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Advanced optimal GA-PID controller for BLDC motor

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ABSTRACT

The brushless direct current (BLDC) motor is characterized by high torque, which made it widely used in many industrial applications. To improve the working performance of the BLDC motor, the addition of controllers such as proportional integral derivative (PID) is adopted. To obtain high-performance controllers, the design process is adopted to develop a suitable algorithm. The genetic algorithm (GA) was chosen to tune the PID controller and get suitable parameters for each of kp, ki and kd with self-tuning. The design process is based on BLDC motor control using the GA to tune the traditional PID controller. Simulations were carried out for three cases including the absence of controllers secondly, by using the traditional control unit and finally with the GA. The integral time absolute error (ITAE) type error control standard for BLDC motor control system was selected. After conducting the simulation, the results demonstrated the superiority of the GA over the traditional ones in terms of response speed, (stability, rise, and settling) time and percentage overshootas details will be mentioned the model in the subsequent paragraphs of the research, finally the simulation results indicate the development and improvement of BLDC motor operation and performance during real time.

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1. INTRODUCTION

Brushless direct current (BLDC) motors are a type of DC motor in which the windings in the rotor are replaced by permanent magnets to provide the required clearance throughput, while the windings are in the stator to produce the magnetic field. The magnetic field produced by the stator and rotor will rotate at the same frequency. BLDC motor is an electric motor that drives electric vehicles and electric cars. BLDC motors have wide industrial uses such as servo applications and applications that require stable operation and precise speed control in industrial processes. The use of BLDC motor in industrial applications has huge advantages in saving costs and time compared to dc motor [1]–[4]. BLDC motors are preferred as small motors in horsepower control because of the outstanding performance characteristics of high efficiency, high torque, silent operation, reliability, compact shape, low maintenance, small size compared to brushed DC motors [5]–[8] BLDC motors must be appropriately designed to have good magnetic coupling in order to be used in applications cutting, lifting and bracing [9]–[11]. BLDC motor permanent magnet type its rotor and electromagnetic stator was used and its speed was controlled by a microcontroller and a the inverter was simulated using the MATLAB software [6], [12]–[14].

The some of past studies included controlling the direct torque control (DTC) and monitoring the flow of the BLDC motor of the centrifugal actuator, and the researchers used a program MATLAB/Simulink and to simulate the system. The speed of the DC motor was controlled using proportional integral derivative (PID) controller and the MATLAB simulation program in cases of no load, gradual change of loads and sudden load. Also include MATLAB/Simulink program for BLDC motor speed control using neural networks with closed loop control for and testing the efficiency and sensitivity of this controller. The researchers introduced the MATLAB/Simulink program to control the speed of BLDC motor using the controller type PID and conducted tests to verify the use of the controller to control is appropriate and efficient. The parameters of PID were tuned by using genetic algorithm (GA) and design synchronous controller which depends on the speed and phase difference of the motor, which achieves the effect of control that the dual device-driven mechanical vibration system in terms of motor speed and phase difference in stable condition. PID is the most widely used control algorithm in industrial applications for several decades due to its good robustness, simple, good performance that ensures automated control systems [15]–[19]. The PID control algorithm is described by 3-parameters proportional (P), integral (I), derivative (D), where P depends upon the present error, I depends upon the cumulating of past error, D depends upon the retelling of future error based on current rate of change in error. Currently there are several methods developed for the synthesis of model control algorithms are widely used to optimize the problem of PID controller [20]–[22]. GA have been successfully used to solve complex optimization problems to provide practical solutions in calculating different parameters for the control unit due to their high accuracy and fast convergence [23]–[25].

GA are based on the essential (natural selection and natural inheritance). Natural selection means that organisms continue to survive those that have adapted to environmental conditions, and organisms that have been eliminated are those that have not natural inheritance is breeding of individuals chosen to produce new ones through intermarriage. In GA to solve the problems, the number of individuals that make up the first population is completely randomly determined and the following stages can be grouped into two stages: genetic operations (crossover and mutation) and evolutionary process (selection). GA that starts to solve problems are set of points, by encoding theses points first. Each structure makes a solution set (population) called a chromosome (individual). Chromosomes are made up chains of symbols called Genes [26]–[29]. This paper presents simulation models by using MATLAB to improve operation and performance of BLDC motor by using PID controller and GA-PID controller and comparison without controller in order to obtain best results.

2. FUNCTION AND MATHEMATICAL MODEL OF BLDC MOTOR

The BLDC motor is different from the traditional DC motor in that it has three phases, its dynamic features is like to permanent magnet DC motor. Figure 1 shows transfer function of BLDC motor [30], [31]. The mathematical equations of BLDC motor are:

$$V_{app}(t) = L\frac{di(t)}{dt} + R.i(t) + V_{emf}(t) \quad (1)$$

$$V_{emf}(t) = K_b.\omega(t) \quad (2)$$

$$T(t) = K_t.i(t) \quad (3)$$

$$T(t) = J\frac{d\omega(t)}{dt} + D.\omega(t) \quad (4)$$

The transfer function of BLDC motor can be shown in (5):

$$\frac{\omega(s)}{V_{app}(s)} = \frac{K_t}{LJS^2(LD+RJ)S+K_tK_b} \quad (5)$$

Where R is stator resistance, L is inductance of the stator, Kt is motor torque constant, Kb is back electromotive force constant, J is moment of inertia and D is viscous coefficient.

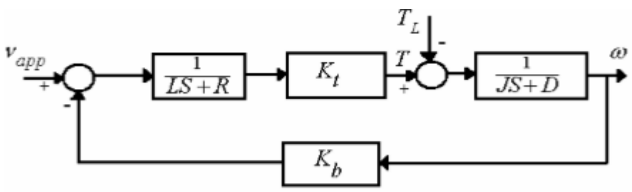


Figure 1. Transfer function of BLDC motor system

3. SIMULATION MODELS OF BLDC MOTOR

This section shows the simulation model of BLDC motor include input and output system and transfer function of BLDC motor. Table 1 shows the parameters of BLDC motor proposes in this paper. Figure 2 shows simulation model of BLDC without controller, while Figure 3 illustrates the simulation model by using traditional controller PID which using to improve performance of BLDC motor. Figure 4 shows two simulation model of BLDC motor without and with PID controller. Figure 5 indicates to the simulation model by using optimum system GA-PIC to obtain essential modification by select best values for control parameters of PID controller tooptimize system. Figure 6 shows the flow chart of GA.

Table 1. Parameters of BLDC motor

Number	Parameters	Symbols	Amounts
1	Stator resistance	R	21.2 Ohm
2	Inductance of the stator	L	0.052 H
3	Motor torque constant	Kt	0.1433 Kg.m/A
4	Back electromotive force constant	Kb	0.149 V/rad/S
5	Moment of inertia	J	1×10-5 k.gm S2/rad
6	Viscous coefficient	D	1×10-4 kg.m S/rad

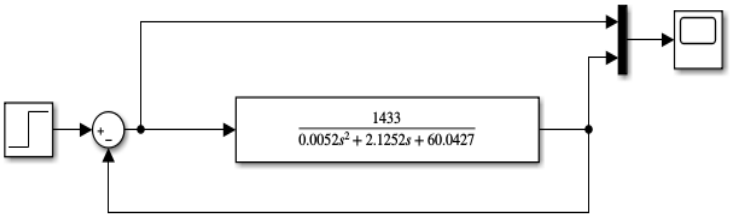


Figure 2. Simulation model of BLDC motor without controller

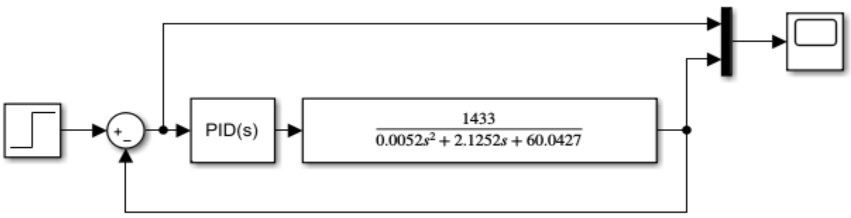


Figure 3. Simulation model of BLDC motor with tuning PID controller

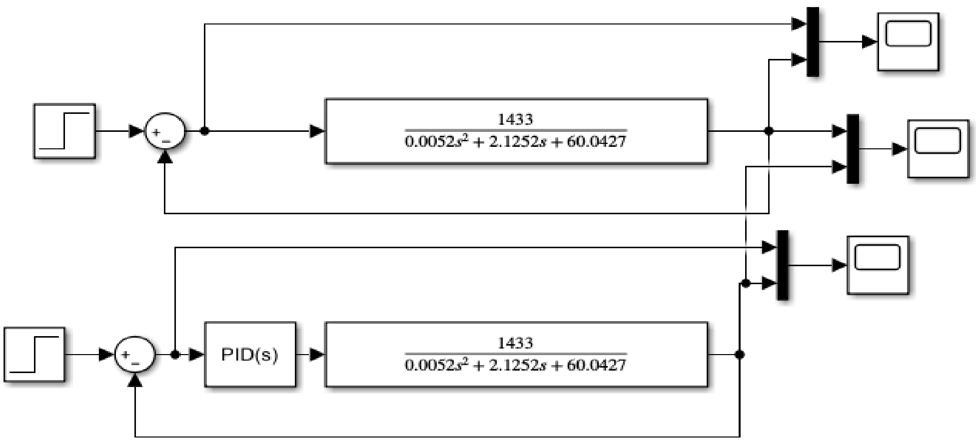


Figure 4. Simulation model of BLDC motor without and with PID controller

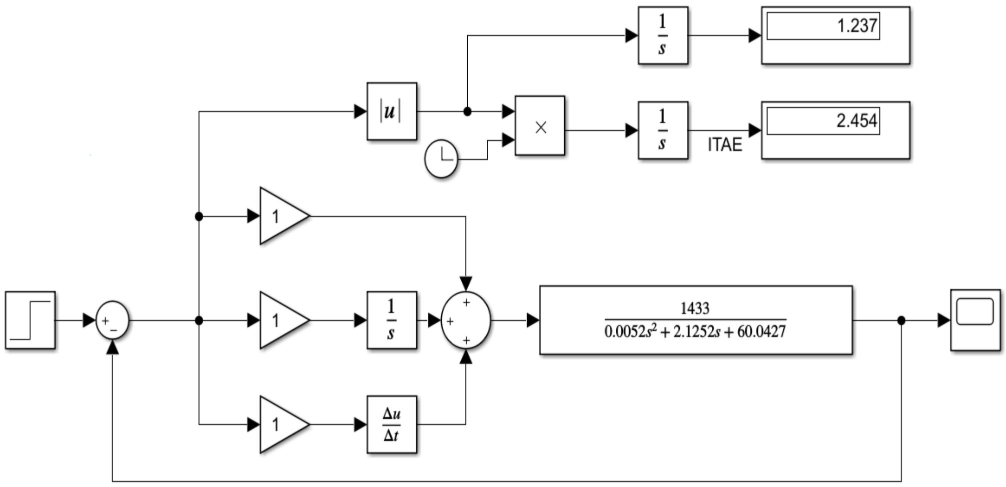


Figure 5. Simulation model of BLDC motor with GA-PID controller

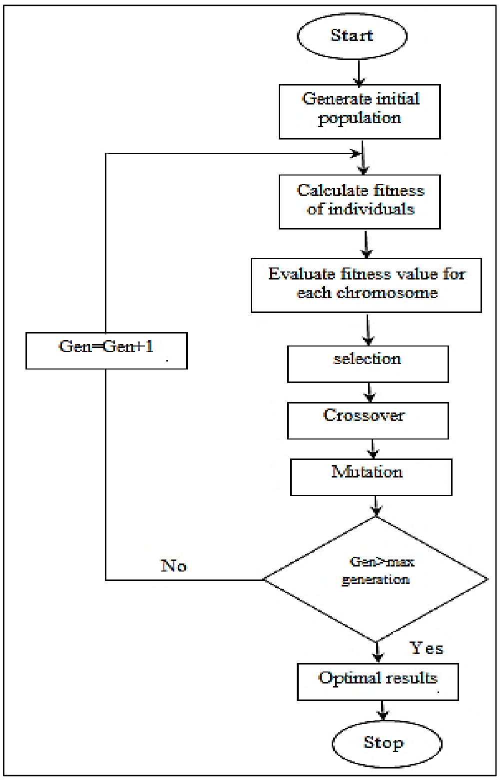


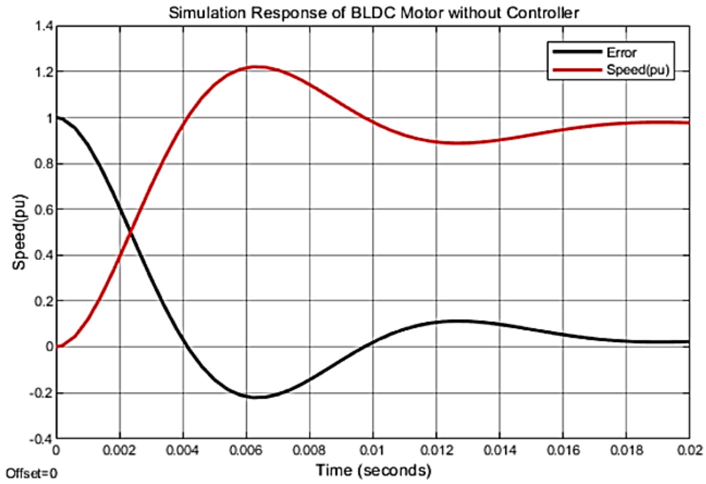
Figure 6. The flowchart of genetic algorithm

4. RESULTS AND DISCUSSION

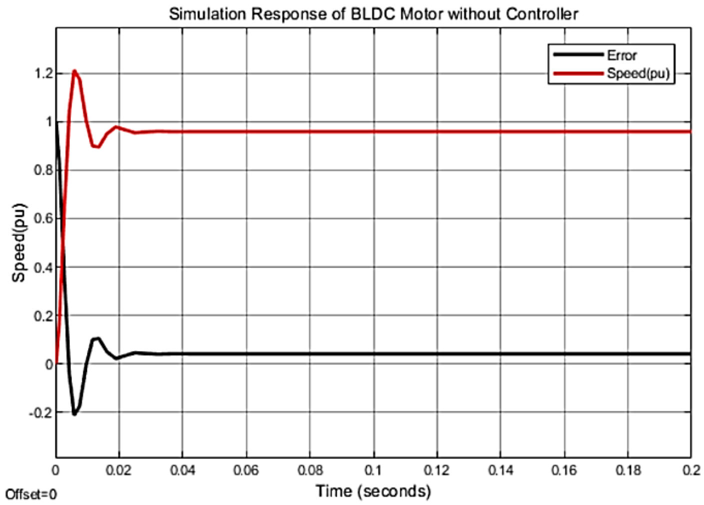
In this section, there are three parts, first part simulation results without controller that show in subsection 4.1. Second part simulation results with PID controller that show in subsection 4.2. Third part simulation results with GA-PID controller that show in subsection 4.3.

4.1. Simulation results without controller

This section discuss the simulation results obtain by using MATLAB/Simulink program. Figure 7(a) shows the response of the system without controller at time 0.02 sec and Figure 7(b) at time 0.2 sec represented in speed of motor. From this figure, the percentage over shoot=20%, rise time=0.003 sec where as settling time=0.018 sec.



(a)



(b)

Figure 7. Simulation response of BLDC motor without controller (a) at 0.02 sec and (b) at 0.2 sec

4.2. Simulation results with PID controller

This section discuss the response of system by using PID controller that using to improve operation and performanceof BLDC motor. Figure 8 shows the response of system that indicates to reduce overshoot to 7.1%, rise time=0.0279 sec, and settling time=0.102 sectherefor the system reaches to steady state at less time than the first case without controller, the value of the parameters for PID controller are Kp=0.062988, Kd=4.7342e-05, and Ki=3.242. Figure 9 shows controller parameters of PID controller and (performance and robustness). Figure 10 is illustrated the response of system for each simulation model of BLDC without and with PID controller these results refers to obtain a good response by using PID controller compared without controller.

4.3. Simulation results with GA-PID controller

This section deals with the use of the genetic-PID optimization for improving the response of BLDC motor and obtaining the best results in order to develop and improve the performance and operation of the motor by improve parameters of PID controller to reach optimization. Figure 11 shows response of system by using GA-PID optimization, this figure indicates to the overshoot decrease to 0, each of settling time and rise time are 0.65×10-7 sec and 0.22×10-7 sec respectively, and the system reaches the steady state in a much shorter time than the previous two states (without controller and with controlling PID controller). The values of control parameters are KP=0.183, Kd=4.996, Ki=0.001 at iteration=127. Figure 12 indicates tothe optimization tools for GA-PID, Figures 13-15 show the GA, fitness value, average distance between individuals respectively.

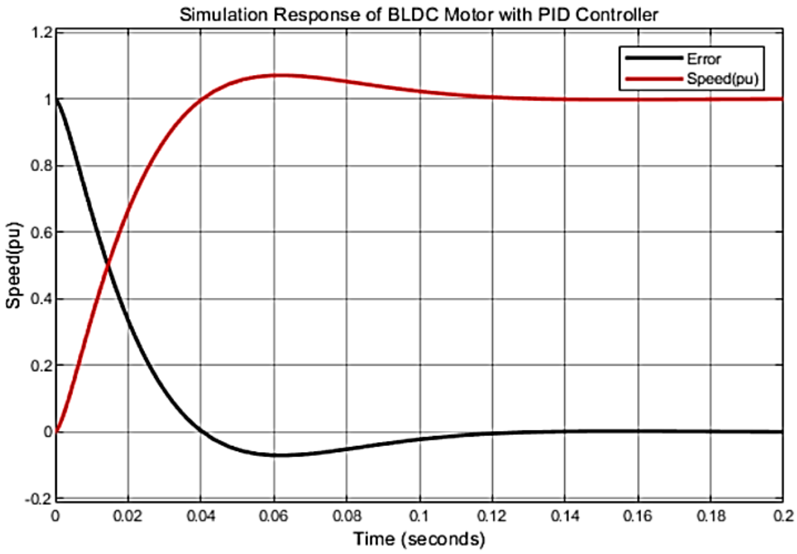


Figure 8. Simulation response of BLDC with PID controller

Controller Parameters

	Tuned	Block
P	0.062988	1
I	3.2421	1
D	4.7342e-05	0
N	6131.777	100

Performance and Robustness

	Tuned	Block
Rise time	0.0279 seconds	0.0028 seconds
Settling time	0.102 seconds	NaN seconds
Overshoot	7.1 %	22.5 %
Peak	1.07	1.22
Gain margin	Inf dB @ Inf rad/s	Inf dB @ Inf rad/s
Phase margin	69 deg @ 53.7 rad/s	43 deg @ 461 rad/s
Closed-loop stability	Stable	Stable

Figure 9. Controller parameters of PID controller & performance and robustness

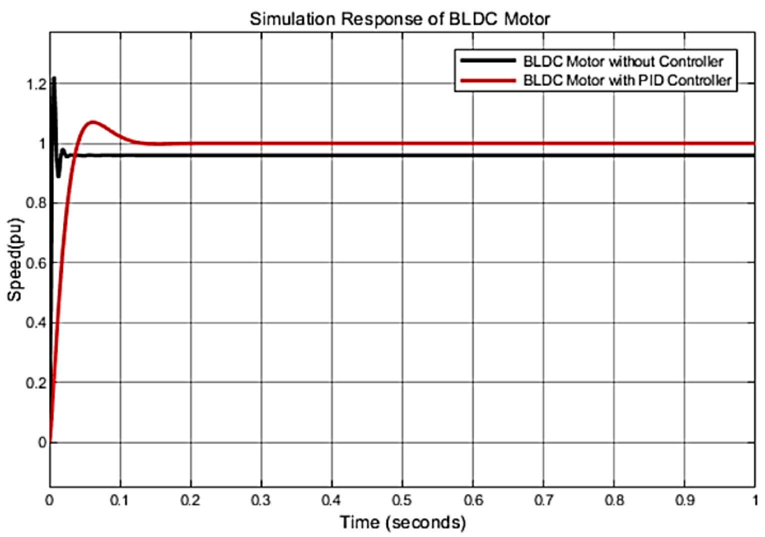


Figure 10. Simulation response of BLDC without and with PID controller

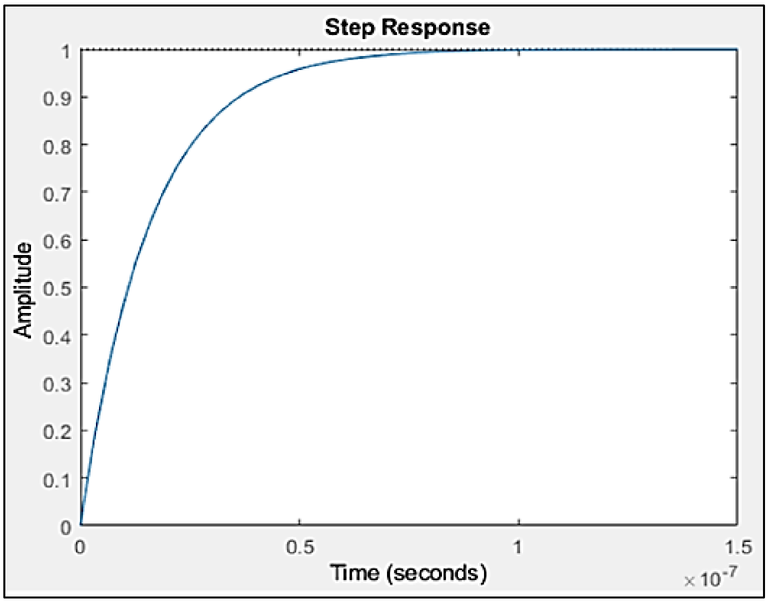


Figure 11. Response of system by using GA-PID optimization

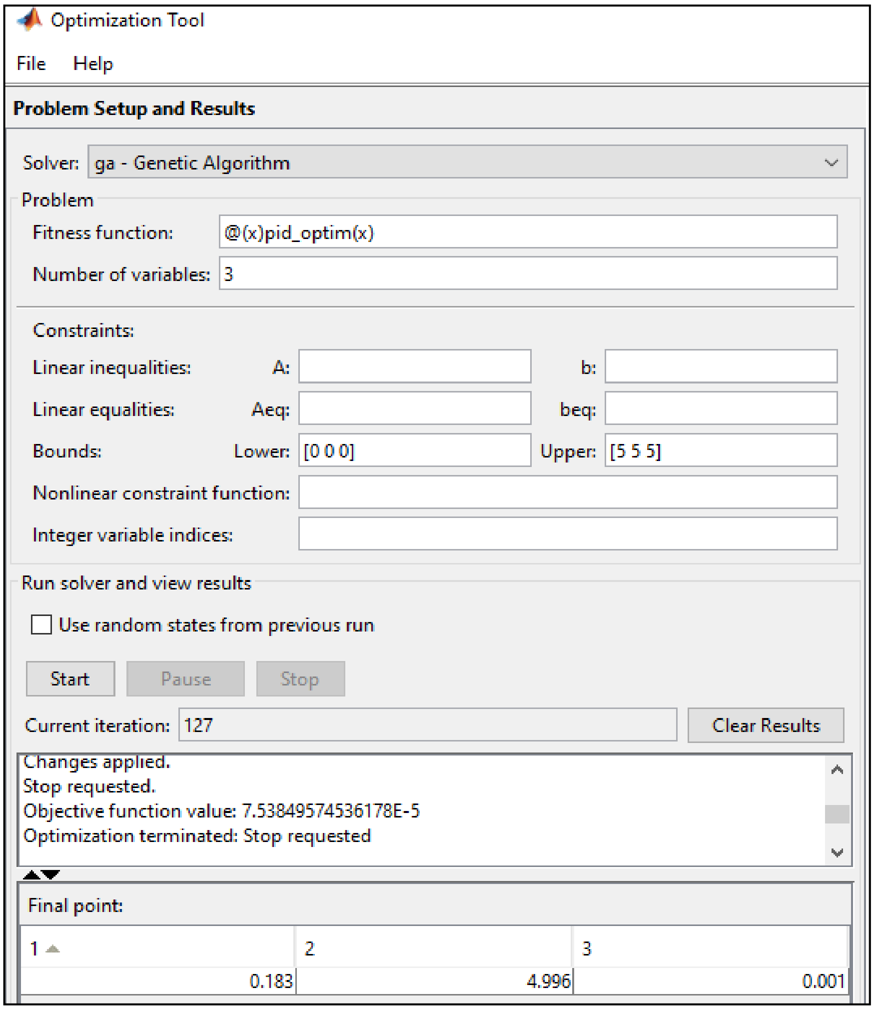


Figure 12. The optimization tools for GA-PID controller

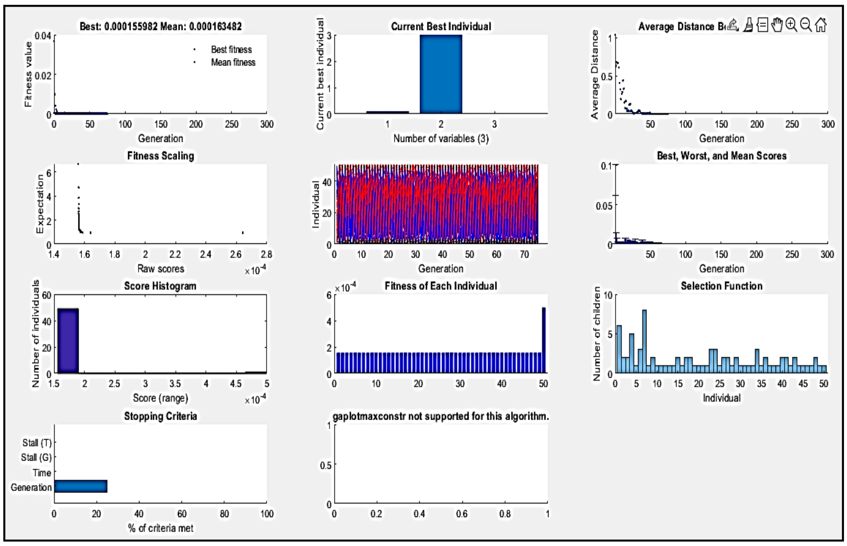


Figure 13. Simulation response for genetic algorithm

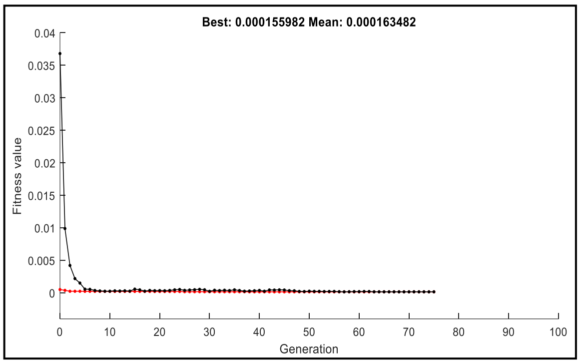


Figure 14. Fitness value

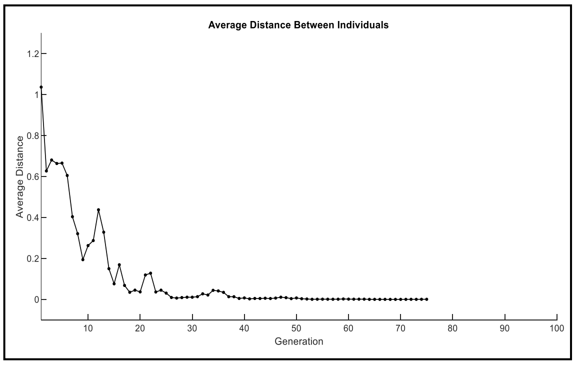


Figure 15. Average distance between individual

Table 2 shows the values of control parameters (KP, Kd and Ki) for PID controller and GA-PID optimization while Table 3 shows the values of simulation results for each of percentage overshoot, rise time and settling time with comparison between two states (with PID controller and GA-PID). From simulation results, it is clear that the response of the system in the case of using PID controller is better than the case without controller by reducing the overshoot, rise time, and settling time. In addition, the response of system by using GA-PID is improved more than the previous two cases, and the system reached to optimization through reduce overshoot to zero and rise time, settling time lowest possible values, thus achieving the best results, led to improve, develop the operation, and performance of the BLDC motor.

Table 2. Control parameters

Parameters	With PID controller	With GA-PID
Kp	0.062988	0.183
Kd	4.7342e-5	4.995
Ki	3.2421	0.001

Table 3. Response of system

Parameters	With PID controller	With GA-PID
Overshoot	7.1%	0
Rise time	0.0279 sec	0.22×10-7 sec
Settling time	0.102 sec	0.65×10-7 sec

5. CONCLUSION

In the study, the genetic method was proposed to adjust the control parameters of the traditional PID controller that is designed as a BLDC motor control system, where the genetic controller has much higher time response characteristics comparative with the PID controller also it provides us with the initial point for the values of the control parameters. The GA-PID is the best in relations (settling time, rise time, and overshoot). In addition, the error associated with GA-PID is much less than the traditional control methods, therefor; GA-PID has succeeded in obtaining the best results for BLDC motor.

REFERENCES

[1] Y. I. M. A. Mashhadany, A. K. Abbas, and S. S. Algburi, "Modeling and analysis of brushless DC motor system based on intelligent controllers," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 6, pp. 2995–3003, 2022, doi: 10.11591/eei.v11i6.4365.

[2] S. Kanagaraj and S. Nithaiyan, "Speed control of hybrid energy sources fed BLDC motor drive with FOPID controllerusing various optimization techniques," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 6, pp. 3069–3078, 2022, doi: 10.11591/eei.v11i6.4095.

[3] S. W. Shneen, H. S. Dakheel, and Z. B. Abdulla, "Design and implementation of variable and constant load for induction motor," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 2, pp. 762–773, 2020, doi: 10.11591/ijpeds.v11.i2.pp762-773.

[4] M. I. Mosaad, H. S. M. Ramadan, M. Aljohani, M. F. E. -Naggar, and S. S. M. Ghoneim, "Near-optimal PI controllers of STATCOM for efficient hybrid renewable power system," *IEEE Access*, vol. 9, pp. 34119–34130, 2021, doi: 10.1109/ACCESS.2021.3058081.

[5] P. Majewski, D. Pawuś, K. Szurpicki, and W. P. Hunek, "Toward optimal control of a multivariable magnetic levitation system," *Applied Sciences*, vol. 12, no. 2, pp. 1–14, 2022, doi: 10.3390/app12020674.

[6] F. N. Abdullah, G. A. Aziz, and S. W. Shneen, "Simulation model of servo motor by using MATLAB," *Journal of Robotics and Control (JRC)*, vol. 3, no. 2, pp. 176–179, 2022, doi: 10.18196/jrc.v3i2.13959.

[7] R. Firmansyah and R. Irmawanto, "Comparison study of PI controller tuning method to regulate the DC motor speed," in *2021 3rd International Conference on Research and Academic Community Services (ICRACOS)*, 2021, pp. 93–97, doi: 10.1109/ICRACOS53680.2021.9702007.

[8] K. Gadekar, S. Joshi, and H. Mehta, "Performance improvement in BLDC motor drive using self-tuning PID controller," in *2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA)*, 2020, pp. 1162–1166, doi: 10.1109/ICIRCA48905.2020.9183219.

[9] R. G. Kanojiya and P. M. Meshram, "Optimal tuning of PI controller for speed control of DC motor drive using particle swarm optimization," in *2012 International Conference on Advances in Power Conversion and Energy Technologies (APCET)*, 2012, pp. 1–6, doi: 10.1109/APCET.2012.6302000.

[10] M. R. Corapsiz and H. Kahveci, "The speed control of DC motor under the load condition using PI and PID controllers," in *AIP Conference Proceedings*, 2017, p. 020116, doi: 10.1063/1.4981764.

[11] J. C. Basilio and S. R. Matos, "Design of PI and PID controllers with transient performance specification," *IEEE Transactions on Education*, vol. 45, no. 4, pp. 364–370, 2002, doi: 10.1109/TE.2002.804399.

[12] D. A. Barkas, G. C. Ioannidis, C. S. Psomopoulos, S. D. Kaminaris, and G. A. Vokas, "Brushed DC motor drives for industrial and automobile applications with emphasis on control techniques: a comprehensive review," *Electronics*, vol. 9, no. 6, pp. 1–26, 2020, doi: 10.3390/electronics9060887.

[13] M. Daigavane, H. Suryawanshi, and J. Khan, "A novel three phase series-parallel resonant converter fed DC-drive system," *Journal of Power Electronics*, vol. 7, no. 3, pp. 222–232, 2007.

[14] A. Consoli, M. Cacciato, A. Testa, and F. Gennaro, "Single chip integration for motor drive converters with power factor capability," *IEEE Transactions on Power Electronics*, vol. 19, no. 6, pp. 1372–1379, 2004, doi: 10.1109/TPEL.2004.836636.

[15] S. Waley, C. Mao, and N. K. Bachache, "Biogeography based optimization for tuning FLC controller of PMSM," in *Advances in Swarm and Computational Intelligence*, Cham: Springer, 2015, pp. 395–402, doi: 10.1007/978-3-319-20466-6_42.

[16] J. L. -Flores and H. S. -Ramirez, "A smooth starter for a DC machine: a flatness based approach," in *(ICEEE). 1st International Conference on Electrical and Electronics Engineering, 2004.*, pp. 589–594, doi: 10.1109/ICEEE.2004.1433953.

[17] R. S. -Ortigoza, J. M. A. -Martinez, M. M. -Melchor, V. M. H. -Guzman, and M. M. -Aranda, "Flatness based control of a buck-converter/DC-motor combination," in *2012 IEEE Ninth Electronics, Robotics and Automotive Mechanics Conference*, 2012, pp. 294–299, doi: 10.1109/CERMA.2012.55.

[18] H. S. Dakheel, Z. B. Abdullah, N. S. Jasim, and S. W. Shneen, "Simulation model of ANN and PID controller for direct current servo motor by using MATLAB/Simulink," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 20, no. 4, pp. 922–932, 2022, doi: 10.12928/telkomnika.v20i4.23248.

[19] R. Sureshkumar and S. Ganeshkumar, "Comparative study of proportional integral and backstepping controller for buck converter," in *2011 International Conference on Emerging Trends in Electrical and Computer Technology*, 2011, pp. 375–379, doi: 10.1109/ICETECT.2011.5760146.

[20] F. B. Lynser, M. Sun, M. Sungoh, N. Taggu, and P. Konwar, "Comparative analysis of different control schemes for DC-DC converter: a review," *ADBU Journal of Electrical and Electronics Engineering (AJEEE)*, vol. 2, no. 1, pp. 13–20, 2018.

[21] S. W. Shneen and G. A. Aziz, "Simulation model of 3-phase PWM rectifier by using MATLAB/Simulink," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 5, pp. 3736–3746, 2021, doi: 10.11591/ijece.v11i5.pp3736-3746.

[22] S. R. Bhagwatkar and A. P. Dhande, "Automatic closed loop speed control of DC motor," *International Journal of Science and Research (IJSR)*, vol. 4, no. 5, pp. 137–139, 2015, doi: 10.17148/ijarcce.2015.4128.

[23] C. T. Katsambe, V. Luckose, and N. S. Shahabuddin, "Effect of pulse width modulation on DC motor speed," *International Journal of Students' Research in Technology & Management*, vol. 5, no. 2, pp. 42–45, 2017, doi: 10.18510/ijsrtm.2017.522.

[24] E. Can and H. Sayan, "The performance of the DC motor by the PID controlling PWM DC-DC boost converter," *Tehnički glasnik*, vol. 11, no. 4, pp. 182–187, 2017.

[25] S. W. Shneen, D. H. Shaker, and F. N. Abdullah, "Simulation model of PID for DC-DC converter by using MATLAB," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 5, pp. 3791–3797, 2021, doi: 10.11591/ijece.v11i5.pp3791-3797.

[26] P. Karpagavalli and A. E. Jeyakumar, "Simulation analysis on proportional integral and derivative control of closed loop dc motor drive with bipolar voltage switching," *American Journal of Applied Sciences*, vol. 10, no. 7, pp. 714–723, 2013, doi: 10.3844/ajassp.2013.714.723.

[27] T. Dogruer and N. Tan, "Design of PI controller using optimization method in fractional order control systems," *IFAC-PapersOnLine*, vol. 51, no. 4, pp. 841–846, 2018, doi: 10.1016/j.ifacol.2018.06.124.

[28] S. K. Singh, H. Kumar, K. Singh, and A. Patel, "A survey and study of different types of PWM techniques used in induction motor drive," *International journal of engineering science & advanced technology*, vol. 4, no. 1, pp. 18–22, 2014.

[29] G. C. Ioannidis *et al.*, "AC-DC & DC-DC converters for DC motor drives," in *Proceedings of the 2013 International Conference on Electronics and Communication Systems*, 2021, vol. 12, pp. 155–162, doi: 10.37394/232017.2021.12.20.

[30] K. C. Ramya, J. G. Ramani, A. Sridevi, R. S. Rai, and D. R. A. Shirley, "Analysis of the different types of electric motors used in electric vehicles," in *E-Mobility*, Cham: Springer, 2022, pp. 43–57, doi: 10.1007/978-3-030-85424-9_3.

[31] S. Ekinci, B. Hekimoğlu, and D. Izci, "Opposition based Henry gas solubility optimization as a novel algorithm for PID control of DC motor," *Engineering Science and Technology, an International Journal*, vol. 24, no. 2, pp. 331–342, 2021, doi: 10.1016/j.jestch.2020.08.011.

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