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OPTIMAL SPEED AND POSITION CONTROLLER FOR PMDC MOTOR BASED GWO ALGORITHM

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ABSTRACT

The Grey Wolf Optimizations GWO Algorithm, is the newer technique to optimize the uncertain optimization problems by autotuning parameters. GWO algorithm is very useful due to its ease of implementation, direct results, robustness, and low computation cost. However, any application involving control systems can also use proportional integral derivative (PID) controllers. Numerous researchers use a variety of techniques, including fuzzy logic, particle swarm optimization, evolutionary algorithms, and others, to attempt to determine the ideal values of P, I, and D. Nonetheless, the primary goal of this work is to determine how well the intelligent algorithm GWO performs while autotuning the PID controller for a permanent magnet direct current (PMDC) motor. The GWO algorithm was selected as an optimization method, and the standard PID's settings were adjusted using integral time absolute error (ITAE). The results proved that GWO as an autotuning PID Controller is better compared to classical PID controller in terms of high performance of the motor's speed, and good response with steady -state error equal to zero moreover it can be used to obtain optimal position tracking by using PMDC for many applications.

KEYWORDS

Speed Controller, Position controller, The Grey Wolf Optimizations GWO Algorithm, Proportional integral derivative (PID), Permanent magnet direct current (PMDC) motor.

1. INTRODUCTION

Numerous industrial applications have made extensive use of PMDC motors. Position and speed control are the primary focal points of these applications. Many control strategies are used, including PID as a conventional controller, linear quadratic regulator LQR which is used in optimal control theory, and fuzzy logic controller FLC. Nonetheless, due to its resilience and simplicity, the PID method is the most often used approach (Sanprasit and Artrit,2019; Aloo, et al.2016).

In order to ensure that the process variable and set point are equal, the PID controllers keep the output at a certain level (Jasim et al., 2021). PID controllers are widely utilized in industrial facilities because of their dependability and simplicity of usage. Numerous methods, including Ziegler-Nichols, Cohen-coon tuning, and Z-N step response, are available in the literature to adjust the settings of PID controllers. However, a number of these traditional approaches have drawbacks (Johnson and Moradi,2005).

For the design of a PMDC motor speed controller, a controlling restricted optimum PID parameters (KP, KI, KD) is proposed (Molina et al.,2019; Potnuru et al.,2019). In order to execute angle and speed tracking, a high-performance motor drive system frequently has to have a strong dynamic reaction. In addition, the motor drive must to react to variations in the load in real time (El-Deen et al.,2015; Gaing ,2004; Syafaah et al.2017).

In 2014, Mir Jalili et al. introduced the Grey Wolf Optimizer (GWO) algorithm, a novel meta-heuristic approach inspired by the social hierarchy and hunting behavior of grey wolves in nature (Mirjalili et al ,2014; Mirjalili et al.,2016; Mirjalili 2015; Shahrzad 2015). The GWO algorithm mimics the leadership structure and collaborative hunting tactics of grey wolves in the wild, offering a powerful optimization technique. The approach mimics the hunting techniques and social structure of the grey wolf community. As seen in Fig. 1, the grey wolf hierarchy applies four different types of simulations: Alpha (α), Beta (β), Delta (δ), and Omega (ω). The Alpha (α) wolf, the group's leader, is mostly in charge of deciding on things like where to hunt, where to sleep, when to get up, etc. The second place in the hierarchy is occupied by Beta (β) wolves, who are subordinate to Alpha (α) wolves. The Beta (β) wolf is referred to as an Alfa (α) decision-assistant.

The following are the primary stages of grey wolf hunting (Song, et al,2015)

• Following, tracking, and getting close to the prey.

• Challenging, surrounding, and irritating the victim until it yields.

• Make an assault on the target.

The function of each group has also been defended in Fig.1. (Faris et al.2018; Soni et al,2021)

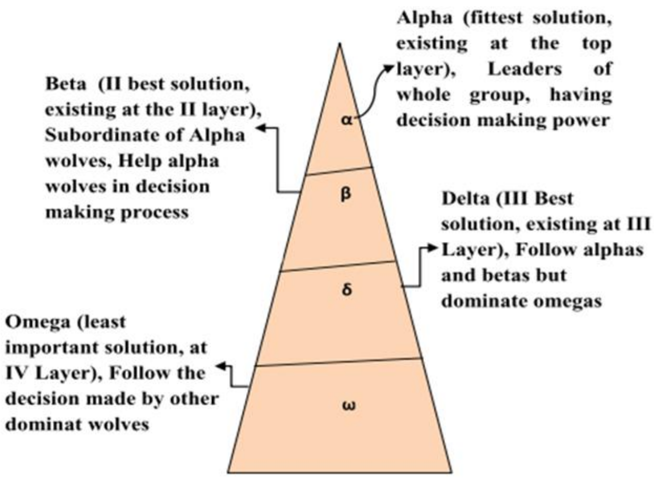

Fig. 1. Hierarchy of GWO (Faris et al., 2018)

Several studies will be presented as a related work:

(Zaber et al., 2017) presented PID controller based on slope variation method to controlling on position of a radio telescope the results of the response were without overshot.

(Deshpande and Bhavikatti, 2018) presented artificial neural network integrated PID controller for mor efficient tracking performance (Idir et al., 2018) presented Proportional-Integral Derivative PID (FOPID) for speed control DC motor. used Differential Evolution (DE) and Particle Swarm Optimization (PSO) for designing fractional order PID controller. The results showed improve the tracking proses, minimize the error and measurement noise attenuation.

(Saputra et al., 2019) used PID controller as a speed control for servo motor to stabilize the antenna. (Alsayed et al., 2020) presented speed control of DC motor based on a Krill Herd Optimization (KHA) algorithm. (Sule et al., 2020) to overcome the limitation of PSO and GA technique used Grey Wolf algorithim to tun the parameter of PI controller for speed wind turbine. (Abedulabbas and Yaseen, 2022), used PI controller for BLDC motor the improve the speed performance for a proposed motor by using GWO and PSO. the results which are obtained by using GWO is more efficient under different mechanical loads and speeds. (Paul et al., 2022) designed PID with GA for four models of transfer function of direct current motor the results had a much faster response than the response of the classical method. (Rahayu et al., 2022) presented tunning PID based PSO algorithm for DC motor. The results showed optimal performance using Simulink MATLAB, then entering the optimal value of PID in hardware Arduino (IDE) software to produce a stable speed response.

The main problem statement in the present research is autotuning PID parameters to obtain optimal speed and position of PMDC motor, where the conventional methods take a long time to reach optimal values.

In the current work the first step: study the response of speed and position of a PMDC motor without controller then with using conventional PID controller, as main objective achieves optimal speed and optimal position tracing for PMDC motor using intelligent algorithm GWO to tune the parameters of PID controller.

2. MODELING OF PMDC MOTOR

the motor's velocity and the voltage provided to the armature is the aim of the mathematical model's creation. By taking the system's mechanical and electrical properties, two balancing equations may be created. (Khanam and Parmar, 2017)

2.1. Electrical Properties

The graphic illustrates the electrical circuit of a PMDC motor. a voltage source (Va) placed across the coil of the armature. The electrical equivalent of an armature coil can be represented as an inductance (La) in series with a resistance (Ra) in series with an induced voltage (Vc) that opposes the voltage source. The induced voltage is created when the electrical coil rotates across the fixed flux lines of the permanent magnets. (Suresh Kumar et al., 2008)

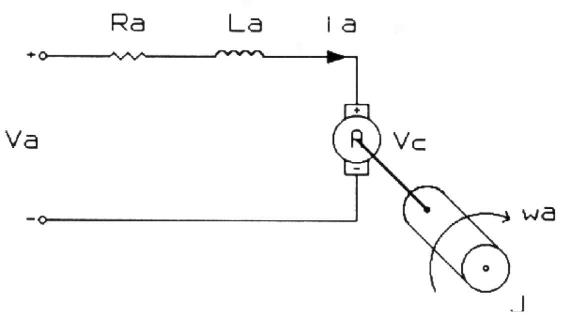

Fig.2 . Electrical representation of a PMDC motor. (Muruganandam and Madheswaran, 2009)

A differential equation for the matching circuit may be found by applying Kirchoff's voltage law around the electrical loop. Kirchoff's voltage rule states that all of the surrounding voltages must either sum up to zero as in Eq.1.(Muruganandam and Madheswaran, 2009).

$$V_a - V_{Ra} - V_{La} - V_c = 0 \tag{1}$$

Where:

$$V_{Ra} = i_a R_a \tag{2}$$

$$V_{La} = L_a \frac{d}{dt} i_a \tag{3}$$

$$V_c = k_v \omega_a \tag{4}$$

V_a is input voltage, V_c output voltage. armature current denoted i_a, k_v is the velocity constant that is derived from the armature's iron core's reluctance, the flux density of the permanent magnets, and the winding's number of turns. The armature's rotational velocity is represented by ω_a.

The differential equation that results from substituting Eqs.2,3, and 4 into Eq.1 is as follows: (Muruganandam and Madheswaran, 2009).

$$V_a - i_a R_a - L_a \frac{d}{dt} i_a - k_v \omega_a = 0 \tag{5}$$

2.2. Mechanical Features

The torques of the motor added together must equal zero in order to perform an energy balance on the system. (Muruganandam and Madheswaran, 2009)

$$T_e - \mathrm{T}\omega' - T_\omega - T_L = 0 \tag{6}$$

where $T_e$is the electromagnetic torque, Tω' is the torque due to the rotor's rotational acceleration, T_L is the torque of the mechanical load, and rotor velocity is the source of Tω. The armature winding current is directly proportional to the electromagnetic torque.

$$T_e = k_t i_a \tag{7}$$

where, k_t the torque constant, depends on the iron core's reluctance, the flux density of the fixed magnets, and the number of turns in the armature winding, much way the velocity constant does $T_{\omega'}$ may be expressed as

$$\mathrm{T}\omega' = J \frac{d\omega a}{dt} \tag{8}$$

J represents the mechanical load that aligns with the rotor's inertia. The torque may be represented as follows in relation to velocity:

$$T_\omega = B\omega_a \tag{9}$$

where B is the damping coefficient connected to the machine's mechanical rotating mechanism. Upon substituting Eqs.7,8, and 9 into Eq.6, the subsequent differential equation is obtained.

$$K_t i_a - J\frac{d\omega_a}{dt} - B\omega_a - T_L = 0 \tag{10}$$

The differential equations for the armature current and angular velocity found in Eqs.5 and 10 may be expressed as

$$\frac{d}{dt} \mathrm{i_a} = - \frac{R_a}{L_a} \mathrm{i_a} - \frac{k_v}{L_a} \omega_a + \frac{V_a}{L_a} \tag{11}$$

$$\frac{d}{dt}\omega_a = \frac{k_t}{J} \mathrm{i_a} - \frac{B}{J} \omega_a - \frac{T_L}{J} \tag{12}$$

2.3. Block Diagram and Transfer Function

It is possible to create a block diagram for the system by using the differential equations provided in Eqs.11 and 12. Using each equation's Laplace transform yields.(Siong et al., 2010)

$$SI_a(s) - i_a(0) = -\frac{R_a}{L_a} I_a(s) - \frac{k_v}{L_a}\omega_a(s) + \frac{1}{L_a} V_a(s) \tag{13}$$

$$S\omega_a(s) - \omega_a(0) = \frac{k_t}{J} I_a(s) - \frac{B}{J}\omega_a(s) - \frac{1}{J} T_L(S) \tag{14}$$

The starting conditions go to zero and all the variables become some change around a reference state if perturbations about some steady state values are taken into account. The equations may be stated as follows:

$$I_a(s) = \frac{-k_v\Omega_a(s)-V_a(s)}{L_as+R_a} \quad (15)$$

$$\omega_a(s) = \frac{-k_tI_a(s)-T_L(s)}{Js+B} \quad (16)$$

The block diagram for a proposed model is shown in the Fig.3. by assuming that the torque applied to the load is constant. The only load torque that has to be considered in the system is friction, which remains mostly constant while the motor is operating. $T_L$is not necessary as shown in the block diagram because its change is zero. Furthermore, apply block diagram algebra then reduces this block diagram to find an overall transfer function for PMDC motor as shown in Eq.17 (Shanmugasundram et al,2009).

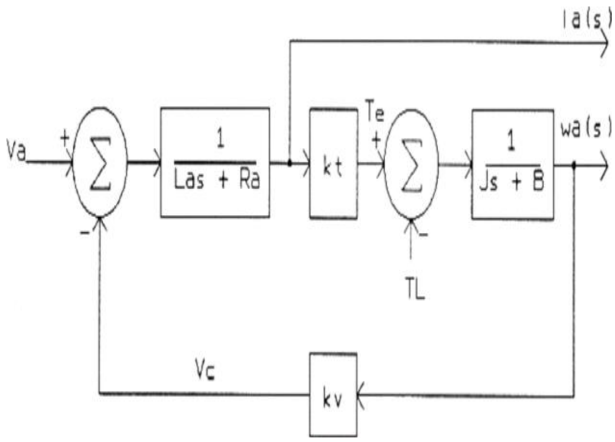

Fig. 3. Block diagram of the PMDC motor as modeled in this study.(Suresh Kumar et al., 2008)

$$\frac{\omega_a}{v_a} = \frac{K_v}{L_aJs^2+(R_aJ+L_aB)s+(R_aB+K_vK_t)} \quad (17)$$

3. SIMULATION MODEL OF PMDC MOTOR

The specifications and settings for the PMDC motor utilized in this paper have been provided in Table 1 for simulation purposes (Moussavi et al.,2012). The modeling control systems are very important in terms of examining the behavior of the system (Alyousuf, and Korkmaz, 2023) from this fact used conventional controller then enhancement the performance of the system by artificial intelligent strategi

Table 1: Parameters of DC motors. (Moussavi et al.,2012)

PARAMETERS	VALUES	UNITS
R_a	7.72	Ω
L_a	0.1627	H
K_t	1.25	Nm/A
B	0.003	N.m.s/r
J	0.023	Kg.m^2
K_v	1.25	v.sec/rad

The main contribution for a present study is designing a PID controller and tuned it by GWO to obtain optimal speed and position for PMDC motor, used MATLAB 2023b.Fig. 4 shows the flow chart of the proposed GWO algorithm.

The final expression of open loop PMDC motor for Speed and position control is in Eq.18 and 19 respectively

$$\frac{\omega_a}{v_a} = \frac{325.5}{s^2+47.57s+412.9} \quad (18)$$

$$\frac{\theta}{v_a} = \frac{325.5}{s^3+47.57s^2+412.9s} \quad (19)$$

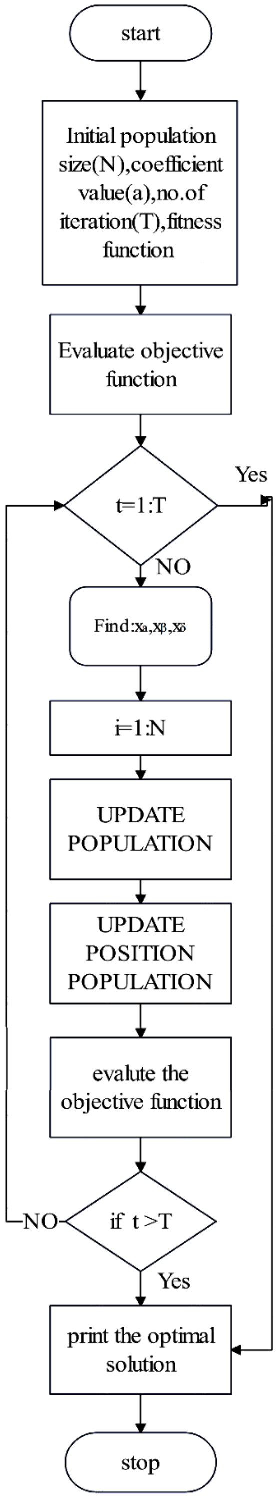

Fig. 4. Flow chart for GWO

4. SIMULATION RESULTS AND DISCUSSION

4.1. Results of PMDC Motor Without Controller

The simulation for open loop PMDC motor is tested in MATLAB-Simulink model as shown in Fig. 5 where, the input is unit step and the output is position and speed. The results of speed and position response respectively are shown in the Figs. 6 and 7. where the speed is unacceptable with high study error and, the response of position is unstable. the Simulink model for closed loop PMDC motor in Fig. 8.the response curves of speed and position still unstable as shown in Figs. 9 and 10.

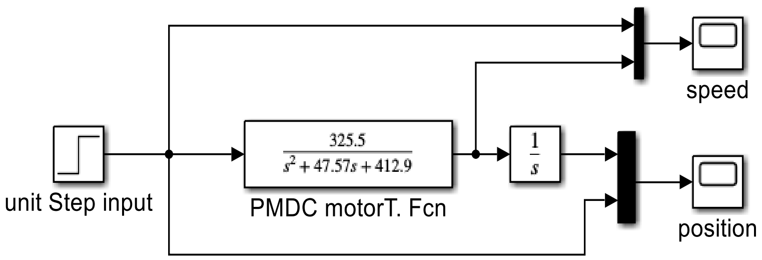

Fig. 5 .Simulink model of open loop PMDC motor

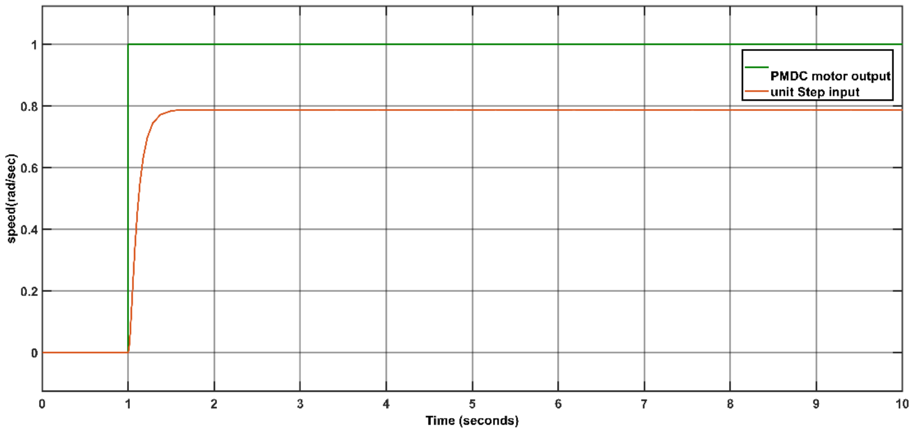

Fig. 6. speed response for open loop PMDC motor

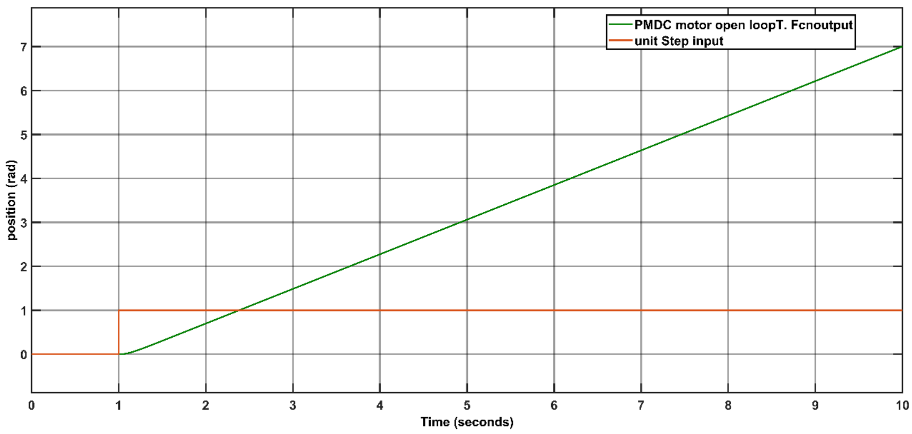

Fig. 7 position response of open loop PMDC motor

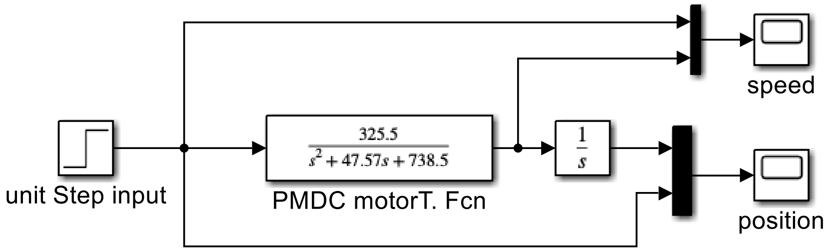

Fig. 8 .simulinlk model for closed loop PMDC motor

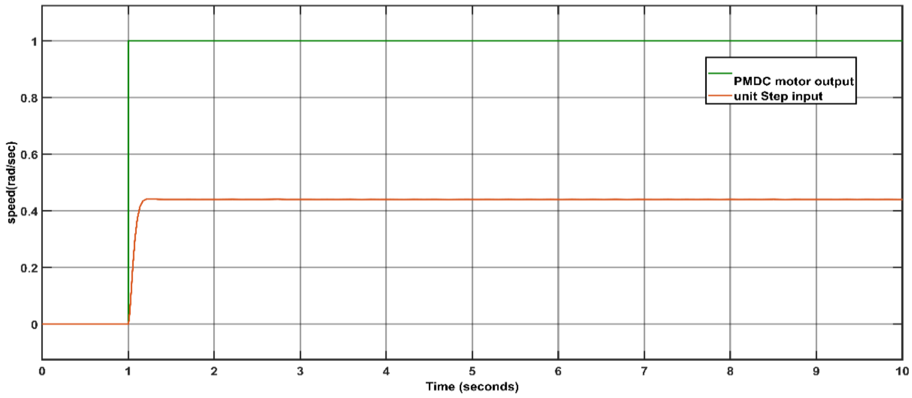

Fig. 9. speed response for closed loop PMDC motor

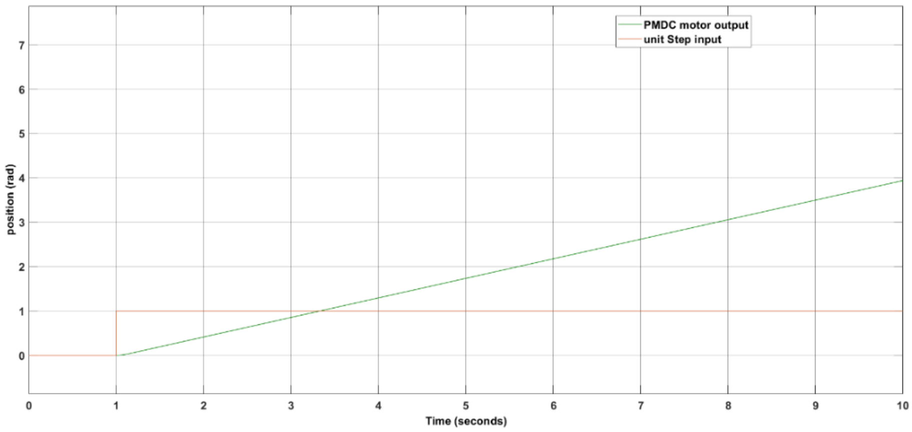

Fig. 10. position response for closed loop PMDC motor

4.2. Results of PMDC Motor With Controller

The first controller is PID tuner controller .the value for gains of PID controller for speed control are:$k_p = 4.7882, k_i = 92.67, k_d = 0.0516$. ,for postion controller are: $k_p = 47.55, k_i = 41.8, k_d = 4.7406$. the response for speed and position control have over shot so the system excessively deviate from its desired value the syteme take long because has an acceptable period for settiling time .to improve the performance of motor must be use optimal parameter of PID controller by GWO algorithm. Fig. 11 shows the comparative between the three speed response (witiout controller ,with PID controllere,and PID tunning with GWO algorithm). The results when used the intelligent algorithm to tun the parameter of conventional controller is demonstrated the superiority of the optimum response speed, in term of time, a stable state, and accuracy. Table 3 shows the comparative for the values of performance parameter for PMDC motor when motor without controller ,at PID controller, and PID based intelligent technique (GWO) for speed.

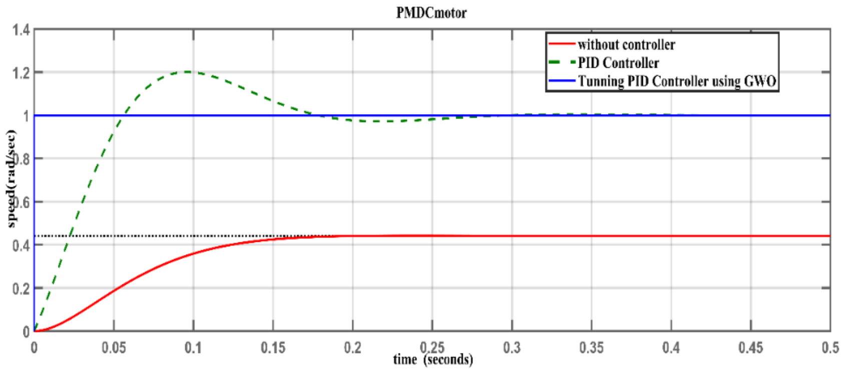

Fig. 11. speed response (witiout controller ,with PID controllere,and tunning PID with GWO algorithm)

Table 3 performanse response for speed control

parameters	Without controller	With PID controller	Tunning PID using GWO
Rise time	0.1021	0.0428	6.835e-06
Transient Time	0.1634	0.2471	1.218e-05
Settling Time	0.1634	0.2471	1.218e-05
Overshoot	0.3390%	20.0346%	0%
Peak Time	0.2381	0.0946	3.279e-05

moreover, the Gray wolf technology algorithm was chosen as an optimization technique and ITAE to adjust the parameters of the traditional PID controller to achieve optimum position tracking response as shown in Fig. 12 where it's more difficult to obtain perfect tracking position with optimal performance parameter as shown in Table 4. Fig. 13 shows ITAE with each iteration close to zero. Fig. 14. Shows Window of T.F code for PMDC motor. Fig. 15. shows window of code for GWO-PID.

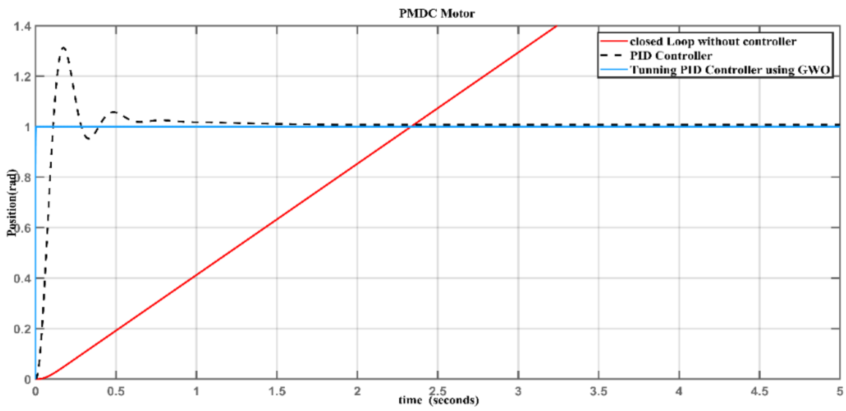

Fig. 12 position response (witiout controller ,with PID controllere, and tunning PID with GWO algorithm)

Table 4 Performance Response for Position Control

parameters	Without controller	With PID controller	Tunning PID using GWO
Rise time (s)	non	0.0715	5.6708e-04
Transient Time (s)	Non	0.9128	0.0010
Settling Time(s)	Non	0.9128	0.0010
Overshoot	Non	31.3324%	0%”
Peak Time(s)	∞	0.1749	0.0028

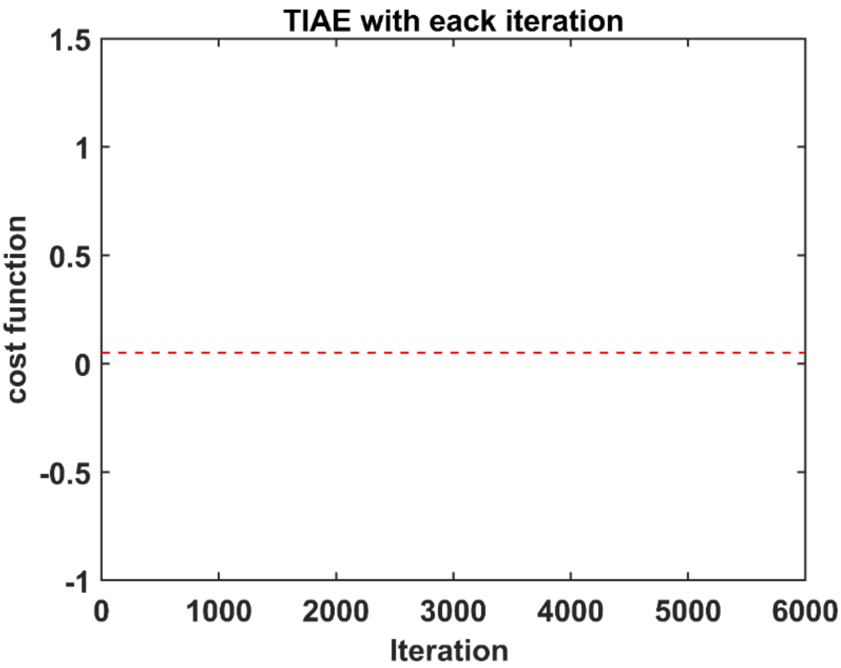

Fig. 13 ITAE with each iteration at speed control

```
Gf =

          325.5
  ---------------------
  s^2 + 47.57 s + 738.4

Continuous-time transfer function.


ans =

  struct with fields:

         RiseTime: 0.1021
    TransientTime: 0.1634
     SettlingTime: 0.1634
      SettlingMin: 0.3978
      SettlingMax: 0.4423
        Overshoot: 0.3390
       Undershoot: 0
             Peak: 0.4423
         PeakTime: 0.2381


Gcf1 =

     16.79 s^2 + 1559 s + 3.016e04
  -----------------------------------
  s^3 + 64.36 s^2 + 1972 s + 3.016e04

Continuous-time transfer function.
```

Fig. 14. Window of T.F code for PMDC motor

```
% PMDC
clc
close all;
clear;
n1=325.5;
d1=1;
d2=47.57;
d3=412.9;
ns= [n1];
ds = [d1 d2 d3];
G= tf(ns,ds)
Gf=feedback(G,1)
%Config = RespConfig('Delay',.5);
 step(Gf)
stepinfo (Gf)
grid on
hold on
kp1=4.7887;
 ki1=92.67;
 kd1=0.0516;
 Gc1=pid(kp1,ki1,kd1);
 Gcf1=feedback(Gc1*G,1)
%Config = RespConfig('Delay',.5);
step(Gcf1)
 stepinfo (Gcf1)
  hold on
%Gwo parameters
iter=100;
pop=60;
a_gwo=2;
Var=3;
% search space
al=0; %lower bound
au=1000; %upper bound
```

Fig. 15. Window's code for GWO-PID

5. CONCLUSIONS

This study submitted behavior of PMDC motor in the case of open and closed loop, and study the characteristics of the speed and position response without controller that gave an unstable response. Then suggested a traditional PID controller. To get an optimal response must be used an intelligent algorithm, so to improve the value of gains parameters of PID controller used GWO algorithm. The results showed speed control without over shot and fast response with study state error equal zero. also 100% position tracking has been achieved with study state error equal zero and more accuracy for many applications.

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