Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

A Genetic Algorithm Based Approach for Tuning PID Controller Parameters for Speed Control of a Permanent DC Motor Considering First Order Time Delay

[1]Ero, E.O. and *[2]Obayuwana, A.
[1]Department of Electrical/Electronic Engineering, University of Benin, Benin City, Nigeria.
[2]Department of Computer Engineering, University of Benin, Benin City, Nigeria.
osazee.ero@uniben.edu; *augustine.obayuwana@uniben.edu

ARTICLE INFORMATION

Article history:
Received 25 February, 2019
Revised 19 April, 2019
Accepted 19 April, 2019
Available online 30 June, 2019

Keywords:
DC motor
PID controller
GA-PID
GA-PI
Ziegler-Nichols
PID tuning

ABSTRACT

The paper presents a genetic algorithm (GA) based approach for turning proportional integral derivative (PID) controller for a permanent magnet direct current (PMDC) motor considering first order time delay. The main objective was to obtain PID controller gain values that would provide better system response. The model of the PMDC was considered as a second order system. The integral square error (ISE) objective function was chosen for the genetic algorithm (GA) optimization, and it was employed in such a way that system performance criteria such as rise time, settling time, and overshoot were minimized. The system step response using GA based PID controller was compared with that of the conventional Ziegler-Nichols method for turning PID controllers. It was observed that the proposed GA PID controller gain values provided better system performance compared to the Ziegler-Nichols method. The proposed method could be applied to both linear and non-linear system models.

1. INTRODUCTION

The position and speed control of the permanent DC motor has attracted considerable research as a result of their excellent speed and torque characteristics, better dynamic response, high efficiency, no noise operation, high weight to torque ratio and relatively low cost compared to other conventional motors (Tibor et al., 2011), These motors are widely employed in the industry. From studied literature there are generally three methods of controlling these motors (Velagic and Galijasevic, 2009). These are either using a PID controller, using a modern controller (adaptive and improving) or using intelligent controllers (fuzzy and neural). The modern and intelligent controllers have been proposed for the control of the permanent DC motor, these controllers exhibit good control performance in the presence of significant disturbances and variation of controlling parameters (Velagic and Galijasevic 2009). These controllers have fast, and dynamic system response, not sensitive to system's parameters, and exhibit good stability characteristics nevertheless the classical method of control (PID controller) is still predominantly used in majority of real-world servo systems (Ho and Sen, 1991).

Improper selection of PID parameters could lead to poor system performance thus motivating researchers to explore best methods for tuning these controllers. The conventional way of tuning these controllers is the Ziegler-Nichols method which either involves using the step response of the system to be controlled, or using the frequency response of the closed-loop system (Saad et al., 2012). This method may face several challenges when the system is complex such as high-order, time-delay, non-minimum phase and non-linear processes. For example, the Ziegler-Nichols method may give high overshoots, high oscillatory and longer settling time for high-order systems (Saad et al., 2012).

In this work a genetic algorithm-based approach was proposed for the selection of PID controller parameters $(K_p, K_I\ K_d)$ for speed control of a permanent magnet DC motor (PMDC) considering first order lag time delay. Genetic algorithm is a computational procedure that mimics the natural process of evolution (Malhotra et al., 2011). They are stochastic global methods that works by evolving a population of solutions over several generations. For each generation, solutions are selected from the population based on the fitness value (Bindu and Namboothiripad, 2012). The most important step in applying GA for PID controller parameters selection is the definition of an objective function that would be used in evaluating the fitness of each solutions.

2. METHODOLOGY

2.1. System Model

Physically the PMDC motor is made of two major parts: the rotor or armature and the stator, the stator consists of permanent magnet which creates a magnetic field flux. The rotor consists of an electromagnet created by a coil wound around an iron core. The rotor rotates as a result of the attractive and repulsive forces of the magnetic fields. A magnetic field is generated by the armature by passing electric current through its coil, and the polarity of the field is constantly changed as a result of the alternating nature of the electric current through the coil by a process known as commutation (Velagic and Galijasevic, 2009). Thus, the dynamic model of an armature controlled PMDC derived from both the electrical and mechanical characteristics can be described as follows (Thomas and Poongodi, 2009):

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a}{dt} + V_b(t) \tag{1}$$

$$V_b(t) = K_v w(t) \tag{2}$$

$$T_m(t) = J_m \frac{dw(t)}{dt} + Bw(t) + T_t(t) \tag{3}$$

$$T_m = K_t I_a(t) \tag{4}$$

Where V_a is applied DC voltage on the armature in volts, I_a is the armature current in amperes, L_a and R_a are the armature inductance and resistance in henry and ohms respectively, *w* is the rotational velocity of the armature, T_m is the motor driving torque, T_t is the mechanical torque load, J_m and B are the moment of inertia and damping coefficient at the motor shaft in $kg - m^2/rad, and\ Nm, K_v$ and K_t are the back voltage and torque constant respectively, and V_b is the back voltage generated at the motor's armature. Rearranging Equations (1), (2), (3) and (4) gives Equations (5) and (6).

$$\frac{dI_a(t)}{dt} = \frac{V_a(t)}{L_a} - \frac{R_a I_a(t)}{L_a} - \frac{K_v w(t)}{L_a} \tag{5}$$

$$\frac{dw(t)}{dt} = \frac{K_t I_a(t)}{J_m} - \frac{Bw(t)}{J_m} - \frac{T_t(t)}{J_m} \tag{6}$$

Transforming Equations (5) and (6) to state space, choosing state variables as $I_a,\ and\ w(t)$, the matrix form of the state space becomes:

$$X = \frac{d}{dt}\begin{bmatrix} I_a(t) \\ w(t) \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_a} & -\frac{K_v}{L_a} \\ \frac{K_t}{J_m} & \frac{B}{J_m} \end{bmatrix} \begin{bmatrix} I_a(t) \\ w(t) \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} & 0 \\ 0 & -\frac{1}{J_m} \end{bmatrix} \begin{bmatrix} V_a(t) \\ T_t(t) \end{bmatrix} \tag{7}$$

$$Y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} I_a(t) \\ w(t) \end{bmatrix} + \begin{bmatrix} 0 & 0 \end{bmatrix} \begin{bmatrix} V_a(t) \\ T_t(t) \end{bmatrix} \tag{8}$$

From Equations (7) and (8), and assuming the motor torque and back emf constants are equal, the system transfer function of the PMDC motor is obtained as:

$$\frac{w(s)}{V(s)} = \frac{K}{L_a J_m s^2 + (R_a J_m + L_a B)s + (R_a B_m + K^2)} \tag{9}$$

2.2. System Model with Time Delay

When system parameters or operating conditions are not certain, a fixed PID controller may not guarantee a good system performance. In such scenarios, adaptive control methods, sliding mode control, trial and error approach are possible solutions (Hyalij et al., 2009). Another possible approach is to assume a first order time lag delay which would comprise of the time interval between when the control signal from the controller was sent, to the time it takes for the control action to be effected. The time lag delay assumption would help reduce the effects of uncertainties thus improving the overall controller performance. Figure 1 shows the effect of transport lag (delay) assumption on the input signal. This causes a time-shift of the input signal, but ideally does not affect the signal characteristics

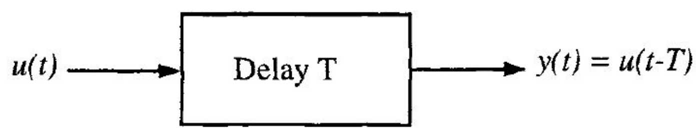

Figure 1: Effect of delay on signal input

Thus, a PMDC motor considering first order time lag can be modelled as:

$$G(s) = \frac{w(s)}{V(s)} = \frac{Ke^{-sT}}{L_a J_m s^2 + (R_a J_m + L_a B)s + (R_a B_m + K^2)} \tag{10}$$

Where T is the delay within the system.

2.3. PID Controller

The proportional-integral-derivative controller is widely employed in the industries as a result of its simplicity and effectiveness. The controller captures the history of the system and anticipates the future behavior of the system. The basic PID controller structure consists of three terms: Proportional (K_p), derivative (K_D) and Integral (K_I). Appropriate settings of these terms would improve the dynamic response of a system, reduce overshoot, eliminate steady state error and increase stability of the system (Åström and

Hägglund, 1995). The transfer function of the PID controller can be written as (Saad, Jamaluddin et al., 2012):

$$C(s) = \frac{u(s)}{E(s)} = k_p + \frac{k_I}{s} + k_d s \quad (11)$$

Where: $k_p\ k_I\ and\ k_d$ are the gain of the controller with $k_p, k_I\ and\ k_d$ all non-negative denoting the coefficients for the proportional, integral and derivative terms respectively. E(s) and u(s) are the error and control signal respectively. Assuming a unity feedback system, the block diagram for the overall control system for the PMDC motor is shown in Figure 2, and the overall transfer function of the unity feedback system is stated in Equation (12).

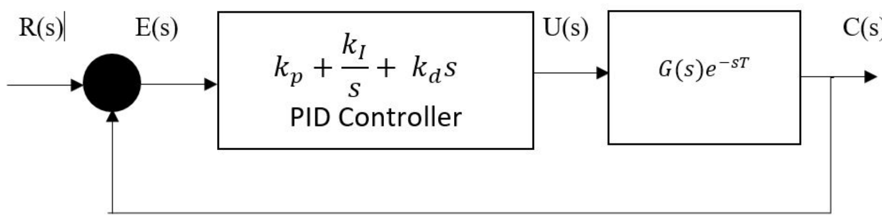

Figure 2: Block diagram of control system

$$T(s) = \frac{G(s)e^{-sT}(K_d s^2 + sK_p + K_I)}{S + G(s)(K_d s^2 + sK_p + K_I)} \quad (12)$$

2.4. Genetic Algorithm

GA, a heuristic optimization algorithm based on the process of natural evolution was first introduced by John Holland as reported in (Holland and Goldberg, 1989). It works by optimizing a fitness function by starting out with an initial generation consisting of possible solutions to the problem. These initial solutions are called populations, while each individual solution is called an individual or chromosomes. The fitness of each chromosome is evaluated using several fitness criteria, which is used as a basis of selection of individuals in the next generation. GA typically consists of three major operations: selection, crossover and mutation. The application of these operations gives birth to offspring's that may be better than their parents thus yielding better solutions. The process is repeated for several generations stopping only when preset conditions have been met. The GA architecture is shown in Figure 3.

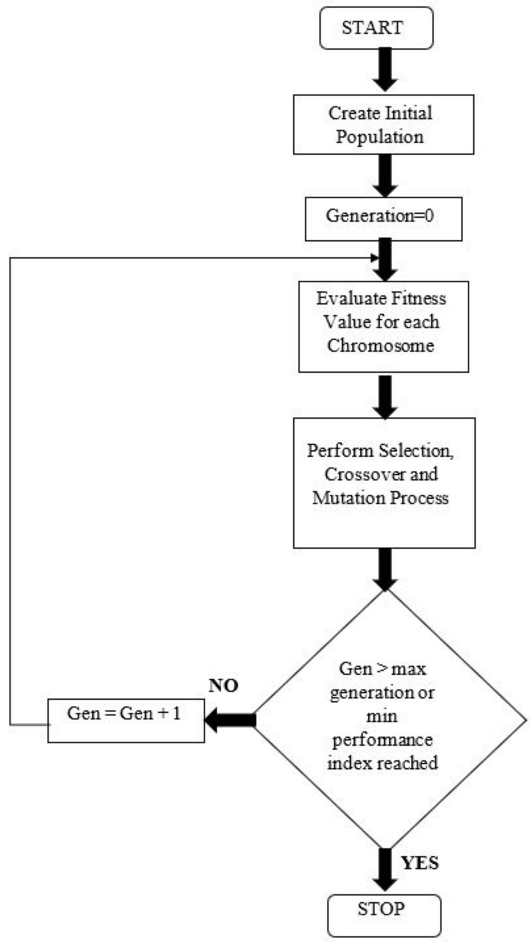

Figure 3: GA Architecture flowchart (Thomas and Poongodi 2009)

2.5. Tuning of PID Parameters using GA

In using GA for selection of PID parameters, an essential step is choosing an objective function that would be used in evaluating the fitness of each chromosomes in a generation. Some works have used performance indices as objective functions (Griffin and Bruton, 2003, Mirzal et al., 2012, Kamal et al., 2014). In Kamal et al. (2014) integral of the squared error (ISE) was used, (Griffin and Bruton, 2003) used mean of the squared error (MSE), integral of time multiplied by absolute error (ITAE), integral of absolute magnitude of the error (IAE), and ISE, while in Mirzal et al. (2012) the author used ISE, ITAE, and IAE. The performance indices are defined as follows:

$$ISE = \int_0^{\tau} e(t)^2 dt \tag{13}$$

$$ITSE = \int_0^{\tau} te(t)^2 dt \tag{14}$$

$$MSE = \frac{1}{t}\int_0^{\tau} e(t)^2 dt \tag{15}$$

$$ITAE = \int_0^{\tau} t|e(t)|dt \quad (16)$$

$$IAE = \int_0^{\tau} |e(t)|dt \quad (17)$$

Where e(t) is the error signal. In this work the ISE was used. The ISE was employed in a way such that different values of performance criteria (rise time, settling time and overshoot) are minimized, and the control input into the system is tracked as quickly as possible with minimal error and with little control input. Thus, the objective function was defined as (Kamal et al., 2014):

$$J = \int_0^{\tau} (W_1 e(t)^2 + W_2 u(t)^2)dt + W_3 t_r \quad (18)$$

Where W_1, W_2, and W_3 are weights coefficients, t_r is rise time, and U(t) is the control input, weight coefficient W_2 is to ensure minimal control input.

2.6. PID Tuning using Ziegler-Nichols Method

The Ziegler-Nichols method for tuning PID controllers is widely used and accepted in the control field. There two variations of the method. The first is based on the step response of the system, while the second is based on the frequency response of the closed-loop system by determining the point of marginal stability under pure proportional control (Saad et al., 2012). The former which involves using a step input on the PMDC was adopted. Figure 4 and Table 1 was used to solve for the PID parameters.

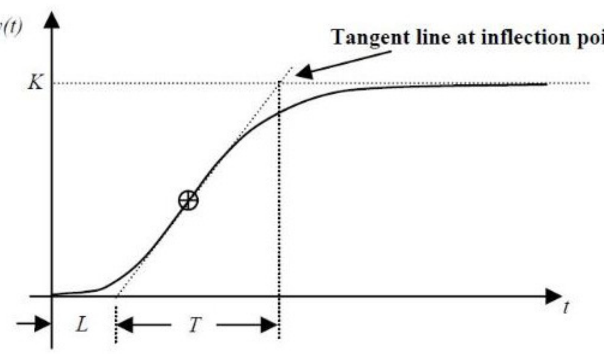

Figure 4: Ziegler-Nichols curve (Copeland, 2008)

Table 1: Ziegler-Nichols chart (Copeland, 2008)

PID TYPE	Kp	Ti=Kp/Ki	Td=Kd/Kp
P	T/L	Infinity	0
PI	0.9T/L	L/0.3	0
PID	1.2T/L	2L	0.5L

Ti and Td are the controller’s integrator and derivative time constant

3. RESULTS AND DISCUSSION

The GA based PID controller was implemented in MATLAB. The PMDC motor under study has the following specifications and parameters (Thomas and Poongodi, 2009).

Specifications: 2 hp (horse power), 230 V, 8.5 A, 1500 rpm

Parameters: Ra=2.45 ohm (armature resistance), La=0.035 H (armature inductance), K=1.2 volt/(rad/sec) (motor torque and back emf constants), J=0.022 kg-m^2/rad (Moment of inertia), B=$0.5 * 10^{-3}$ N-m/rad/sec (damping coefficient at the motor shaft) .

Thus, the open loop transfer function of the control system from Equation (10) becomes:

$$G(s) = \frac{w(s)}{V(s)} = \frac{1.2e^{-0.1s}}{0.00077s^2 + 0.05392s + 1.441}$$

Figure 5 shows the step response of the system without compensation.

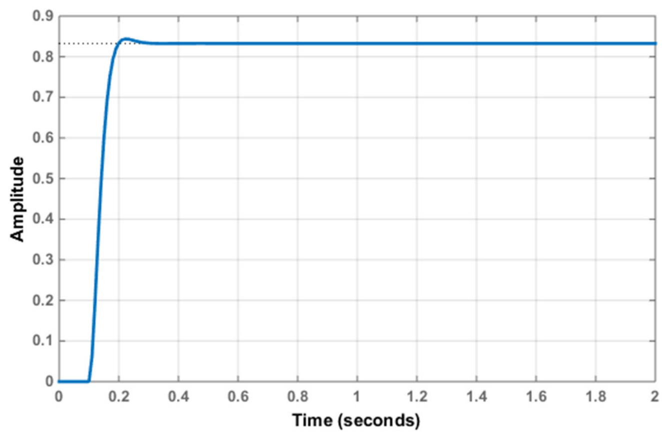

Figure 5: Step system response of system without compensation

The system performance of the uncompensated system has a settling time of 0.1886 seconds, a rise time of 0.0579 seconds, and the system did not attain the reference input (step input). A GA based PID compensator was thus designed for the system, after which the system response was compared with that of the conventional Ziegler-Nichols method used for PID tuning. The genetic algorithm parameters for the tuning purposes are shown in Table 2.

Table 2: GA parameters used for PID tuning

Parameters	Values (GA-PID)	Values (GA-PI)
Population size	100	100
Generation number	250	250
Selection method	Stochastic uniform	Stochastic uniform
Performance index/fitness function	ISE	ISE

The system response for the GA based PI and PID compensator is shown in Figure 6 and Figure 7, with derived PID parameters values shown in Table 3. The PI compensator was also studied for comparison purposes as it has been observed that sometimes optimal system performance can be gotten from using only a PI compensator.

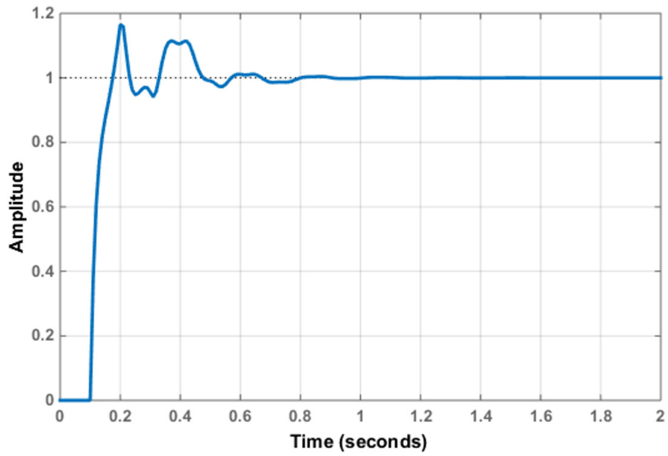

Figure 6: Step response of control system using GA PID compensator

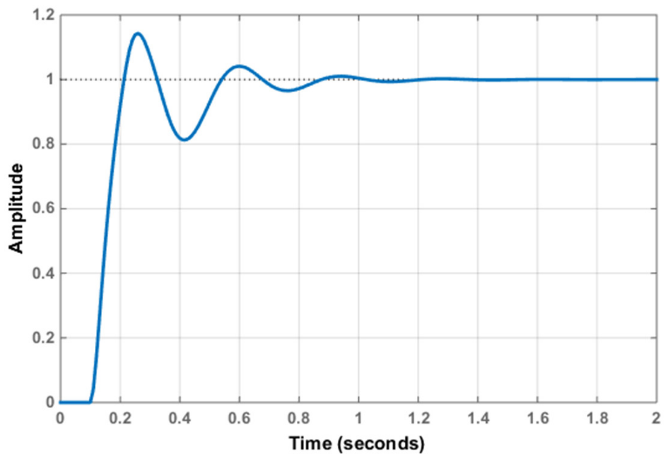

Figure 7: Step Response of control system using GA PI compensator

Table 3: Controller gains values for GA PID compensator

Compensator	Kp	Ki	Kd
PID	0.6817	10.9572	0.0309
PI	0.6608	7.1339	0

The summary of the system performance from a step input is shown in Table 4 for both compensators. From Table 4 it is seen that in PID compensator mode, the system response has a rise and settling time of 0.05 s and 0.56 s respectively, with a percentage overshoot of 19.4%, while in PI compensator mode the system response has a rise and settling time of 0.08 s and 0.82 s respectively with a percentage overshoot of 14.3%. If the control goal is a fast system response with minimum system percentage overshoot (as large overshoot could destroy control system hardware), the PID compensator would be desired as it has a lower rise time (the time it takes for the system to rise from 10% to 90% of its steady state value) and settling time (the time it takes for the error between system and steady-state response to fall within 2% of steady-state response)

Table 4: System performance for GA PID compensator

Performance metrics	PID	PI
Rise time	0.0505s	0.0809s
Settling time	0.558s	0.823s
Percentage overshoot	19.4%	14.3%
Steady state value	1	1
fitness Function	0.1228	0.1495

For comparison purposes, the system was also tuned using the conventional Ziegler Nichols method, the system response and PID parameters values is shown in Figure 8, Figure 9 and Table 5.

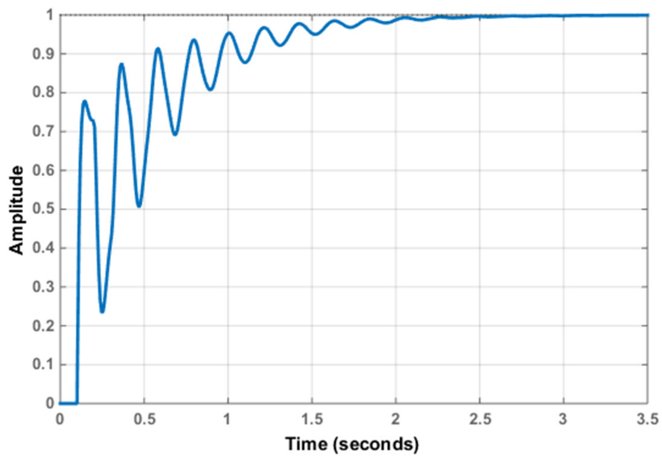

Figure 8: Step response of control system using ZN PID compensator

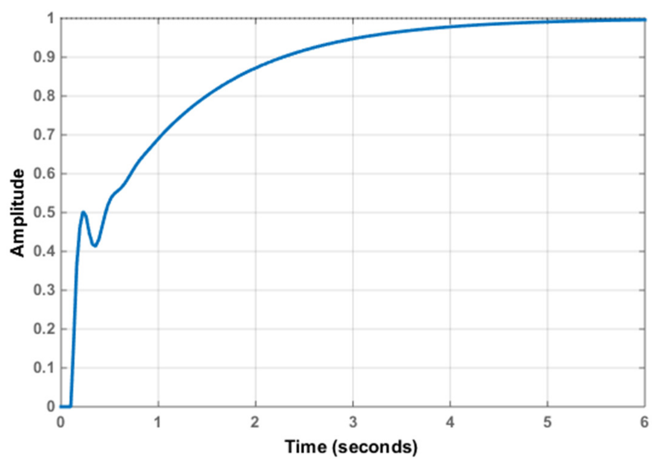

Figure 9: Step response of control system using ZN PI compensator

Table 5: Controller gains values for ZN PID compensator

Compensator	Kp	Ki	Kd
PID	0.6453	3.0438	0.0342
PI	0.484	1.3697	0

The summary of the system performance for PID tuning using Ziegler Nichols is shown in Table 6 for both compensators. From Table 6, we see that for the ZN PID compensator, a system response of 0% percentage overshoot with a rise and settling time of 0.47seconds and 1.95seconds respectively was gotten. Comparing this with that of the GA PID compensator we observe that the ZN PID compensator provides a sluggish system response as it has a higher system rise and settling time, but with minimal system overshoot. Thus, it can be concluded that the GA tuned PID controller gave a faster system response compared to that of the conventional Zeigler Nichols method, but with a larger percentage overshoot.

Table 6: System performance for ZN PID compensator

Performance metrics	PID	PI
Rise time	0.468s	2.16s
Settling time	1.9504	4.09s
Percentage overshoot	0%	0%
Steady state value	1	1

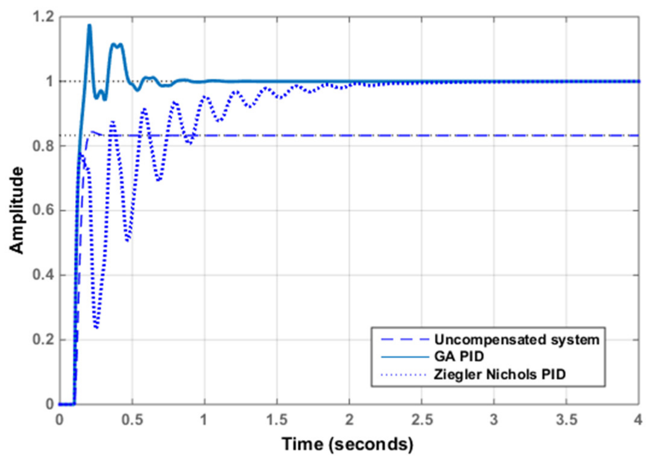

Figure 10: Comparison of system step response using GA PID and Ziegler Nichols based compensator

4. CONCLUSION

A GA based PID controller for a permanent magnet dc motor system considering first order time lag delay has been presented. The GA based compensator system response was compared to that of the conventional Ziegler-Nichols PID tuning method, and it was observed that the GA PID compensator provided faster system response with a higher system percentage overshoot. Often in control applications a system response that closely follows the input is desired, thus it can be concluded that the GA tuned PID compensator resulted in better overall system performance.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Åström, K. J. and Hägglund, T. (1995). *PID controllers: theory, design, and tuning*. Instrument society of America Research Triangle Park, NC.

Bindu, R. and Namboothiripad, M. K. (2012). Tuning of PID controller for DC servo motor using genetic algorithm. *International Journal of Emerging Technology and Advanced Engineering,* 2(3), pp. 310-314.

Copeland, B. R. (2008). *The design of PID controllers using Ziegler Nichols tuning*. Zieglar-Nicholos Method.

Griffin, I. and Bruton, J. (2003). *On-line PID controller tuning using genetic algorithms*. Dublin City University.

Ho, E. Y. and Sen, P. C. (1991). Control dynamics of speed drive systems using sliding mode controllers with integral compensation. *IEEE Transactions on Industry Applications*, 27(5), pp. 883-892.

Holland, J. and Goldberg, D. (1989). *Genetic algorithms in search, optimization and machine learning*. Massachusetts: Addison-Wesley.

Hyalij, G., Deshpande, A., Shendge, P. and Patre, B. (2009). Real time implementation of time delay controller for DC motor speed control. *International Journal of Recent Trends in Engineering*, 1(3), pp. 353.

Kamal, M. M., Mathew, L. and Chatterji, S. (2014). Speed control of brushless DC motor using intelligent controllers. *Engineering and Systems (SCES), 2014 Students Conference on, IEEE.*

Malhotra, R., Singh, N. and Singh, Y. (2011). Genetic algorithms: Concepts, design for optimization of process controllers. *Computer and Information Science,* 4(2), p. 39.

Mirzal, A., Yoshii, S. and Furukawa, M (2012). PID parameters optimization by using genetic algorithm. *arXiv preprint arXiv:1204.0885.*

Saad, M. S., Jamaluddin, H. and Darus, I. Z. (2012). PID controller tuning using evolutionary algorithms. *Wseas transactions on Systems and Control*, 7(4), pp. 139-149.

Thomas, N. and Poongodi, D. P. (2009). Position control of DC motor using genetic algorithm based PID controller. *Proceedings of the World Congress on Engineering, London, UK.*

Tibor, B., Fedak, V. and Durovský, F. (2011). Modeling and simulation of the BLDC motor in MATLAB GUI. *Industrial Electronics (ISIE), 2011 IEEE International Symposium on, IEEE.* pp. 1403-1407

Velagic, J. and Galijasevic, A. (2009). Design of fuzzy logic control of permanent magnet DC motor under real constraints and disturbances. *Control Applications, (CCA) & Intelligent Control, (ISIC), 2009 IEEE, IEEE.* pp. 461-466.