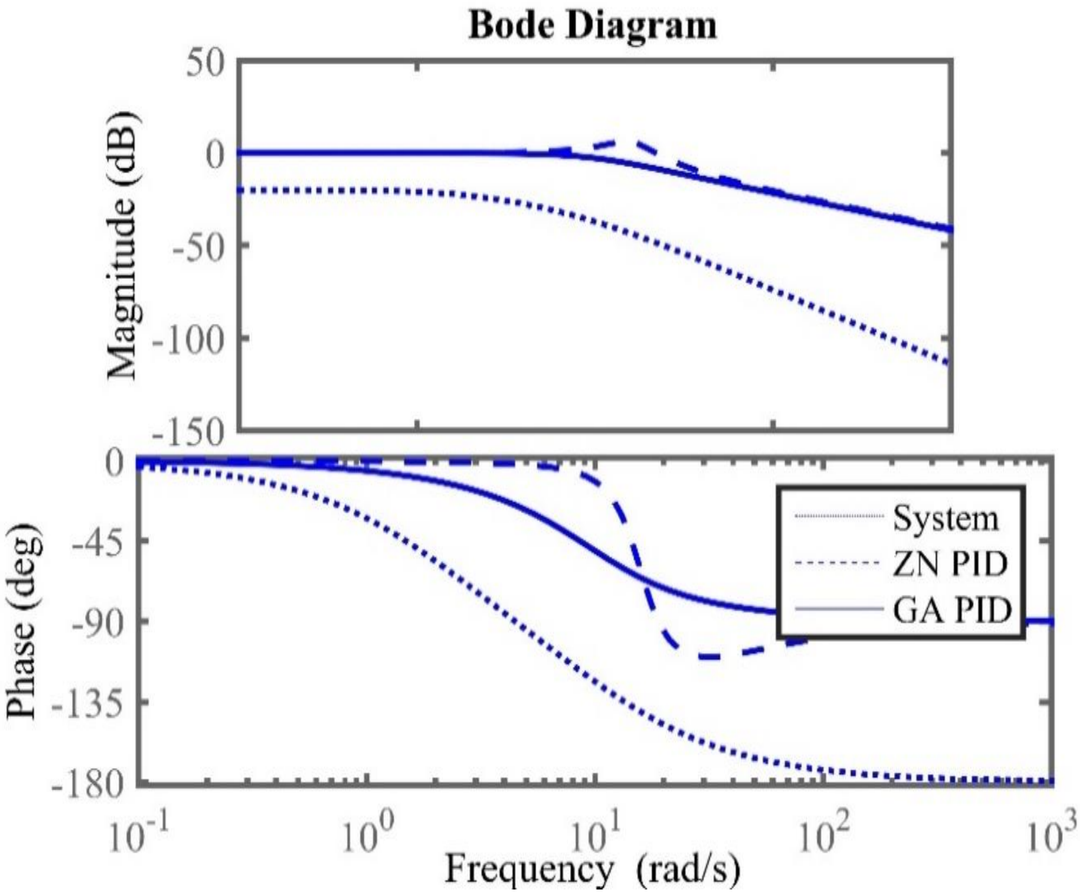

Figure 20: *Bode diagram for motor model-1.*

5.6 Bode Diagram for Motor Model Two

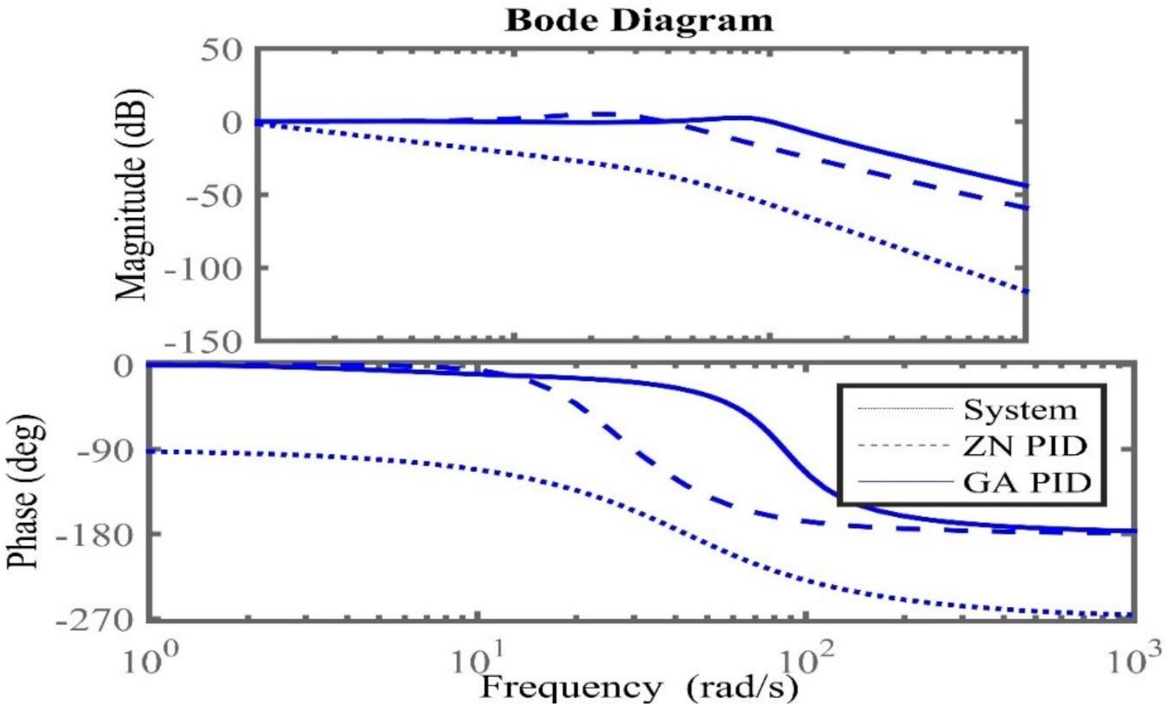

Figure 21: *Bode diagram for motor model-2.*

5.7 Bode Diagram for Motor Model Three

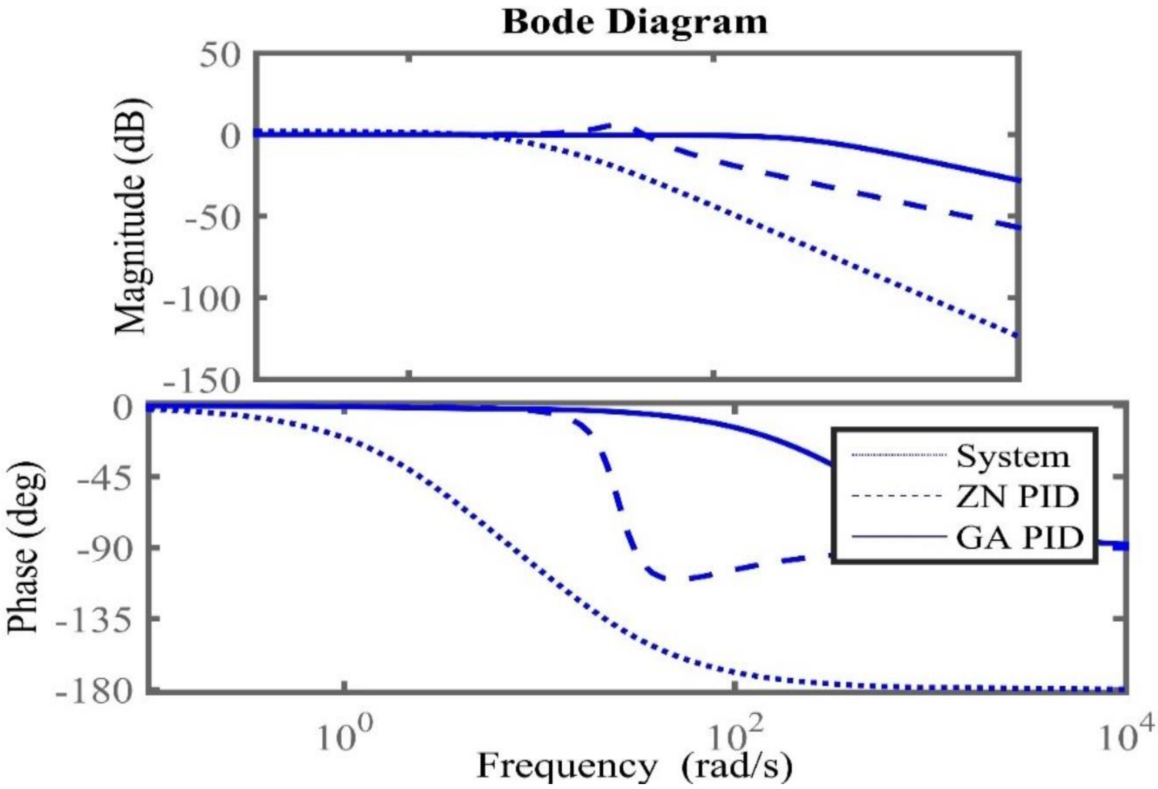

Figure 22: *Bode diagram for motor model-3.*

5.8 Bode Diagram for Motor Model Four

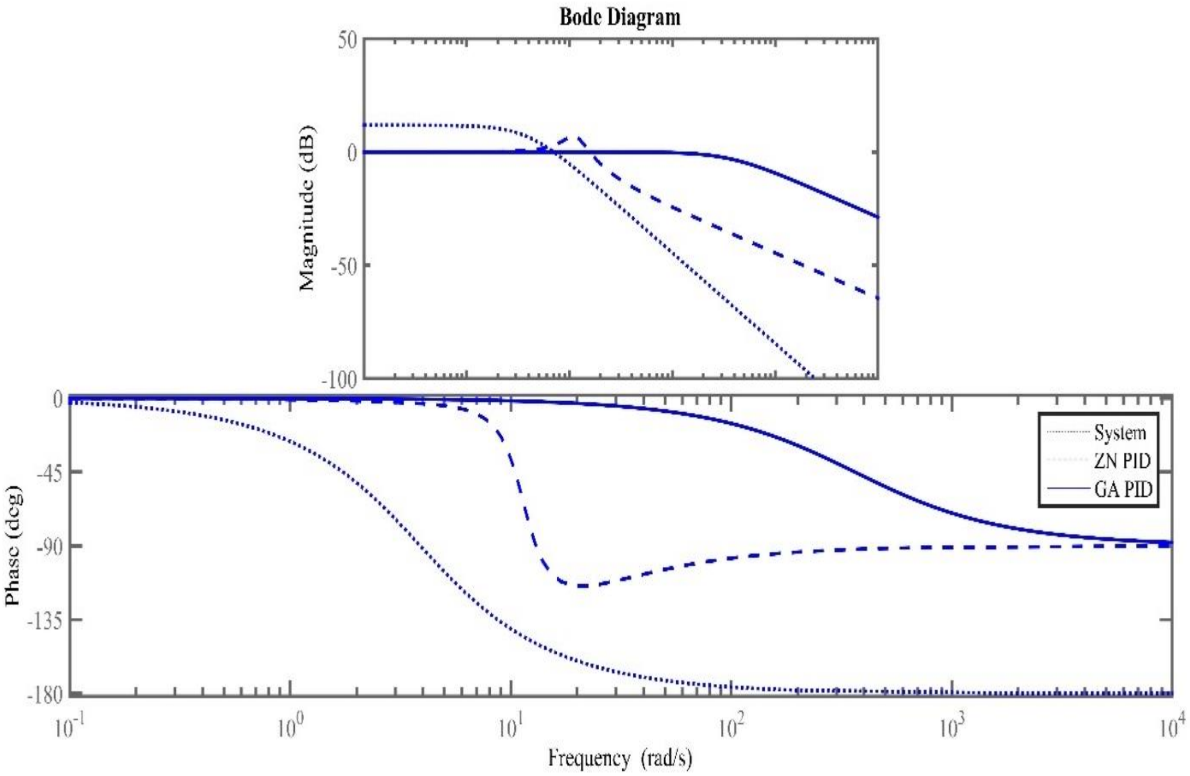

Figure 23: *Bode diagram for motor model-4.*

5.9 Step Response for Motor Model One, Two, Three and Four

Table 6: *Step response for motor model 1, 2, 3 and 4.*

Step response	**Motor 1**		**Motor 2**		**Motor 3**		**Motor 4**	
	ZN+ PID	**GA+PID**	**ZN+ PID**	**GA+PID**	**ZN+ PID**	**GA+PID**	**ZN+ PID**	**GA+P ID**
Rise Time	0.0679	0.207	0.0396	0.0185	0.0055	0.0166	0.0965	0.0060
Settling Time	0.8520	0.323	0.3315	0.4952	0.0572	0.0267	1.4338	0.0108
Overshoot	43.558	0.00	48.9026	17.603	41.738	0.0693	44.965	0.00
S-S Error	0.00%	0.00%	0.00%	0.00%	24.8%	0.00%	78.4%	0.00%
Bandwidth	25.304 Hz	2.911 Hz	116.253 Hz	116.253 Hz	2.800 Hz	129.176 Hz	2.9107 Hz	362.906 Hz

NB: Green color numbers indicates improvement in system response.

There are four motor models used in this study and they are motor models one, two, three and four. For motor model one, the system is getting stable after almost 2.5s and it takes 2.5s to settle. In this comparison, if added a PID controller structure with this, then see a close loop response comparison. For motor model two, the system is unstable and if added a PID controller structure with this, then see a close loop response comparison. For motor model three, getting output is 1 but the model is giving 1.2 which means there is an error in the system and it takes time to settle to 1.5s. For motor model four, the system getting output is 1 but the model is giving almost 4 which means there is a huge error in this system and it takes time to settle to almost 1.4s.

Table 7: *Observation of previous experimental work from the research paper.*

References	Working on	Observation
[6]	PID Controller	The author gets the best value of PID Controller for controlling the speed of DC motor is proportional gain Kp = 20, integral gain Ki = 2.57, and derivative gain Kd = 0.0235 with steady-state error = 0.53017, rise time= 0.0527, settling time = 0.097, overshoot = 0 and the modification in the objective function will obtain the best and consistent solution.
[17]	Intelligent Control	The author's work on the subject highlights the idea, creation, development and implementation of intelligent control and finally, the results considering the application and development for the purpose are presented exposed: • To within the controller, a value is entered within a range of 1600 RPM to start control of engine speed. • Achieving values of error of 3%, which is acceptable in a practical manner.
[20]	Intelligent Control	The author's work on the subject highlights the idea, creation, development and implementation of intelligent control and finally, the results considering the application and development for the purpose are presented exposed: • To the speed of the motor is slowed down only for about 270 rpm (9%) in 980 milliseconds under the effect of full load. • The motor speed is hunting about 200 rpm (6.66%) in 900 milliseconds on unloading conditions.
[21]	Genetic Algorithm	The results obtained from the simulations clearly show the genetic algorithm is used for integral absolute error, integral time-weighted absolute error, integral square error, and integral time-weighted square error. It is ascertained that; the proposed controller works very well in all operating conditions than the other considered controllers.
[22]	PID Controller	The author gets the best value of PID Controller for controlling the speed of DC motor is proportional gain Kp = 5.0196, integral gain Ki =80.8051, and derivative gain Kd =0.0549 with steady-state error =0.0763, rise time= 0.0527, settling time =0.116, overshoot = 0 and the modification in the objective function will obtain the best and consistent solution.
[24]	DC Motors	The results of experiments prove that the approach has lots of good performances in response speed, control accuracy, adaptability and robustness. The modification in the objective function will obtain the best and most consistent solution.

The future works of this control system can be concluded:

- Apply GA with other controller structures such as MPC, LQR, LQG, and different non-linear controllers.
- Apply another optimization method such as Particle swarm optimization (PSO), gray wolf optimization (GWO) etc.
- To work on different systems other than motor such as different power electronics circuit control such as buck-boost converter, PWM inverter, microgrid etc.

6 CONCLUSIONS

None of the four models open-loop responses is good. So, if don't use the proposed controller but will not be able to give good performance. The designed PID with GA has a much faster response than the response of the classical method. The classical method is good for giving us the starting point of what are the PID values. However, the GA-designed PID is much better in terms of the rise time and the settling time than the conventional method. Finally, the genetic algorithm provides much better results compared to the conventional methods. And also, the error associated with the genetic-based PID is much lesser than the error calculated in the conventional scheme. There are four motor models used in the study. For model one, the system is getting stable after almost 2.5s and it takes 2.5s to settle. In this comparison, if added a PID controller structure with this, then see a close loop response comparison. For model two, the system is unstable and if added a PID controller structure with this, then see a close loop response comparison. For model three, getting output is 1 but the model is giving 1.2 which means there is an error in the system and it takes time to settle to 1.5s. For model four, the system getting output is 1 but the model is giving almost 4 which means there is a huge error in this system and it takes time to settle to almost 1.4s. In this paper, the implementation of the genetic algorithm-based PID controller for the DC motor position control system is covered. Adding a genetic algorithm (GA) with PID has improved system performance significantly more than the conventional tuning rules of PID. It has added robustness to the system model. It has added adaptation and intelligence to the system as the controller itself can decide which gains values can act best for system performance. The controller is highly customizable as the objective function can be programmed/ set from the user end.

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