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Implementation of a DSP- TMS320F28335 Based State Feedback with Optimal Design of PI Controller for a Speed of BLDC Motor by Ant Colony Optimization

***Abstract**. This paper presents the design for control system and Implementation of a DSP TMS320F28335 Based State Feedback with Optimal Design of PI Controller for control Speed of BLDC Motor by genetic algorithm (GA), particle swarm optimization (PSO) and Ant Colony Optimization (ACO) for comparison the control Speed of BLDC Motor System. The experimental results show that Optimal Design of PI controller is the ACO controller, was able to control speed of BLDC motor. In load and non-load condition, control system can maintain the level of speed in steady state. According to the responses of the reference signal, this can be concluded that controlling speed round using an ACO controller is highly effective in controlling the speed of BLDC motor.*

***Streszczenie.** W artykule przedstawiono projekt systemu sterowania i implementację DSP TMS320F28335 opartego na sprzężeniu zwrotnym z optymalnym kontrolerem PI do sterowania prędkością silnika BLDC za pomocą algorytmu genetycznego (GA), optymalizacji roju cząstek (PSO) i optymalizacji kolonii mrówek (ACO) dla Porównanie kontroli prędkości systemu silnika BLDC. Wyniki eksperymentalne pokazują, że optymalną konstrukcją kontrolera PI jest kontroler ACO, który był w stanie kontrolować prędkość silnika BLDC. W warunkach obciążenia i bez obciążenia układ sterowania może utrzymać poziom prędkości w stanie ustalonym. Zgodnie z odpowiedziami sygnału odniesienia można stwierdzić, że sterowanie prędkością obrotową za pomocą kontrolera ACO jest wysoce skuteczne w sterowaniu prędkością silnika BLDC. (**Zastosowanie sprzężenia zwrotnego opartego na DSP-TMS320F28335 z optymalnym projektem kontrolera PI dla sterowania prędkością silnika BLDC przez optymalizację z wykorzystanie algorytmów genetycznych**)*

Keywords: BLDC Motor, PI Controller, Ant Colony Optimization.
Słowa kluczowe Silnik BLDC, kontroler PI, optymalizacja kolonii mrówek.

Introduction

There are many types of brushless DC motor use in industries. The proposed controller will be a state feedback with controller incorporating integrator. BLDC motor is one of motor type gaining popularity nowadays. We find that brushless DC (BLDC) [1] motor modellingก can be simply implemented using transfer function analysis. With rapid developments in power electronics, power semiconductor technologies, modern control theory for motors and manufacturing technology for high performance magnetic materials, the Brushless DC (BLDC) motors have been widely used in many applications. A speed control system for a brushless DC motor can control basis by using the state feedback controller [2]. The control system is to meet a given set of specifications and achieve a rise time which is as fast as possible. In control system is to meet a given set of specifications and achieve a rise time which is as fast as possible. The design will be implemented, and its performance evaluated. The speed control system to be considered in this system is illustrated in Figure 1[3-4].

Propose a method to adjust the speed control system used the PI to achieve the least error for the BLDC Motor drive and genetic algorithm (GA) to adjust the received controller to completely improve the speed response to the change of speed and load requirements. Tariq NN E-Balluq [5]. on the other hand, a hybrid method for speed control of BLDC motor became increasingly concerned in the aspect of improving the performance. K. Prathibanandhi and R. Ramemesh proposes a PID controller for BLDC motor speed control used in conjunction using Neuro-fuzzy controller to adjust the error. Such as bat algorithm, PSO and ant-lion optimization compared to the proportional control techniques [6]. the PI controllers supplemented with batteries to provide the power needed to drive the BLDC motor. Applied to electric vehicles (EV) and hybrid electric vehicles (HEV). Praveen YADAV. [7] establish a method to control the speed, current and voltage by the PWM control method derived from the PID controller optimized using particle swarming optimization (PSO) to study the behaviour of the controller by Adel A. obed, Abbas K. Kadhim [8]. Design PI (D) controller for BLDC motor speed control for the TMS320F28335 DSP board connected to MATLAB / SIMULINK to perform control performance. The results show that BLDC motor speed response can be controlled at operating speeds of 800 and 1200 rpm in both no-load and full-load conditions. Chookiat Kiree et al. [9] introduce the speed control of BLDC motor with fuzzy Sliding Mode Control (FUZZYSMC) compared to PI controller. FUZZYSMC provides better control than the PI controller in the BLDC motor in the aspect of powerful speed response by Priyanka Bharat More and Dr. AA Godbole [10]. T.V. Narmadha, J.Velu and T.D.Sudhakar analyze of PV Luo Super-loft converters using various controllers such as PI controller modified with the Ziegler Nichols. The results provide good temporary performance compared to conventional PI. For similar simulations in theoretical analysis the precipitation time and the overload obtained by using a hybrid controller are compared with fuzzy and conventional controllers. The results show that the hybrid controller has good dynamic performance and can reach real-time performance, efficiently [11].

Based on the mentioned studies, this article focused on designing mathematical simulation using state space instead of the original simulation. Also speed controller of BLDC motor for an optimized PI control design using ACO, PSO and GA to be further applied DSP model TMS320F28335 for testing BLDC motor speed controlling system [12]. This is one of the research tools used for testing the BLDC motor speed controller of high quality.

Modelling of BLDC Motor

To comprehend and describe the behaviour of the motor drive, such as the current, voltage, speed and torque at the instantaneous state and a constant state of the motor, the equivalent circuit of the BLDC Motor is shown in Figure 1.

Figure 1 shown equivalent circuit is which can be written as a matrix form of the BLDC Motor in the phase variable, which describes the BLDC Motor equation. V_a, V_b, V_c is the voltage (V) in the three-phase coil series with the phase variable, which can be described as defined in the matrix form R as the motor's winding, $i_a i_b i_c$ is the current in the winding of the BLDC Motor, which $L_s - L_m$ is the motor winding (H) or $L_1 = L_s - L_m$ is the inductance of the coil on the phase $e_a e_b e_c$, which is the back emf. The matrix form, equation 1 is as follows.

(1) $$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_s - L_m & 0 & 0 \\ 0 & L_s - L_m & 0 \\ 0 & 0 & L_s - L_m \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

where

V_a, V_b, V_c is voltages (V) at phase *a,b,c* and $e_a e_b e_c$ is voltages (V) of back electromotive forces at phase

a,b,c. R is resistance (*Ohm*) on motor's winding, $L_1 = L_s - L_m$ is motor's winding inductance (H), L_s is motor's winding inductance (H) at phase *a, b, c*.

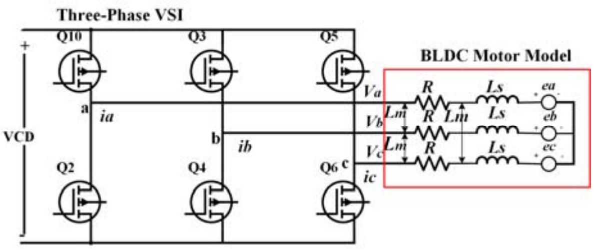

Fig. 1. BLDC Motor System.

For the dynamic model of BLDC Motor, it consists of two parts: The mechanical part and the electrical part of the power and torque equations of the motor can be written as the second equation 2.

(2) $$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega}$$

where ω is angular velocity, T_e is electrical torque (*N.m.)*

Equation 3 accounts for the motor's mechanical movement, which is related to the electrical movement and of the rotor position as in Equation 3.

(3) $$T_e = B\omega_m + J\frac{d\omega_m}{dt} + T_L$$

where T_e is electrical torque (*N.m.*), J is moment of inertia, ω_m is motor angular velocity, T_L is load torque (*N.m*), B is friction force coefficient between motor and load. The relationship between the position and velocity of the electric rotor shown in Equation 4.

(4) $$\frac{d\theta}{dt} = \left(\frac{P}{2}\right) * \omega$$

where θ_m is mechanical degree, P is the number of motor's pole.

State Space Model

To design the BLDC motor using state space model, it is based on the following assumptions.

1) The motor's stator is a star wound type.

2) The motor's three phase are symmetric, including their resistance, inductance, and mutual inductances.

3) There is no change in rotor reluctance with angle due to non-salient rotor.

4)There is no misalignment between each magnet and the corresponding rotor [13].

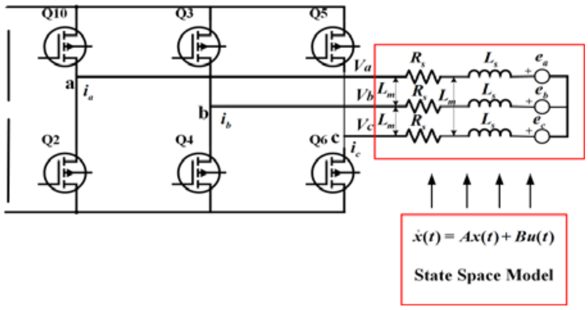

Fig .2. The designing state space model of BLDC motor connected to an inverter.

According to the non-linear property of BLDC motor, state space model is therefore applied to reduce the order of BLDC motor equation to first order derivative equation. The designing state space model of BLDC motor is shown in Figure2. And the general equation for state space modeling is shown below.

(5) $$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

where

(6) $$x = \begin{bmatrix} i_a & i_b & i_c & \omega & \theta \end{bmatrix}^T$$

(7) $$A = \begin{bmatrix} -R_s/L_1 & 0 & 0 & (\lambda_p * f_a \theta)/J & 0 \\ 0 & -R_s/L_1 & 0 & (\lambda_p * f_b \theta)/J & 0 \\ 0 & 0 & -R_s/L_1 & (\lambda_p * f_c \theta)/J & 0 \\ (\lambda_p * f_a \theta)/J & (\lambda_p * f_b \theta)/J & (\lambda_p * f_c \theta)/J & -B/J & 0 \\ 0 & 0 & 0 & P/2 & 0 \end{bmatrix}$$

(8) $$B = \begin{bmatrix} 1/L_1 & 0 & 0 & 0 \\ 0 & 1/L_1 & 0 & 0 \\ 0 & 0 & 1/L_1 & 0 \\ 0 & 0 & 0 & 1/L_1 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

(9) $$u(t) = \begin{bmatrix} V_a & V_b & V_c & T_e \end{bmatrix}^T$$

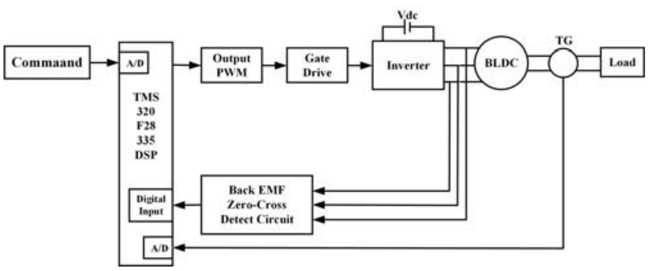

Fig. 2. DSP-based BLDC motor speed control system

DSP controller board

DSP controller C2000 No. TMS320F28335 from Texas Instrument is an effective multi-purposes board capable of rapid data processing. It is suitable for controlling motor using for processing data of 32-bit Floating-point unit (FPU) CPU when the speed of system clock is 150MHz. The structure of TMS320F28335 [14] physical memory of F28335 consists of ram or single access random memory;

SARAM at 34k 16 bit – a type of ram which allows writing and reading data freely at different positions. The data processing functions rapidly. The data storage of ram disappears immediately when DSC system is closed. This is so because this type of ram could store data only when electric current is connected as shown in figure 2.

ACO-based PI design problem

The BLDC motor drive system used in the experiment is considered in Figure 3, it is a motor drive unit which consists of Power filter, processor, and control unit (DSP TMS320F28335 board), three-phase power inverter unit and the motor with known parameters as shown in Table 1, we will calculate the objective function. Here is the closed loop transfer function of the system. Then the PI controller was designed with PSO technique to create a praetor edge. And select the most suitable solution that you want Let's try to compare with the simulation results.

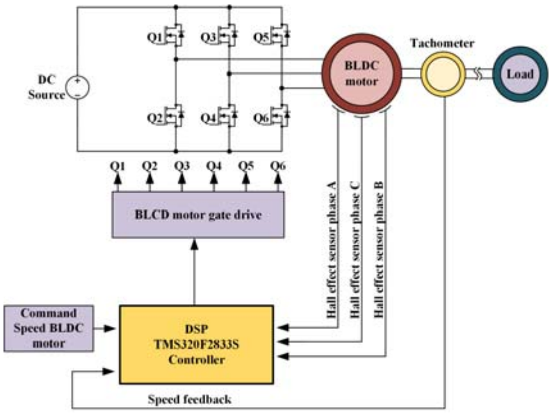

Fig. 3. The proposed BLDC motor speed control system.

Table 1. The parameters of the sensor

Parameter	Given Value
Nominal Voltage (*Vs.*)	24*V*
Stator winding resistance *R*	2.1 *ohm*
Stator winding inductance *L*	180 *uH*
Friction Torque *B*	0.00035 *mNm/rpm*
Back-emf constant *Ke*	1.026 *mV/rpm*
Rotor inertia *J*	6.5 gcm^2
No load Current	0.184*A*
Rated speed	3200*rpm*

PI (proportional-integral -controller) was firstly introduced in B.C. 1922 by Minor sky with the purpose of controlling pilot navigation system. Since then, then PI has been applied widely in industrial sectors. It was found that more than 90-95% of industrial PI problem can be solved using PI. In mathematics, PI has a mechanism functioning on proportional adjusting and integrating. As for mathematics relation signal of PI, when e(t) is input signal and u(t) is output signal as shown in equation (10) when is proportional gain constant and is integral gain constant.

(10) $$G_P(s) = \left[\frac{K_A}{t_A s+1}\right]\left[\frac{1/K_e}{t_m t_e s^2 + t_m s+1}\right]$$

(11) $$G_C(s) = K_P + \frac{K_I}{s} = \frac{K_P s + K_I}{s}$$

The details of how to find the Objective Function or Math model of the system for use in the ACO process to obtain the most suitable PI and designed structure of PI is shown in figure 5. Is gained by Sum Squared Error: SSE in order to calculate suitable PI with Kp and Ki providing satisfactory feedback for controlling currently used BLDC Motor speed.

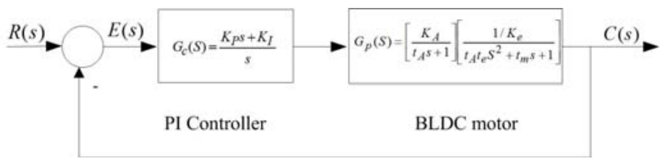

Fig. 4. PI control loop

The figure 4, the values of K_P and K_I are parameters of the speed controller. While the BLDC Motor's power unit and sensing circuit constant, the parameters can be configured as follows:

$$[K_A = 10, \tau_A = 0.1] \qquad [K_R = 1, \tau_R = 1] \qquad [\tau_m = \frac{J(3R_s)}{K_t K_e} = 0.0011]$$

$$[\tau_e = \frac{L_q}{3R_s} = 0.0483]$$

The transfer function of the BLDC Motor is obtained from.

$$G_M(s) = \left[\frac{1/K_e}{\tau_m \tau_e s^2 + \tau_m s + 1}\right] = \frac{0.2857}{53.13\times10^{-6}s^2 + 1.1\times10^{-3}s+1}$$

The transfer function of the BLDC Motor in conjunction with axed the drive unit is available from

$$G_p(s) = \frac{\Omega(s)}{V(s)} = \left[\frac{K_A}{1+\tau_A s}\right]\left[\frac{1/K_e}{\tau_m \tau_e s^2 + \tau_m s+1}\right]$$

$$= \frac{0.2857}{5.313\times10^{-6}s^3 + 1.6313\times10^{-4}s^2 \times 0.1011s + 1.2857}$$

The design of a PI controller using ACO is illustrated in Figure 6. The objective function value $f_{ctrl}(\cdot)$ ctrl f · is entered to the ACO to perform the function of finding the parameters, K_P and K_I of the PI controller appropriately. Objective $f_{ctrl}(\cdot)$ is fed to the ACO to make it to the minimum to find three different parameters of the PI controller suitable for controlling the BLDC motor to make the control system responsive. Satisfies desired, where M_P is the maximum overflow and e_{ss} is the constant error.

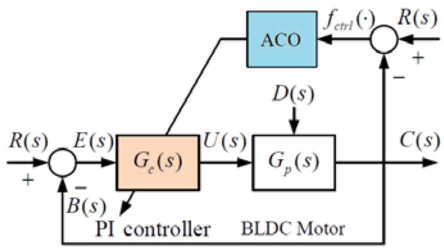

Fig. 5. ACO-based PI controller design

The basic principles of ACO [15] stem from finding food in the Ant Kingdom and establishing a transport route back to the nest. To find food, many ants will leave the nest. It will bring a portion of the food back to the nest, leaving pheromones on the ground. The pheromones can evaporate over time. This pheromone provides a pathway for other ants. Travel to food sources the first ant that returns to the nest with food finds the shortest path to the food source. Shown in figure 6.

The principle to solve the problem of optimal determination, and the ants view the problem as creating a path to the food that the ants will choose from the current member to the next u members, it is calculated from Equation 12.

$$P^{k}(u,t)=\begin{cases}\dfrac{(\tau(u,t))^{\alpha}\cdot(\eta(u,t))^{\beta}}{\sum_{\omega\in\Re(k)}(\tau(\omega,t))^{\alpha}\cdot(\eta(\omega,t))^{\beta}}\\ 0\end{cases} \qquad (12)$$

Where $\tau(u,t)$ Is the pheromone value in u at time t, $\eta(u,t)$ Is the heuristic information of u at time t.

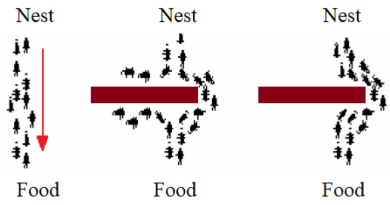

Fig. 6. Finding the Optimal Path of Ants [16].

Simulation results

From Equation 10, the BLDC motor's $G_p(s)$ transfer function model obtained by specifying the parameter identity using ACO gave the open-loop response more consistent with the real dynamics than the open-loop response obtained from the test. BLDC motor efficiency can be shown as Figure 7.

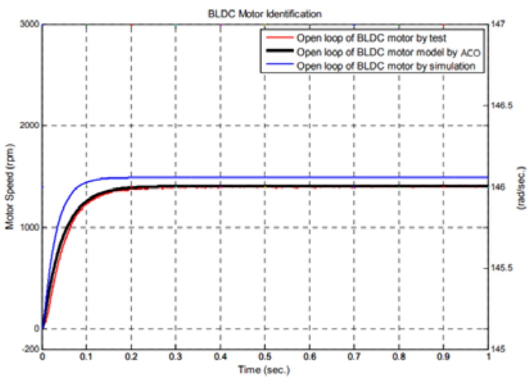

Fig. 7. The open - loop response of a BLDC motor at 1400 rpm.

The simulation results of BLDC motor identification parameters were used to design a PI controller to compare the response of a BLDC motor control system simulation at 1400 rpm using GA, PSO and ACO in speed control BLCC motor.

The Simulates comparing results of PI controller designs using ACO, PSO and GA.

Comparison of PI controller design results for BLDC motors by using GA, PSO and ACO, the PI control design conditions under the scope of the objective function $f_{ctrl}(\cdot)$ are the same. After the search is terminated, the parameters of the PI control are shown as equation 13, 14 and 15.

$$G_C(s)\big|_{PI\_GA}=0.6741+\frac{21.1986}{s}+0.00101s \qquad (13)$$

$$G_C(s)\big|_{PI\_PSO}=0.9736+\frac{31.1964}{s}+0.00001s \qquad (14)$$

$$G_C(s)\big|_{PI\_ACO}=1.3392+\frac{41.1989}{s}+0.00001s \qquad (15)$$

The response results of GA, PSO and ACO controllers to a total of 40 searches, the maximum number of search cycles equal to 200 for searches, ACO's method was found to find response results faster and more. The search cycles that are less than PSO and GA are shown in the table 2 Figure 8.

Table 2. System responses by PI controller

Entry	System responses by PI				Search time(sec.)
	Tr (sec.)	*Mp* (%)	*Ts* (sec.)	*ess* (%)	
GA	0.043	1.823	0.327	0.00	218.67
PSO	0.041	3.102	0.216	0.00	146.17
ACO	0.042	3,145	0.126	0.00	74,48

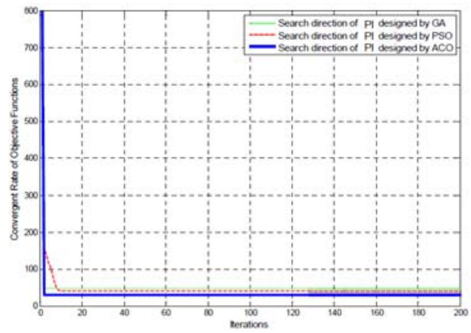

Fig.8. System responses of BLDC with PI controller. Designed by ACO, PSO and GA

Table.3. The simulation results of the control system

Entry	System responses by PI			
	Tr (sec.)	*Mp* (%)	*Ts* (sec.)	*ess* (%)
GA	0.048	1.861	0.357	0.00
PSO	0.045	3.201	0.226	0.00
ACO	0.043	3.185	0.146	0.00

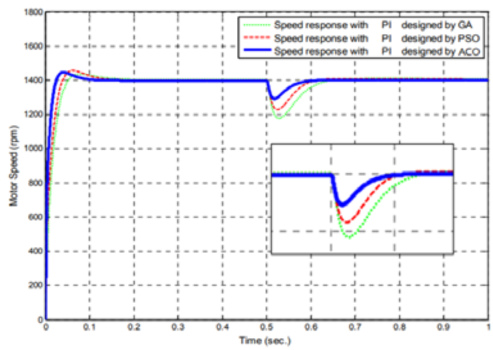

Fig.9. The speed response simulation by PI control using GA, PSO and ACO controller

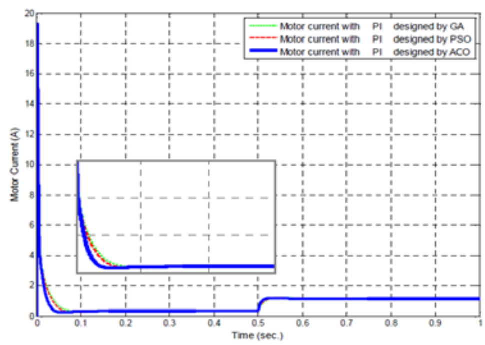

Fig.10. The currents response simulation by PI control system using GA, POS, and ACO controller

From Table 3, the simulation results show that speed T_r, T_s and M_P of cases 1-3 is GA, PSO and ACO of the Optimal Design of PI controller for control Speed of BLDC Motor at 1,400 rpm. The steady state in all cases, the response results are rise time 0.043 sec and overshot 3.185 % of case 3 is ACO the higher performance than case 1 and case 2.

Experimental results

The BLDC motor speed controlling system of 350 Wat, 24 Volt and 3,200 rpm is shown in Figure 11. The motor speed is from 0 - 3,200 round/minute. The speed that is changed into electrical pressure from 0 - 3.3 V will be sent to A / D transformer. This model will enable the users to adjust the motor speed to obtain the efficiency of BLDC motor used on the basis is DSP board; model TMS320F28335 that can test 0.0001 sec.

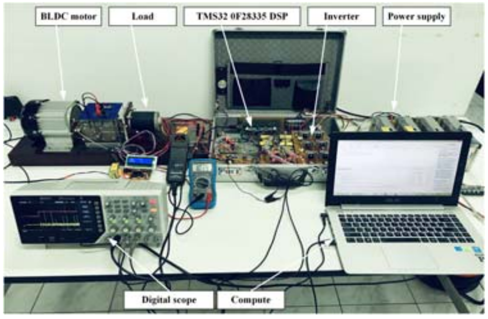

Fig. 11. BLDC motor experimental setup

The response of design controlling PI the actual system using GA, PSO and ACO to test the capability of controlling system for BLDC motor was done in the actual lab was where the result of the test and the record of digital oscilloscope value were kept using Hantek model MSO5074FG at the speed round of 1,400 rpm. The response is shown in Table 4 and Figure 12 – 17. Accordingly

Table 4. Entire system performance by PI controller

Entry	System responses by PI			
	T_r (sec.)	M_P (%)	T_s (sec.)	e_{ss} (%)
GA	0.043	2.823	0.327	0.00
PSO	0.031	3.502	0.216	0.00
ACO	0.022	1,645	0.126	0.00

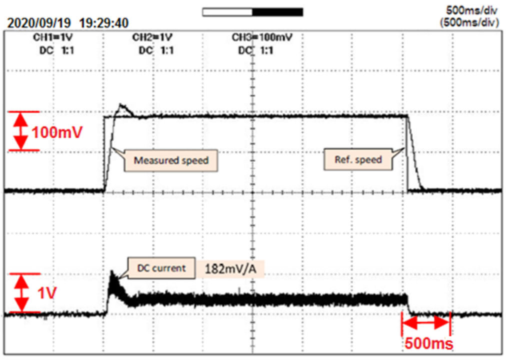

Fig. 12. Speed response 1400 rpm by PI control using GA

The figure 12 - 14, the results were obtained from an optimized PI control design using GA, PSO and ACO to find the best values for comparison of response speed. The results of the experiment showed that Optimized PI controller design for BLDC motor driving system with ACO method has the least interval T_r, T_s and M_P. And effective when compared with PSO and GA as shown in Table 4.

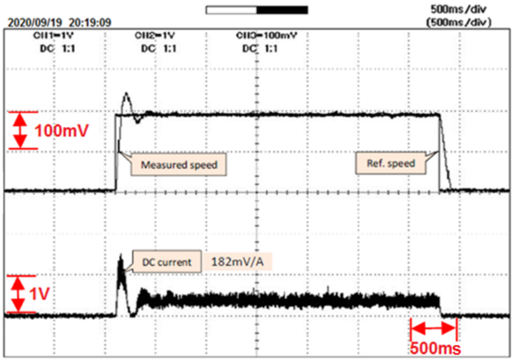

Fig. 13. Speed response 1400 rpm by PI control using PSO

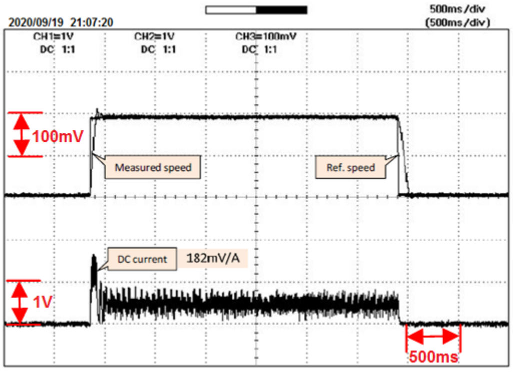

Fig. 14. Speed response 1400 rpm by PI control using ACO

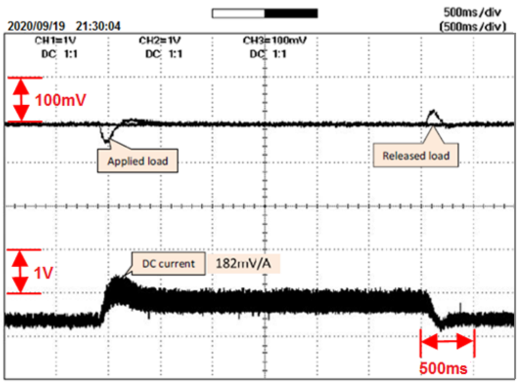

Fig. 15. the applied load rpm by PI control using GA

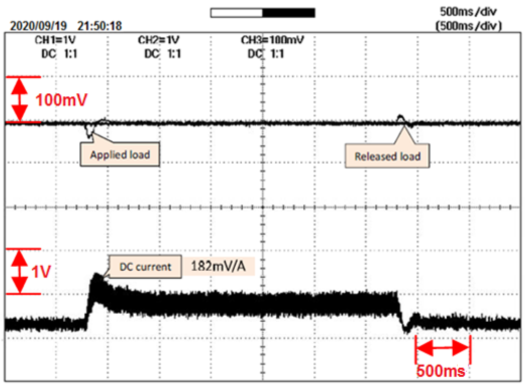

Fig. 16. The applied load rpm by PI control using PSO

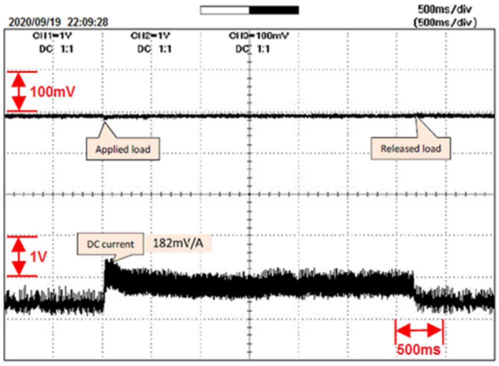

Fig. 17. The applied load rpm by PI control using ACO

The applied load response in a BLDC motor speed control system with PI regulator design using GA, PSO and ACO controller from Figure 15 - 17. PI controller design using ACO when feeding load. The results showed that the system's response returned to a steady state at a much faster and more efficient period than the controller designed using PSO and GA controller.

Conclusions

To design the best controller for PI using GA, PSO and ACO to control the speed round of BLDC motor, this article compared the ability of controllers to test the speed control, speed round at 1,400 rpm. The result of the experiment found that the result of simulation shown in figure 9 - 10 on controlling speed when compared to the actual system the results were obtained from an optimized PI control design using ACO responded quickest. It could also maintain BLDC motor speed round at the satisfactory speed round reference of 1,400 rpm, with load. The result of the experiment correlated very well with the simulation condition. This can be concluded that the guideline for designing PI controller using ACO can be a choice for controlling BLDC motor speed round effectively.

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