Intelligent voltage controller based on firefly algorithm for DC-DC boost converter

Darmansyah[1,2], Imam Robandi[1]
[1]Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2]Department of Electrical Engineering, Universitas Lancang Kuning, Pekanbaru, Indonesia

Article Info	ABSTRACT
	DC-DC boost converter is one of the important tools of photovoltaic (PV) power plant. DC-DC boost converter can be used to adjust the voltage output of photovoltaic before going to the inverter. In addition, DC-DC boost converter can be used as additional devices to make the PV plant operated in maximum power point condition. To get the optimal voltage adjusment, an appropriate controller is essential. Generally, proportional-integral (PI) controller is commonly used to control the switching procedure of the boost converter. However, with uncertainty of the source (uncertainty of the PV output), PI controller is out off dated. Hence designing PI controller based on the metaheuristic algorithm such as firefly algorithm is essential. This paper is proposed an intelligent voltage controller for DC-DC boost converter based on firefly algorithm (FA). From the simulation results it is noticeable that the PI based on FA could provide better control signal (indicated by the fastest settling time of the boost converter). *This is an open access article under the CC BY-SA license.*

Corresponding Author:

Darmansyah
Departement of Electrical Engineering, Institut Teknologi Sepuluh Nopember
Building B, C & AJ Campus Institut Teknologi Sepuluh Nopember, Keputih, Sukolilo, Surabaya
60111 East Java
Email: darmansyah@unilak.ac.id

1. INTRODUCTION

Indonesia has recently encountered a crisis on fuel oil, where the domestic petroleum used by motorized vehicles and other purposes exceeded the local production, making the country a gasoline importer. The limited fossil energy sources, such as fuel and coal, instigated the need for innovation to overcome contingent future challenges [1]. In Indonesia, the abundance of solar sources is also an alternative solution worth examining with other inexhaustible energy. This is because many renewable sources, including photovoltaic (PV) based solar energy, have recently been developed as a potential substitute for fuels and fossils [2]. One component of PV development is also used to manage voltage and output power, toward maximizing the generated electricity [3]. Furthermore, solar energy has emerged as a realistic alternative, which is developed as a sustainable power source regarding the advancements in battery and PV technology [4]. In photovoltaic applications, issues are observed with the performance of the DC-DC converter, where the generated voltage often varies due to the fluctuations of the PV temperature and the solar power radiation intensity [5], [6]. The power source of the converter is also the PV output voltage, which essentially requires modification through a control technique. In this condition, the voltage generated needs to meet all the required criteria for adoption [7].

In 2022, Ertekin *et al.* [8], a proportional-integral (PI) controller was used as the voltage output of the boost converter, in addition it is showing that its utilization caused the optimal operation of the booster's

switching mechanism. The research of [9] also indicated the comparative analysis between the zeta and boost converters using a PI controller. In this condition, both converters had a better response with the addition of the control system. Based on [10], this controller still provided a good performance despite being used in a cascade-controlling mechanism. Irrespective of these great performances, deterioration is still observed with the consideration of the PV plant inanity. This shows the need for the optimal dens of PI, regarding the metaheuristic algorithm. In electrical engineering, the application of this algorithm is presently becoming favourable, specifically in power systems.

In 2021, Setiadi *et al.* [11], the application of the differential evolution algorithm was observed for tuning the PI controller of a six-pulse three-phase rectifier. In this case, the overshoot of the rectifier was damp by designing a PI controller through a differential evolution algorithm. The research of [12] also emphasized the design coordinated controller between the capacitor energy storage and dual-input power system stabilizer, regarding an improved differential evolution algorithm. Moreover, the application of the flower pollination algorithm was used in designing superconducting magnetic energy storage (SMES) for the enhanced dynamic stability of a power system [13]. In this process, the damping performance of the system was significantly enhanced by adding SMES, based on the flower pollination algorithm.

In 2018, Abdulkhader *et al.* [14], the application of particle swarm optimization (PSO) was observed for designing a multi-band power system stabilizer, with the adoption of FFO (fruit fly optimization) also used for developing virtual synchronous machine in [15]. Among all the numerous algorithms, FA (Firefly Algorithm) is still observed as the best model, regarding the simplicity and optimal results [16]. Therefore, this research aims to develop an intelligent voltage controller for DC-DC boost converter, using the firefly algorithm. Based on subsequent evaluations, the remaining parts of this report are organized as follows, section 2 provides the fundamental theory of PV, MPPT, and PI controller. By minimizing the goal function evaluated, the PID controller is designed to lower the settling time, maximum overshoot, and inaccuracy [17]. It also emphasizes system identification, fruit fly algorithm, and the design patterns of the MPPT-based FFA, section 3 describes the simulation results, and section 4 highlights the contribution and conclusions.

2. METHOD
2.1. DC-DC boost converter
The boost converter contains an inductor, a metal oxide semiconductor (MOSFET), diode and capacitor with its output voltage depending on the operating period. The output stress is also higher than the input voltage, with the working framework emphasizing the MOSFET switching functions. Figure 1 shows the open loop DC-DC boots converter electrical circuit. While Figure 2 shows the DC-DC electrical circuit in "ON" condition [18].
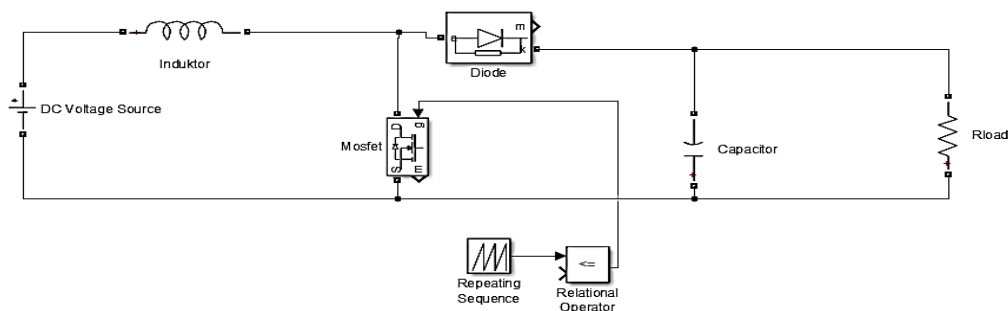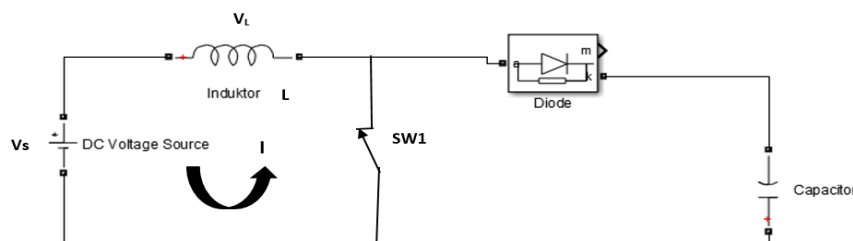

Figure 1. Circuit of DC-DC boost converter

Figure 2. Circuit of DC-DC Boost Converter in "ON" Condition

Based on Figures 1 and 2, the following equation is obtained,

$$V_s = L\frac{dI}{dt} \tag{1}$$

in this condition, the switch was connected for t_{on}. When the following equations were applied, the change in the inductor current was assumed to be constant,

$$V_s = L\frac{\Delta I}{dt} \tag{2}$$

$$L.\Delta I = V_s\, t_{on} \tag{3}$$

When the switch was open, the charging inductor began to discharge, leading to the system being the current source. The load was also supplied by two voltage sources, namely V_s and V_L, causing greater output compared to the input power. Figure 3 depicts the DC-DC boots converter electrical circuits in "Off" condition [19], [20].
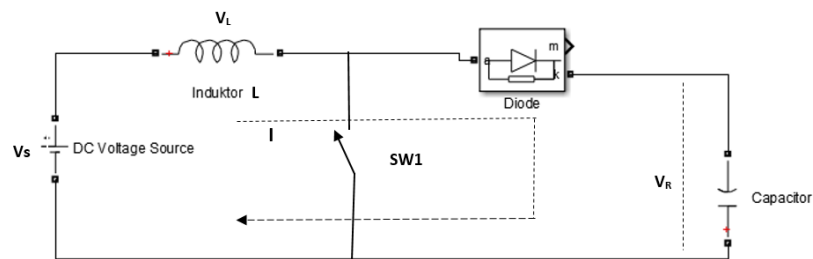

Figure 3. DC-DC boost converter switching transistor is OFF

With the switch opening at t_{off}, the following equation was obtained,

$$V_s + V_L = V_R \tag{4}$$

$$V_s + \frac{\Delta I}{t_{off}} = V_R \tag{5}$$

2.2. DC-DC boost converter continuous conduction mode

Every power converter and its bilinear form was acquired in one of two methods which is creation of a list for all possible configurations and identificantion of transferable. The creation of a list for all possible configurations, with subsequent observation for prevalent bilinear structures. According to the preliminary analysis, a DC-DC Boost Converter operating in ccm likely used the following design in Figure 2, i.e., cases (a) and (b), where the switches (H) were on ($h_1=1$) and off ($h_2=1$), respectively. Since this is a DC-DC Converter example, the switching feature (u) was transformed into two patterns, i.e., $u = h_1 = 1-h_2$. Status variables also included inductor current (i_L) and condenser voltage (V_c), with (6) representing the state space of DC-DC boost converter [21].

$$u = 1; \begin{cases} i_L = E/L \\ \dot{V}_C = -V_C/RC \end{cases}, u = 0; \begin{cases} i_L = E/L - V_C/L \\ \dot{V}_C = i_L - V_C/RC \end{cases} \tag{6}$$

By switching the u-function, (6) was summarized in one form as described in (7), which was directly used for simulation, to represent h_1 and h_2 validation functions. This equation also ensured the production of specified bilinear structures [22].

$$u = 1; \begin{cases} \dot{i}_L = \frac{E}{L}u + \frac{E-V_C}{L}(1-u) \\ \dot{V}_C = -\frac{V_C}{RC}u + (\frac{i_L}{C} - \frac{V_C}{RC})(1-u) \end{cases}, u = 0 \begin{cases} \dot{i}_L = -\frac{(1-u)V_C}{L} + E/L \\ \dot{V}_C = (1-u)(\frac{i_L}{C} - V_C/(RC)) \end{cases} \tag{7}$$

In this situation, the (8) ensured the derivation of the following bilinear structure by (8).

$$\begin{pmatrix} \dot{i_L} \\ \dot{V_C} \end{pmatrix} = \underbrace{\begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}}_{A} \begin{pmatrix} i_L \\ V_C \end{pmatrix} + \underbrace{\begin{bmatrix} 0 & \frac{1}{L} \\ \frac{-1}{C} & 0 \end{bmatrix}}_{B} \begin{pmatrix} i_L \\ V_C \end{pmatrix} u + \underbrace{\begin{pmatrix} E/L \\ 0 \end{pmatrix}}_{d} \tag{8}$$

With $b = [0\ 0]^T$, (8) can be written as state space representation as described in (9).

$$\acute{x} = A.x + B.x.u + d \tag{9}$$

Based on identification of the transferable variables a state variable was initially selected, with i_L and V_c remaining similar as observed in the previous method. In this condition, the switch over parameters included the transistor voltage (V_H) and current (i_D), which were inputted as state variable functions as described in (10).

$$V_H = \begin{cases} 0 \text{ if H is turned on} \\ \dot{V_C} \text{ if H turned off} \end{cases} \text{and} \begin{cases} 0 \text{ if H is turned on} \\ \dot{\iota_L} \text{ if H turned off} \end{cases} \tag{10}$$

By consequently applying the Kirchhoff voltage and current laws to express di_L/dt and dv_C/dt, the equation describing the circuit compartment was obtained as shown in (11) [21].

$$\begin{cases} L.\dot{i_L} = E - V_H \\ C.\dot{V_C} = i_D - \frac{V_C}{R} \end{cases} \tag{11}$$

The transferred variable was also expressed as an appropriate switching function, with an additional feature, provided in (12) and (13). In addition, Figure 4 shows the DC-DC converter operated in CCM.

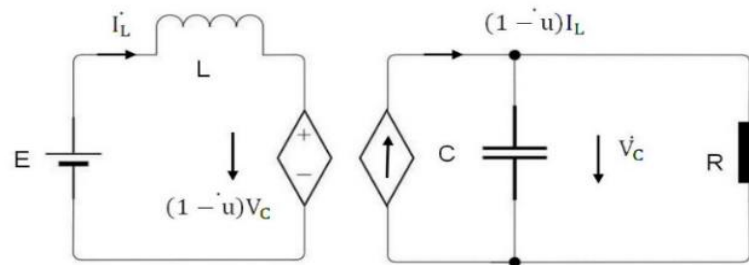$$u = \begin{cases} 1 \text{ if H is turned on} \\ 0 \text{ if H turned off} \end{cases} \tag{12}$$

Figure 4. Equivalent circuit of DC-DC Boost Converter operating in ccm

$$\begin{cases} V_H = V_C(1-u) \\ i_D = i_L(1-u) \end{cases} \tag{13}$$

By substituting (13) into (12), new equation can be form as described in (14).

$$\begin{cases} \dot{i_L} = -\frac{(1-u)V_C}{L} + E/L \\ \dot{V_C} = (1-u)i_L/C - \frac{V_C}{RC} \end{cases} \tag{14}$$

The connection between the input and output circuits was also described by two dependent sources, due to its performance as an ideal DC transformer with a changeable external-regulated ratio. Furthermore, the one-of-a-kind program enabled the simulation of the system described (14). As modelled by Simulink®, the efficiency of the optimal thrust level was then in the phase shift of the duty cycle ratio [22].

2.3. Firefly algorithm

Firefly algorithms (FA) is a metaheuristic algorithm inspired by the characteristics of fireflies. It was also initially established by Dr. Xin-She Yang from Cambridge University in 2007. There are three important rules of FA [23].

− All fireflies are unisex, leading to great attraction levels regardless of their gender. In addition, the brightness of these organisms is also determined by the location of their objective functions.
− The attraction is proportional to the brightness, indicating that the fireflies with lower luminance often move towards those are brighter. This brightness is found to decrease as the distance increases. When none of these organisms has the brightness luminance, their movement are always in a random pattern.
− The fireflies's brightness is determined by the location of their objective functions.

The population will be randomly initialized, and then some fireflies will be chosen as candidate solutions from among the many fireflies. After counting the cost of the candidate solution fireflies, the best candidate will be designated as the 'center,' and all other fireflies will 'fly' to that center. Each iteration will result in a penalty for each firefly. After the maximum number of iterations, the solution with the lowest penalty value will be chosen [24]. In FA, 2 important factors were considered, namely the light intensity variation and the attraction formula. For convenience, the attraction of fireflies was assumably defined by the light intensity brightness, $I_{(r)}$, which varied regarding the inverse quadrant law [25], [26].

$$I_{(r)} = \frac{I_s}{r^2} \tag{15}$$

I is the intensity of the original firefly light, which has a fixed absorption coefficient. This indicated that the light intensity (I) varied with the distance (r), causing the following [27].

$$I = I_o\, e^{-\gamma r} \tag{16}$$

I is the original light intensity to avoid the singular at r = 0, where the combined effect of the two opposites on the best quadrant law and absorption was approximated as Gaussian law [28].

$$I_{(r)} = I_o e^{-\gamma r} \tag{17}$$

The attraction of the fireflies was also proportional to the light intensity of those nearby. This was determined by the following formula [29].

$$\beta = \beta_o e^{-\gamma r 2} \tag{18}$$

Where, β is the attraction when $r=0$. To simplify this equation, the following equation was used [30].

$$\beta = \frac{\beta_0}{1 + \gamma r^2} \tag{19}$$

In (29) and (30) are defined as the characteristic distance, $I = \gamma^{-1/m}$. Where the change in attractiveness changes significantly from 0 to e^{-1}. To simplify the implementation of the calculation can be generalized and become [30].

$$= \beta_0 e^{-\gamma r^m} \quad (m \geq 1) \tag{20}$$

For constant conditions, the long characteristic can be described as (21).

$$I = \gamma^{-1/m} \tag{21}$$

The distance between 2 fireflies (i) at x_i and x_j also represents using Cartesian distance as (22).

$$r_{ij} = \| x_i - x_j \| = \sqrt{\sum_{k=1}^{d}(Xi.j) - (Xi,k)^2} \tag{22}$$

Furthermore, the movement of the fireflies (i) attracted by the lighter ones (j) was defined as (23).

$$x_i = x_i + \beta_0 e^{-\gamma r_{i,j}^2} (x_j - x_i) + \alpha \in_I \tag{23}$$

Where:
x_i : Spacial of position-i
x_j : Spacial coordinate of firefly-j
α : Random parameter
$\in_I$: Random value of eigenvector between 0-1

2.4. Design concept

To determine the design specification, the input of the DC-DC boost converter was very essential. Table 1 shows the specification of DC-DC boost converter used in this research [31]. A metal oxide semiconductor called a MOSFET, as well as diodes, inductors, and capacitor are all components of a boost converter. The running time has an impact on the DC-DC Boost Converter's output voltage. The input voltage is greater than the output stress. The DC-DC Boost Converter's working framework was focused on MOSFET switching capabilities.

These parameters emphasized the design of PI as a voltage controller of the FA-based boost converter. In this condition, the circuit and the firefly algorithm were designed and coded in Simulink and Matlab. The objective function of FA was also used to reduce the error of the boost converter's voltage output, with the fitness function mathematically described using (23) [32], [33]. Table 2 shows the parameter of FA for optimizing the PI controller.

<table>
<tr><td colspan="3">Table 1. DC-DC boost converter parameter</td></tr>
<tr><td>Parameter</td><td>Value</td><td>Unit</td></tr>
<tr><td>Input Voltage</td><td>12</td><td>V</td></tr>
<tr><td>Capacitor</td><td>10^{-6}</td><td>F</td></tr>
<tr><td>Inductor</td><td>10^{-2}</td><td>H</td></tr>
<tr><td>Resistor</td><td>100</td><td>Ohm</td></tr>
</table>

<table>
<tr><td colspan="2">Table 2. FA parameter</td></tr>
<tr><td>Parameter</td><td>Value</td></tr>
<tr><td>Number of fireflies</td><td>30</td></tr>
<tr><td>Alpha</td><td>0.35</td></tr>
<tr><td>Gamma</td><td>1</td></tr>
<tr><td>Betamin</td><td>0.20</td></tr>
</table>

$$E = \int_0^{time} t|e(t)|dt \tag{24}$$

This design process included the following steps:
Step 1.   Start the FA by initializing the numbers of fireflies, iteration, and optimized parameter,
Step 2.   Randomly generate the position of the fireflies as the initial coordinates,
Step 3.   Evaluate the objective function of each firefly's position,
Step 4.   Rank the fireflies based on the objective function and determine the best fitness,
Step 5.   Update the firefly movement,
Step 6.   Update the best fitness,
Step 7.   When j is higher than i, evaluate the fitness function of each firefly and update the light intensity,
Step 8.   Rank the fireflies and obtain the best solution,
Step 9.   When the criterion is not satisfied, repeat step 4,
Step 10.   Print the results (K_p and K_i value).

3. RESULTS AND DISCUSSION

To test the efficacy of the proposed method, two different case study are carried out. The first case study is investigating how the proposed controller reacted to the changing of the voltage input reference. In the second case study the variation of the load is carried out to deeply understand the efficacy of the proposed controller.

3.1. Case study 1

In this section time domain simulation is carried out to evaluate the efficacy of the proposed controller. The controller is tested againt different voltage referensi (25 volt and 20 volt). Figure 4 shows the time domain response of boost converter voltage output under 25-volt voltage reference. While Figure 5 shows the boost conveter voltage output response under 20-volt voltage reference. It is noticeable that on both conditions, the voltage response of the system with proposed controller is better that the system using conventional controller. This is indicated by smaller overshoot and fastest settling time of the system with proposed controller method.

Tables 3 and 4 show the detailed features of time domain simulation in Figures 5 and 6. It is found that the proposed controller method is superior compared with conventional controller method. It is observed that the overshoot for two different conditions could be damp when the proposed controller is introduced in the boost converter. Similar with the overshoot, the settling time is also accelerated when proposed controller is added in the boost converter.
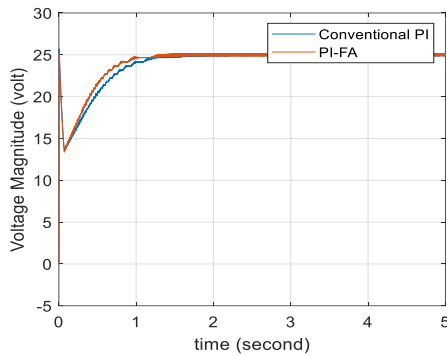

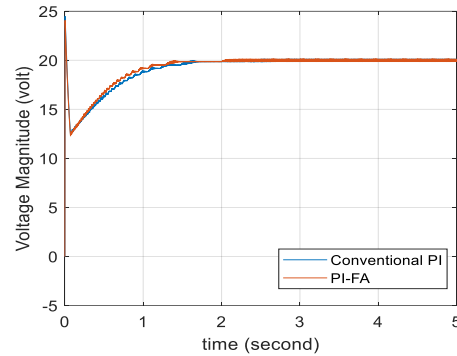Figure 5. Time domain response of DC-DC converter output with 25-volt voltage reference

Figure 6. Time domain response of DC-DC converter output with 20-volt voltage reference

Table 3. Detailed Features of Figure 5

Index	Overshoot (watt)	Settling time (second)	Final value (volt)
Conventional	1.5	2	25
Intelligent based	0.5	1.3	25

Table 4. Detailed Features of Figure 6

Index	Overshoot (watt)	Settling time (second)	Final value (watt)
Conventional	4.18	3	20
Intelligent based	2.41	2	20

3.2. Case study 2

In the second case study, the load is change from 100 Ohm to 90 Ohm. Figure 6 shows the response of the system with 20 volt and 90 Ohm. While Figure 7 depicts the response of the system with 25-volt input reference and 90 Ohm. It is observed that in Figure 8, both of the response (system with conventional controller and system with proposed controller) does not have any overshoot. In addition, from Figure 8 it is noticeable that the settling time of system with proposed controller have faster settling time compared to the system with conventional controller.
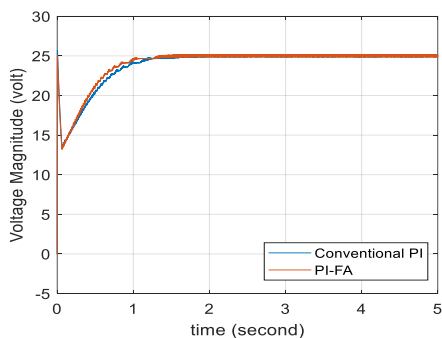

Figure 7. Time domain response of DC-DC converter output with 25-volt voltage reference and 90 Ohm load
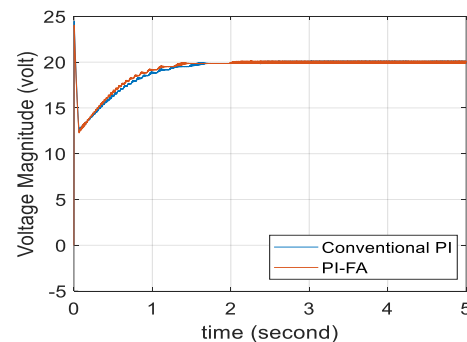

Figure 8. Time domain response of DC-DC converter output with 20-volt voltage reference and 90 Ohm load

Different with response in Figure 7, response in Figure 8 indicated that both of the system have overshoot. However, system with proposed controller provide minimum overshoot. In addition, the settling time is also faster compared with the system with conventional controller. Furthermore, Tables 5 and 6 show

the detailed features of Figure 6 and Figure 7. Similar with the first case study, the best response is provided by DC-DC with the proposed method.

<table>
<tr><th colspan="4">Table 5. Detailed features of Figure 7</th></tr>
<tr><th>Index</th><th>Overshoot (watt)</th><th>Settling time (second)</th><th>Final value (volt)</th></tr>
<tr><td>Conventional</td><td>-</td><td>2</td><td>25</td></tr>
<tr><td>Intelligent based</td><td>-</td><td>1.4</td><td>25</td></tr>
</table>

<table>
<tr><th colspan="4">Table 6. Detailed features of Figure 8</th></tr>
<tr><th>Index</th><th>Overshoot (watt)</th><th>Settling time (second)</th><th>Final value (watt)</th></tr>
<tr><td>Conventional</td><td>4.78</td><td>2</td><td>20</td></tr>
<tr><td>Intelligent based</td><td>2</td><td>2</td><td>20</td></tr>
</table>

4. CONCLUSION

This paper proposes an intelligent design of DC-DC boost converter voltage controller based on FA. The simulation is carried out using MATLAB/Simulink environment. From the simulation results it is observed that the proposed controller method is superior compared to the conventional controller. This statement indicated by the smaller overshoot and faster setlling time of the system with proposed controller method compared with conventional controller method. Further research need to be conducted by making the controller adaptive to any disturbance using artificial neural network or using machine learning technique.

ACKNOWLEDMENT

REFERENCES

[1] H. Setiadi, N. Mithulananthan, R. Shah, T. Raghunathan, and T. Jayabarathi, "Enabling resilient wide-area POD at BESS in Java, Indonesia 500â€.kV power grid," *IET Generation, Transmission and Distribution*, vol. 13, no. 16, pp. 3734–3744, Jul. 2019, doi: 10.1049/iet-gtd.2018.6670.

[2] H. Setiadi, N. Mithulananthan, R. Shah, K. Y. Lee, and A. U. Krismanto, "Resilient wide-area multi-mode controller design based on Bat algorithm for power systems with renewable power generation and battery energy storage systems," *IET Generation, Transmission and Distribution*, vol. 13, no. 10, pp. 1884–1894, Apr. 2019, doi: 10.1049/iet-gtd.2018.6384.

[3] M. Abdillah, R. C. Batubara, N. I. Pertiwi, and H. Setiadi, "Design of maximum power point tracking system based on single ended primary inductor converter using fuzzy logic controller," *International Journal of Intelligent Engineering and Systems*, vol. 15, no. 1, pp. 350–360, Feb. 2022, doi: 10.22266/IJIES2022.0228.32.

[4] H. Setiadi *et al.*, "Influence of adding BESS as ancillary controller of wind power plant on low frequency oscillation," *International Journal of Intelligent Engineering and Systems*, vol. 14, no. 5, pp. 188–198, Oct. 2021, doi: 10.22266/ijies2021.1031.18.

[5] M. Kumar, K. K. Pandey, A. Kumari, and J. Kumar, "Fuzzy logic based MPPT controller for PV panel," in *Algorithms for Intelligent Systems*, Springer Singapore, 2021, pp. 501–510. doi: 10.1007/978-981-15-5243-4_46.

[6] V. Kumar, S. Ghosh, N. K. S. Naidu, S. Kamal, R. K. Saket, and S. K. Nagar, "A current sensor based adaptive step-size MPPT with SEPIC converter for photovoltaic systems," *IET Renewable Power Generation*, vol. 15, no. 5, pp. 1085–1099, Jan. 2021, doi: 10.1049/rpg2.12091.

[7] K. Nebti and R. Lebied, "Fuzzy maximum power point tracking compared to sliding mode technique for photovoltaic systems based on dc-dc boost converter," *Electrical Engineering and Electromechanics*, vol. 2021, no. 1, pp. 67–73, Feb. 2021, doi: 10.20998/2074-272X.2021.1.10.

[8] D. Ertekin, K. Bulut, H. Tekin, and G. Moschopoulos, "A design for switched capacitor and single-switch DC–DC boost converter by a small signal-based PI controller," *International Journal of Circuit Theory and Applications*, vol. 50, no. 5, pp. 1620–1651, Jan. 2022, doi: 10.1002/cta.3213.

[9] Z. U. Haq and A. Ali, "Comparative study of Zeta converter and Boost converter Using PI controller," *2021 7th International Conference on Electrical, Electronics and Information Engineering (ICEEIE)*, 2021, pp. 54-59, doi: 10.1109/ICEEIE52663.2021.9616826..

[10] O. Rabiaa, B. H. Mouna, S. Lassaad, F. Aymen, and A. Aicha, "Cascade control loop of DC-DC boost converter using PI controller," *2018 International Symposium on Advanced Electrical and Communication Technologies (ISAECT)*, 2018, pp. 1-5, doi: 10.1109/ISAECT.2018.8618859.

[11] H. Setiadi, A. Swandaru, and T. A. Nugroho, "Design feedback controller of six pulse three phase rectifier based on differential evolution algorithm," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 22, no. 2, p. 670, May 2021, doi: 10.11591/ijeecs.v22.i2.pp670-677.

[12] H. Setiadi, A. Swandaru, D. A. Asfani, T. H. Nasution, M. Abdillah, and A. U. Krismanto, "Coordinated design of DIPSS and CES using mdea for stability enhancement: Jawa-Bali Indonesian power grid study case," *International Journal of Intelligent Engineering and Systems*, vol. 15, no. 1, pp. 251–261, Feb. 2022, doi: 10.22266/IJIES2022.0228.23.

[13] H. Setiadi, D. A. Asfani, T. H. Nasution, M. Abdillah, and A. U. Krismanto, "Intelligent SMES based on flower pollination algorithm on wind power system for dynamic stability enhancement," *International Journal of Intelligent Engineering and Systems*, vol. 15, no. 1, pp. 341–349, Feb. 2022, doi: 10.22266/IJIES2022.0228.31.

[14] H. K. Abdulkhader, J. Jacob, and A. T. Mathew, "Fractional-order lead-lag compensator-based multi-band power system stabiliser design using a hybrid dynamic GA-PSO algorithm," *IET Generation, Transmission and Distribution*, vol. 12, no. 13, pp. 3248–3260, May 2018, doi: 10.1049/iet-gtd.2017.1087.

[15] H. Setiadi *et al.*, "An extreme learning machine based adaptive VISMA for stability enhancement of renewable rich power systems," *Electronics (Switzerland)*, vol. 11, no. 2, p. 247, Jan. 2022, doi: 10.3390/electronics11020247.

[16] M. Singh, R. N. Patel, and D. D. Neema, "Robust tuning of excitation controller for stability enhancement using multi-objective metaheuristic Firefly algorithm," *Swarm and Evolutionary Computation*, vol. 44, pp. 136–147, Feb. 2019, doi: 10.1016/j.swevo.2018.01.010.

[17] I. A. Abed and S. H. Majeed, "DC/DC converter control using suggested artificial intelligent controllers," *IAES International Journal of Artificial Intelligence*, vol. 10, no. 4, pp. 847–857, Dec. 2021, doi: 10.11591/ijai.v10.i4.pp847-857.

[18] S. V. Madhavi and G. T. R. Das, "Variable structure control for an isolated boost converter used in fuel cell applications," *International Journal of Electrical and Computer Engineering*, vol. 9, no. 6, pp. 4493–4506, Dec. 2019, doi: 10.11591/ijece.v9i6.pp4493-4506.

[19] S. Piróg and R. Stala, "DC–DC boost converter with high voltage gain and a low number of switches in multisection switched capacitor topology," *Archives of Electrical Engineering*, vol. 67, no. No 3, pp. 617–627, 2018, doi: 10.24425/123667.

[20] L. Mitra and U. K. Rout, "Optimal control of a high gain DC-DC converter," *International Journal of Power Electronics and Drive Systems*, vol. 13, no. 1, pp. 256–266, Mar. 2022, doi: 10.11591/ijpeds.v13.i1.pp256-266.

[21] P. Vivek, N. B. Muthuselvan, and J. Nanadhagopal, "Modeling of solar PV system for DC-DC converter with improved voltage stability using hybrid-optimization techniques," *International Conference for Phoenixes on Emerging Current Trends in Engineering and Management (PECTEAM 2018)*, 2018. doi: 10.2991/pecteam-18.2018.33.

[22] H. Y. Ahmed, O. Abdel-Rahim, and Z. M. Ali, "New high-gain transformerless DC/DC boost converter system," *Electronics (Switzerland)*, vol. 11, no. 5, p. 734, Feb. 2022, doi: 10.3390/electronics11050734.

[23] K. Karthikeyan and P. K. Dhal, "Dynamic stability enhancement by selecting optimal location of STATCOM and tuned of Power System Stabilizer(PSS) using Firefly Algorithm," *2016 Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE)*, 2016. doi: 10.1109/PESTSE.2016.7516367.

[24] A. N. Sihananto, M. S. Burhan, and W. F. Mahmudy, "Chicken feed optimization using evolution strategies and firefly algorithm," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 1, p. 585, Feb. 2019, doi: 10.11591/ijece.v9i1.pp585-592.

[25] X.-S. Yang, *Nature-inspired metaheuristic algorithms*. Luniver Press. 2010.

[26] Z. Lukač, "Metaheuristic optimization," *Proceedings of the 11th International Symposium on Operational Research in Slovenia, SOR 2011*, vol. 6, no. 8, 2011, pp. 17–22, doi: 10.4249/scholarpedia.11472.

[27] E. M. Mashhour, E. M. F. El Houby, K. T. Wassif, and A. I. Salah, "Feature selection approach based on firefly algorithm and chi-square," *International Journal of Electrical and Computer Engineering*, vol. 8, no. 4, pp. 2338–2350, Aug. 2018, doi: 10.11591/ijece.v8i4.pp2338-2350.

[28] T. A. Nugroho, R. S. Wijanarko, and H. Setiadi, "Coordination of blade pitch controller and battery energy storage using firefly algorithm for frequency stabilization in wind power systems," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 17, no. 2, pp. 1014–1022, Apr. 2019, doi: 10.12928/TELKOMNIKA.V17I2.9162.

[29] N. T. Thang, N. D. Phuong, P. Van Thanh, and C. T. Hien, "An effectively modified firefly algorithm for economic load dispatch problem," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 16, no. 5, pp. 2436–2433, Oct. 2018, doi: 10.12928/TELKOMNIKA.v16i5.10545.

[30] Mardlijah and Z. Zuhri, "Solar panel control system using an intelligent control: T2FSMC and firefly algorithm," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 16, no. 6, pp. 2988–2998, Dec. 2018, doi: 10.12928/TELKOMNIKA.v16i6.8694.

[31] M. Aslam, "No closed loop control of boost converter," *MATLAB Central File Exchange*, 2022.

[32] H. Setiadi, K. O. Jones, T. A. Nugroho, M. Abdillah, H. Trilaksana, and T. Amrillah, "Design of spark ignition engine speed control using bat algorithm," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 1, pp. 794–801, Feb. 2021, doi: 10.11591/ijece.v11i1.pp794-801.

[33] H. Setiadi *et al.*, "Multi-mode damping control approach for the optimal resilience of renewable-rich power systems," *Energies*, vol. 15, no. 9, p. 2972, Apr. 2022, doi: 10.3390/en15092972.

BIOGRAPHIES OF AUTHORS

Darmansyah was born in Payakumbuh, West Sumatra, Indonesia, in 1972. He obtained S.T degree in Electrical Engineering from Universitas Bung Hatta, Padang, West Sumatra, Indonesia, in 1998. His M.T degree was also obtained in Electrical Engineering from Institut Sains and Teknologi Nasional (ISTN), Jakarta, Indonesia, in 2010. In August 2022, he graduated Ph.D at Electrical Engineering Department, Institut Teknologi Sepuluh Nopember (ITS) Surabaya, Indonesia. Besides, he is also a senior lecturer at the Electrical Engineering Department, Universitas Lancang Kuning, Pekanbaru. His achievements included an experience as a Production Supervisor at PT. KIT Mechatronic Batam, Indonesia, Subsidiary of Matsushita Electric Motor Pte. Ltd Singapore, Motor Plant Department since November 2000-May 2004. He can be contacted at email: darmansyah@unilak.ac.id.

Imam Robandi was born in Gombong, Central Java, Indonesia, in 1963. He obtained a Bachelor's degree in Electrical Engineering from Institut Teknologi Sepuluh Nopember (ITS) Surabaya, Indonesia, with his M.T also acquired in Electrical Engineering from Institut Teknologi Bandung (ITB), Bandung, Indonesia. He also graduated as a PhD student at Tottori University, Japan, in 2001. He is a Professor at the Electrical Engineering Department, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia. He can be contacted at email: robandi@ee.its.ac.id.