Performance Analysis Stability Of Speed Control Of BLDC Motor Using PID-BAT Algorithm In Electric Vehicle

,

Izza Anshory[1)]
[1] Fakultas Teknik Universitas Muhammadiyah Sidoarjo
izzaanshory@umsida.ac.id

Abstract - The research on the development of electric vehicles includes such as power electronics, energy storage capability that the higher the battery, reducing fuel emissions, and the motor efficiency. The electric motor efficiency requires the automatic control on the main parameters such as speed, position, and acceleration. The performance setting of speed Brushless DC (BLDC) Motor can be improved by using the controller *Proportional Integral Derivative* (PID), a combination of PID using nature inspired optimization algorithms such as Bat Algorithm (BA). BA is one of the optimization algorithm that mimics the behavior of bats on the move using a vibration or sound pulses emitted a very loud (*echolocation*) and listen to the echoes that bounce back from the object to determine the circumstances surrounding vicinity

In this paper, simulate of Bat Algorithm to find the best value PID controller parameter to speed control BLDC motor and analyze performance such as the value of overshoot, steady state. The result simulation shows that values for the PID parameters without using algorithm bat is Kp = 208.1177, Ki = 1767, and Kd = -8.6025. While using the algorithm bat got value Kp = 5.4303e+04, Ki = -1.3059e+06, and Kd = 3.0193e+04. The performance of the motor obtained through value rise time of 0. 282, settling time of 1.5, overshoot value of 20.5% and the peak value of 1.21.

Keyword: Electric Vehicle, BLDC Motor, PID and Bat Algorithm.

1. BACKGROUND

In recent years, research on the development of electric vehicle is increasing, due to the increasing number of motor vehicles in the world consumption of 700 million in a 2.5 billion along with the increasing world population of 6 billion in 2000 to 10 billion in 2050 [1]. Research to develop electric vehicles lies in various aspects such as the battery's ability to store energy, improving the efficiency of the electric motor as the driving force, the material component architecture with lighter materials and power electronics [2].

The main parameters of the automatic control such as speed, position, acceleration and current is used to improve the performance of electric motors [3]. There are five types component of electric motors used in electric vehicles, namely DC motors, induction motors, permanent magnet synchronous motors, switched reluctance and brushless DC motors [4]. Motor Brushless Direct Current (BLDC) as one type of electric motor vehicle, is widely used because it has several advantages such as better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges and high power-to-weight ratio [5]

Performance setting motor speed brushless DC can be improved by using the controller proportional integral derivative (PID), a combination of PID using nature inspired optimization algorithms such as particle swarm, cuckoo search, and bat algorithms, through the specification of a time domain such as settling time, undershoot, overshoot, recovery time, and steady-state error and the performance of the motor performance through root mean squared error, integral of absolute error, Multiplied time integral of absolute error and the integral of squared error [6].

Based on this, in this paper will simulate and analyze the performance of bat algorithm to optimize controller PID for the speed control BLDC motor in electric vehicles by reducing the value of steady state error and minimal overshoot.

2. METHODS DESIGN STABILITY SPEED CONTROL BLDC MOTOR OPTIMIZED BY BAT ALGORITHM

2.1. Electric Vehicle

The electric vehicle is a vehicle that uses electrical energy as the driving force. Electric vehicles are classified into three types: pure electric vehicle (PEVs), hybrid electric vehicles (HEVs), and fuel cell electric vehicles (FCEVs). Figure 1 shows the component parts of the electric vehicle is battery, inverter, controller and electric motor. A battery is a major component of an electric car that serves to store energy and used to power electric vehicle [7].

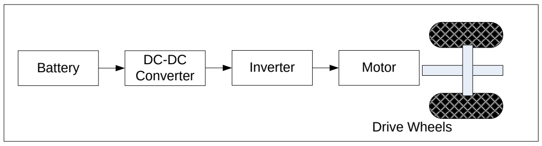

Figure 2.1. Electric vehicle architecture

Battery electric vehicle have the advantage of high efficiency, low noise level, and has the potential to reduce air pollution when charged from a source of renewable energy. The next component is the inverter, which is a bi-directional converter, which receives high voltage traction battery and converts it to a three-phase AC voltage suitable for traction. Another component is the controller, is a component that serves to regulate drive torque, the braking energy optimization control, the vehicle energy management, fault diagnosis and processing, and vehicle condition monitoring. The last component is the electric motor. The electric motor can be used as the driving kinds of motors, such that DC motors, induction motors, permanent magnet synchronous motors, switched reluctance and Brushless DC motors.[4]

A DC-DC converter is used to adjust the voltage on the battery and motor drive system. Feedback and speed profile of the motor is taken as a reference for the inverter control pulse generator. Charged state of the battery at the time considered to control the converter. DC voltage converter to bring the needs of the inverter. [8]

2.2. Mathematical Model of BLDC Motor

Brushless DC motors (BLDC motor) which is known as an electronic commutated motors have many advantages such as simple structure, reliable operation, low maintenance, high dynamic speed, better control performance and good mechanical properties. A Brushless DC motors have a rotor with permanent magnets and a stator with the windings connected to the electronic control. Electronic controls replace the function of the commutated and energize the proper winding. Each turn of the sequence has one roll of electrical energy to the positive (current into the windings), the second winding negative (when exiting the turns) and the third is in a state of non-energy. The torque generated due to the interaction between the magnetic field generated by the stator coils and permanent magnets. [9]

The circuit diagram for the stator winding is as shown in figure.2.

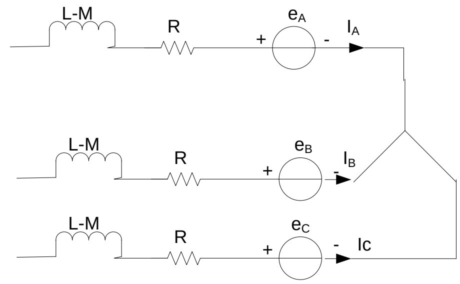

Figure 2.2. Circuit diagram stator winding

BLDC motor circuit equations can be described by the equation (1-3).[10]

$$V_a = I_a R + L\frac{di_a}{dt} + E_a \quad (1)$$

$$V_b = I_b R + L\frac{di_b}{dt} + E_b \quad (2)$$

$$V_c = I_c R + L\frac{di_c}{dt} + E_c \quad (3)$$

Where, L_a=L_b= L_c = L : self-inductance [H]
R_a=R_b= R_c = R : phase resistance [Ω]
V_a=V_b= V_c= V : phase voltages [V]
I_a= I_b = I_c = I : phase current[A]
E_a= E_b =E_c = E : back EMF [V]

The transfer function is therefore obtained as follows using the ratio of and the angular velocity, ω_m to source voltage, V_s.[11] That is,

$$G(s) = \frac{\omega_m}{V_s} = \frac{\frac{1}{K_e}}{\tau_m \tau_e s^2 + \tau_m . s + 1}$$

Where the mechanical (time constant) is

$$\tau_m = \frac{RJ}{K_e K_t}$$

The electrical (time constant),

$$\tau_e = \frac{L}{3xR} \quad (6)$$

$$K_e = \frac{3R_\emptyset J}{K_t \tau_m} \quad (7)$$

where, R=R_ϕ is terminal resistance phase to phase, T_e is the input torque of the winding, J is the inertia of the system, L is the inductance armature, k_T is the torque constant, P is the number of poles. The coefficient B is calculated from the moment of inertia J

The parameters used for the modeling BLDC motor is shown in Table 1. The parameters are taken from [12]

Table 2.1. BLDC Parameter Motor

No.	Parameter	Value
1	Armature Resistance (Ra)	0.94 Ω
2.	Armature Inductance (La)	1.19 x 10^{-3} H
3.	Moment Inertia (J)	5.1 x 10^{-3} Kgm^2
4.	Torque constant (Kt)	0,426 Nm/A
5.	Mechanical Time constant (τ_m)	0.00491sec

$$\tau_e = \frac{L}{3xR} = \frac{1.19x10^{-3}}{3x0.94} = \frac{1.19x10^{-3}}{2.82} = 422x10^{-6}$$

J_{Rotor} = 5.1x10^{-6} Kgm^2

$$K_e = \frac{3R_\emptyset J}{K_t \tau_m} = \frac{3x0.94x5.1x10^{-6}}{0.426x0.00491} = \frac{14.382x10^{-6}}{2.092x10^{-3}} = 6.87x10^{-3}\ {}^{V.sec}/_{rad}$$

$$G(s) = \frac{\omega_m}{V_s} = \frac{\frac{1}{K_e}}{\tau_m \tau_e s^2 + \tau_m . s + 1}$$

$$G(s) = \frac{\omega_m}{V_s} = \frac{{}^1/_{6.87x10^{-3}}}{0.00491x422.x10^{-6}.s^2 + 0.00491.s + 1}$$

$$G(s) = \frac{145.5}{2.072.10^{-6}.s^2 + 0.00491.s + 1}$$

2.3. Bat Algorithm

Algorithm (Bat algorithm) is one of the optimization algorithm that mimics the behavior of bats on the move using a vibration or sound pulses emitted a very loud (echolocation) and listen to the echoes that bounce back from the object to determine the circumstances surrounding. Bats will tend to choose a place more lonely than a noisy place. Each pulse noise include frequency, loudness, and rate of pulse emission. Bat algorithm is based on the following aspects; all bats use echolocation and distinguish the difference between the victim and obstruction. Bats fly at random, in a random location, with a variable frequency, loudness, and rate of pulse emission. [6].

Stages Bat algorithm begins by initializing a set of bat populations ({B_1, B_2,…, B_N}). Each bat are defined as the position (x_i^t), velocity(v_i^t), frequency(F_i), loudness (A_i^t) and the rate of pulse emission (r_i^t). In ordert to get the right frequency, Fmin and Fmax, are identified as lower and upper bound emission frequencies. Alfa (α) and gamma (γ) are parameters to be set 0.9 before the run. Algorithmanya stages as follows [13]:

Step 1: While t < maximum number of iterations

Step 2: For i = 1: N_b , generate B_{new} , If rand > r_{new} with select one among the best solutions and generate a local solution around this one.

Step 3: If else so select randomly a solution and generate a local solution around this one, and if evaluate for the bats.

Step 4: If (rand < A_i) ∧ (B_{new} < B_i) so B_i = B_{new} become increase r_1 and reduce A_i

Step 5: End for rank bats to find the best solution in population find the best bat.

2.4. PID (Proportional Integral Derivative)

Proportional Integral Derivative control system is a feedback control technology that is widely used as an automatic controller in industrial control systems. The PID control system has an important role to carry out energy saving system on any closed loop control system [14].

The rapid development of science and technology, demand accuracy, speed of response and stability control system becomes higher. For this process, the classic PID control has been widely used because of its simple construction and good durability. The PID control principle is to establish control with proportional, integration and differentiation, then choose a linear combination of the right to control the target [15].

3. RESULT AND ANALYSIS

BLDC motor parameters based on data that has been mentioned, the open-loop analysis by considering several factors of stability and making some necessary plot for this analysis, like to include the step response open loop, root locus, and bode plot diagram.

3.1. Open Loop System

After obtaining the transfer function equation, then we are modeling the transfer function in the form of Simulink such as Figure 3.1.

Figure 3.1. Block Simulink Open Loop System

Figure 3.2.a. Shows open loop step response diagram BLDC Motor with t=2 sec, achieving stability in the value of t = 1.023 and amplitude = 144.7.

Figure 3.2.b. Shows open loop step response diagram BLDC Motor with t=0.05 sec, achieving stability in the value of t = 0.0304 and amplitude = 145.

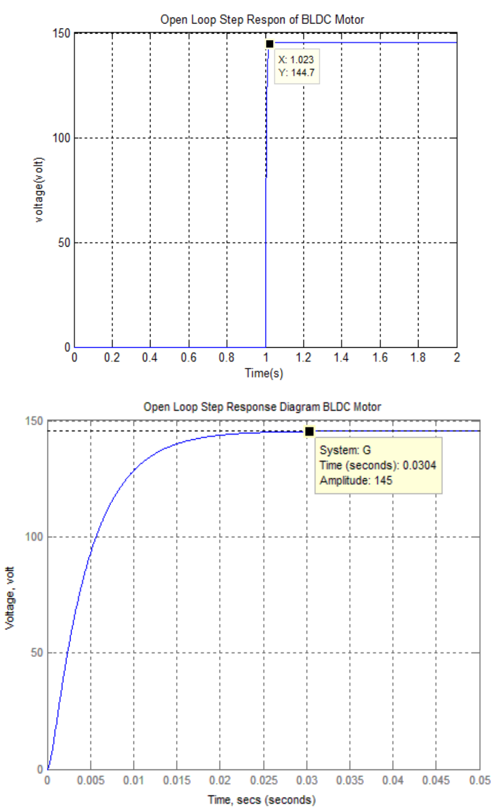

Figure 3.2.a. Open Loop Step Response Diagram BLDC Motor with t=2 sec

3.2.b. Open Loop Step Response Diagram BLDC Motor with t=0.05 sec

3.2. PID Controller Tuning Parameter

Controller tuning PID parameter using Zeigler-Nicholas method can write in block diagram Simulink. Figure 3.3. Explains the PID control system applied to be able to improve the transient response in particular rise time, settling time, eliminating the steady-state response, and improve transient response with error predicting what will happen.

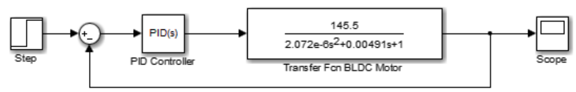

Figure 3.3. PID Schematic for BLDC Motor

Table 3.1. Magnitude PID parameter values used to determine the stability of the system.

Table 3.1. Controller PID Parameter

No.	Parameter	Value
1.	P (Proportional)	0.0118
2.	I (Integral)	3.0718
3.	D (Derivative)	-1.422e-05

There are several parameters in determining a closed loop system, the rise time is the time it takes the output of the plant, according to the level desired at the first season run. Overshoot, settling time, and steady-state error. Peak overshoot is how much higher level of steady state, to create a more normal steady state. Settling time is the time it takes the system to reach steady state. Steady state error is the difference between the steady state output to the desired output.

Figure 3.4. Close PID loop graph shows the step response with the graphic form P (*Proportional*), PI (*Proportional Integral*) and PID (*Proportional Integral Derivative*). With P system value of Time (seconds) of 0.0065 and an amplitude value of 0.627. PI system is the value of time (seconds) of 0.008, and the amplitude value of 1:01. And the last system PID is the value of Time (seconds) of 0.011 and the amplitude value is 0.996.

Table 3.2. Demonstrate the value obtained from the rise time, settling time, overshoot and peak after PID tuning parameters. The value achieved for the rise time is 0:00357 second, settling time of 0.011, the value of overshoot 8.76 % and the peak value is 1. 09.

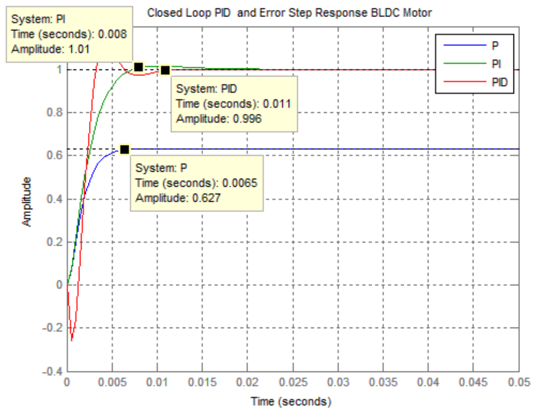

Figure 3.4. Diagram Close Loop PID step response

Table 3.2. Performance and Robustness PID Controller

No.	Parameter	Value
1.	Rise time	0.00357 second
2.	Settling time	0.011 second
3.	Overshoot	8.76 %
4.	Peak	1.09
5.	Closed-loop stability	Stable

3.3. Bat Algorithm for Optimal Design Stability Speed Control Tuning PID

In this paper, Bat Algorithm is applied to find the best PID parameters so that the system is performing dynamic control and better. Figure 3.5. shows performance analysis stability of speed control of BLDC motor using Bat algorithm.

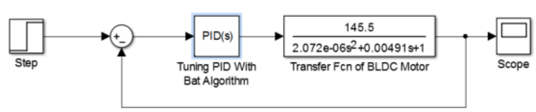

Figure 3.5. Block Simulink Bat Algorithm For Tuning PID

Table 3.3. shows parameters Bat algorithm which is used to obtain the best value in the PID tuning controller

Table 3.3. shows parameters Bat algorithm

Information	Value
Size Population	20
Loudness	0.2
Pulse rate	0.5
Alpha and Gamma	0.9
Frequency minimum	0
Frequency maximum	20
The First Iteration	1
Maximum Iteration	30
Dimension parameter	3

Figure 3.6 shows result running of optimal speed controller design stability using bat algorithm, managed to get the best value from proportional (Kp) amounted to 5.4303e+04, the integral value (Ki) of -1.3059e+06 and derivatives value (Kd) of 3.0193e+04 and Figure 3.7 shows graph controller PID have tuning with Bat algorithm.

```
ANALYSIS PERFORMANCE STABILITY SPEED CONTROL OF BLDC MOTOR
                 USING PID-BAT ALGORITHM
                    By: Izza Anshory
---------------------------------------------------------
Best =54302.879459     -1305935.7243        30193.0035
fmin =15.546

kp_bat =

   5.4303e+04


ki_bat =

  -1.3059e+06


kd_bat =

   3.0193e+04
```

Figure 3.6. Running result for Tuning PID Controller using Bat Algorithm

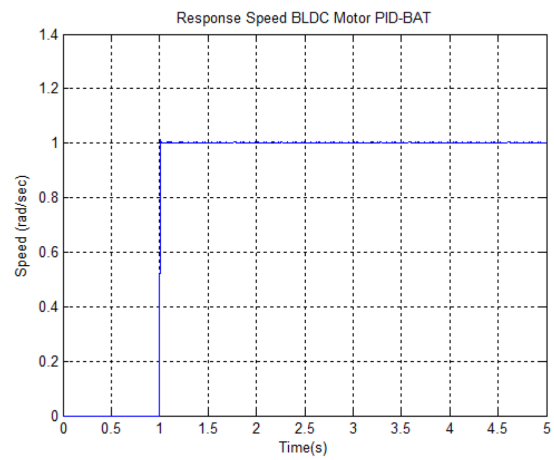

Figure 3.7. Graph for Response Speed BLDC Motor with PID-Bat Algorithm

Table 3.3. Shows the value of the performance of the optimal design speed stability control after using a bat optimization algorithm.

Table 3.3. Performance and Robustness Using Bat Algorithm

No.	Parameter	Value	
		Bat Algorithm	PID
1.	Rise time	0.282 second	0.00357 second
2.	Settling time	1.5 second	0.011 second
3.	Overshoot	20.5 %	8.76 %
4.	Peak	1.21	1.09
5.	Closed-loop stability	Stable	Stable

After be comparing the performance, stability when using PID controller and assistance Bat algorithm for PID tuning parameters, then the peak value and settling time better when without the use of artificial intelligence.

4. CONCLUSIONS

The aim of the BLDC motor speed control is for stability, reduce error steady state, produces the desired response and increase reliability. Performance analysis of the stability of the BLDC motor speed regulation is analyzed using Matlab simulations produce:

1. The open loop system, using the input unit step response at time range up to t = 0.05 has achieved stability in the value of t to 0.0304 and amplitude is 145.
2. The close loop system, using a PID controller have obtained for the value of rise time is 0. 00357 second, settling time of 0.011, the value of overshoot 8.76% and the peak value is 1. 09.
3. The close loop system with PID controller have tuned with Bat algorithm, is obtained value from gain proportional (Kp) amounted to 5.4303e+04, the gain integral value (Ki) of -1.3059e+06 and gain derivatives value (Kd) of 3.0193e+04.

REFERENCE

[1] C. Shen, P. Shan, and T. Gao, "A comprehensive overview of hybrid electric vehicles," *Int. J. Veh. Technol.*, vol. 2011, 2011.

[2] S. Mahapatra, T. Egel, R. Hassan, R. Shenoy, and M. Carone, "Model-Based Design for Hybrid Electric Vehicle Systems," 2008.

[3] J. A. Mohammed, "Modeling, Analysis and Speed Control Design Methods of a DC Motor," vol. 29, no. 1, pp. 141–155, 2011.

[4] N. Hashemnia and B. Asaei, "Comparative study of using different electric motors in the electric vehicles," *2008 18th Int. Conf. Electr. Mach.*, no. c, pp. 1–5, 2008.

[5] E. H. E. Bayoumi and H. M. Soliman, "PID / PI tuning for minimal overshoot of permanent-magnet brushless DC motor drive using particle swarm optimization," *Electromotion Sci. J.*, vol. 14, no. 4, pp. 198–208, 2007.

[6] K. Premkumar and B. V. Manikandan, "Bat algorithm optimized fuzzy PD based speed controller for brushless direct current motor," *Eng. Sci. Technol. an Int. J.*, 2015.

[7] M. Zhou, L. Zhao, Y. Zhang, Z. Gao, and R. Pei, "Pure Electric Vehicle Power-train Parameters Matching based on Vehicle Performance," vol. 8, no. 9, pp. 53–62, 2015.

[8] S. George, R. V. Chacko, and S. K, "Modelling and simulation of Electric Vehicle Power train in SEQUEL," *IEEE Int. Conf. Power Electron. Drives Energy Syst.*, 2014.

[9] S. K. A, Y. Laxminarayana, and S. Tarakalyani, "Modeling and Simulation of Bldc Motor for Aiding and Opposing Loads," *IOSR J. Electr. Electron. Eng.*, vol. 7, no. 4, pp. 9–67, Oct. 2013.

[10] Y. S. Jeon, H. S. Mok, G. H. Choe, D. K. Kim, and J. S. Ryu, "A new simulation model of BLDC motor with real back EMF waveform," in *The 7th Workshop on Computers in Power Electronics, 2000. COMPEL 2000*, 2000, pp. 217–220.

[11] B. Das, S. Chakrabarti, P. R. Kasari, and A. Chakraborti, "Novel reverse regeneration technique of BLDC motor for capacitor charging," in *2014 International Conference on Control, Instrumentation, Energy and Communication (CIEC)*, 2014, pp. 246–253.

[12] K. L. Shenoy, "Design Topology and Electromagnetic Field Analysis of Permanent Magnet Brushless DC Motor for Electric Scooter Application," 2016.

[13] T. C. Bora, L. D. S. Coelho, and L.

Lebensztajn, “Bat-inspired optimization approach for the brushless DC wheel motor problem,” *IEEE Trans. Magn.*, vol. 48, no. 2, pp. 947–950, 2012.

[14] A. Oi, C. Nakazawa, and T. Matsui, “Development of PSO-based PID Tuning Method,” vol. 2, pp. 1917–1920, 2008.

[15] J. Guo, G. Wu, and S. Guo, “Fuzzy PID algorithm-based motion control for the spherical amphibious robot,” in *2015 IEEE International Conference on Mechatronics and Automation (ICMA)*, 2015, pp. 1583–1588.