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Firefly algorithm for optimizing single-axis solar tracker motion

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Abstract

Solar cells mounted on solar panel modules are expected to track sunlight throughout the day to produce maximum energy. The Firefly algorithm (FA) is embedded in the Arduino Mega microcontroller to control the tracking of the sun's position by the solar panel so that the absorption of solar energy can be as much as possible to get maximum electrical energy. The brightest light captured by the solar panel is represented as the light intensity of a firefly. The output of the solar tracking system is obtained by finding the best value of light intensity between fireflies. Parameter changes in FA, such as firefly population, random numbers, and number of iterations affect the results of FA. The largest population, the highest random number and iteration provide the best solution but take a long time to execute. FA can control solar panels in tracking the sun's position precisely with an average error of 1.28% and can absorb a total energy of 666.14 Watt/day. The best solution (98% of setpoint 720) was obtained when the population was set to 50, the random number to 0.8, and iteration to 50. This research can be used as a reference for later using a controller with higher specifications to speed up the FA process time in getting maximum control results.

1. Introduction

Indonesia is at the equator of the earth which lies between 95°E to 141°E and 6°N to 11°S [1]. It receives more than 12 hours of sunlight every day and 6 hours of direct sunlight. In Indonesia, the altitude of the sun's position does not change much and its solar radiance does not vary by season. Based on Dewan Energi Nasional's data, Indonesia has a solar irradiation level of around 4.8 kWh/m^2/day [2]. So, there will be a lot of potentials to implement solar panel systems as power plants in Indonesia. The energy produced by solar panels depends on solar radiation, temperature, and the angle of sunlight emission on the surface of the solar panels. Therefore, it is very suitable to use a single-axis tracking system to keep the surface of the solar panel perpendicular to the direction of the solar radiation [3][4]. To get the position of the solar panels that can always be perpendicular to the direction of the sun's rays, an automatic control system is needed. To build the system, a sensor is needed that can detect the direction of the sun's rays and a motor that drives the solar panels in the direction of the sun's rays. So that the whole system can synergize well, it needs to be controlled by a microcontroller that has an artificial intelligence-based optimization algorithm embedded in it [5]. In case the sun becomes invisible e.g. in cloudy weather, the panel sensor unable to detect the sun. When the cloud vanishes, it will scan the sky and realign to face the sun vertically, thus maximum energy absorption can be obtained throughout the day [3].

Optimization algorithms as part of Artificial Intelligence are applied to search for optimum values including for solar power plant control systems [4]. Previous similar studies used the Bat Algorithm for a solar tracker control system [5], Ant Colony Optimization on a Single Axis Photovoltaic Tracker [6]. Firefly Algorithm (FA) to solve three-dimensional square packaging problems [7]. Optimization of PID and ANFIS Controller on Dual Axis Tracking for Photovoltaic Based on Firefly Algorithm, [8]. These previous studies have proven that FA succeeds in obtaining optimal values in different cases, because when compared to other algorithms, FA can handle multimodality and automatically subdivision. FA has a faster program convergence and a very simple computational process [9]. The Firefly algorithm is very effective and outperforms conventional algorithms for solving many optimization problems, such as global optimization problems, routing problems, including tracking problems [10]. The Firefly algorithm is used in this study to optimize the direction control of a 100 Wp single-axis solar panel in tracking the sun's position to get maximum energy conversion.

2. Research Method

2.1 Single Axis Solar Tracking System

Solar system technologies directly convert energy from sunlight into electricity. Sunlight strikes the semiconductor material and releases electrons from their atomic bonds, producing an electric current. Solar panel power output peaks at midday when the sun is at its highest point in the sky [11]. The tracking control system is made to be further applied to a solar panel device as a means of collecting solar energy so that the position of the solar panel is dynamic [12]. The sunlight has two parts: direct sunlight which radiates directly from the sun, making up 90% of the solar energy, and diffused sunlight, which refers to the scattered light or indirect light from the sun that can be reflected and become a large proportion in the cloudy sky [13]. The ratio in the cloudy sky between direct sunlight and diffused sunlight is 60 to 40. It indicates that solar panels do not have to always face the direction of the sun, but rather find a more effective source of light, whether direct or diffused sunlight [14].

A solar tracker is useful for tracking where the light source is most effective. A solar tracker is built from a control circuit that can detect and track the movement of sunlight across the sky from sunrise to sunset where solar cells are made always perpendicular to the sun so that the intensity of sunlight is received optimally by adjusting the motor movement and produces maximum energy as well. The movement of a single axis solar panel in tracking sunlight is shown in Figure 1 [15][16][17].

A microcontroller as a system controller uses Arduino Mega 2560 which is a microcontroller board based on ATmega2560, has 54 digital input/output pins, is easy to apply, and is a place to embed the firefly algorithm. Mega is compatible with most shields designed for Arduino. Control of the elevation angle for solar radiation reception will be carried out in this module, as well as motor motion control [18].

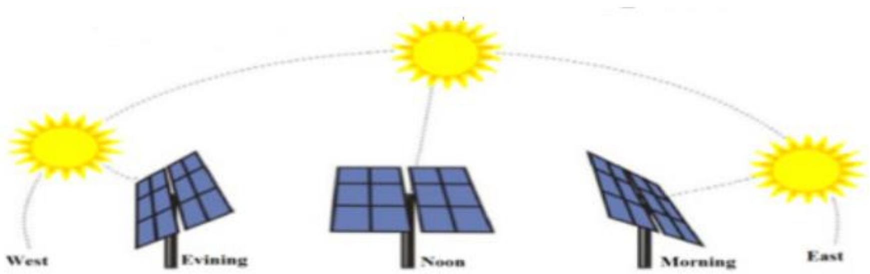

Figure 1. Single Axis Solar Tracker

2.2 Firefly Algorithm (FA)

Firefly Algorithm (FA) was based on the flashing patterns and behavior of fireflies and the phenomenon of bioluminescent communication [19][20]. FA is inspired by the behavior of fireflies that use the flashlight they emit in their activities. The unique behavior of fireflies is that the less bright ones will approach the lighter fireflies, represents its position as a solution, and the brightness level is represented as a fitness value. FA is formulated with the following assumptions [21]:

1. Fireflies will be attracted to each other regardless of their sex because they are unisexual.
2. Attractiveness is proportional to their brightness whereas the less bright firefly will be attracted to the brighter firefly. However, the attractiveness decreased when the distance between the two fireflies increased.
3. If the brightness of both fireflies is the same, the fireflies will move randomly. The generations of new solutions are by random walk and attraction of the fireflies. The brightness of the fireflies should be associated with the objective function of the related problem. Their attractiveness makes them capable to subdivide themselves into smaller groups and each subgroup swarm around the local models.

FA is a very powerful technique to solve constrained optimization problems even in a dynamic environment. For applied mathematics, the algorithm must be just simple math and logic [22]. FA works based on global communications among the fireflies. Hence, it can find global and local optimal simultaneously. FA use mainly real random numbers. Different fireflies work independently and it is suitable for parallel implementation [23][24].

The light intensity of a firefly is given by Equation 1. Where: γ is the absorption coefficient and (I_0) is the initial value at (r = 0) [25][26][27].

$$I_\gamma = I_0 e^{-\gamma r_{ij}} \tag{1}$$

The attractiveness is expressed by Equation 2. Where β_0 is the firefly attractiveness value at (r = 0).

$$\beta(\gamma) = \beta_0 * e^{-\gamma r^2} \tag{2}$$

Equation 3 evaluates the distance between two fireflies i and j, at positions xi and xj, respectively, and can be defined as Cartesian distance. Where xik is the kth element of the spatial coordinate xj of the ith firefly and D denotes the dimensionality of the problem.

$$r_{ij} = |r_i - r_j| = \sqrt{\sum_{k=1}^{D} (x_{ik} - x_{jk})^2} \quad (3)$$

The movement of a firefly i at position xi moving to a brighter firefly j at position xj by Equation 4.

$$x_i(t+1) = x_i(t) + \beta_0 e^{-\gamma r^2}(x_i - x_j) + \alpha\varepsilon_i \quad (4)$$

Where x_i (t + 1) is the position of firefly i at iteration t +1 displacement. As it can be seen, the first part of the right side of Equation (4) is the position of firefly i at iteration t, the second term is relative to the attractiveness and the last one is randomization (blind flying if there is no light) where α is the random walk parameter α ∈ [0,1).

2.3 Block Diagram System

The Single-Axis Solar Tracker Optimization System using Firefly Algorithm is shown in the block diagram in Figure 2. Five light sensors are installed in a row from west to east with each angle of 30^0 (total 120^0), which will detect the direction of the sun's rays. The detection results are the changes in resistance and inserted into the voltage divider circuit to produce an electric voltage and become input for the controller system. The voltage value will be mathematically processed by the firefly algorithm by comparing the voltage generated by each sensor. The output of the firefly algorithm is processed by a microcontroller to control the movement of the solar panels according to the angle and direction of sunlight comes.

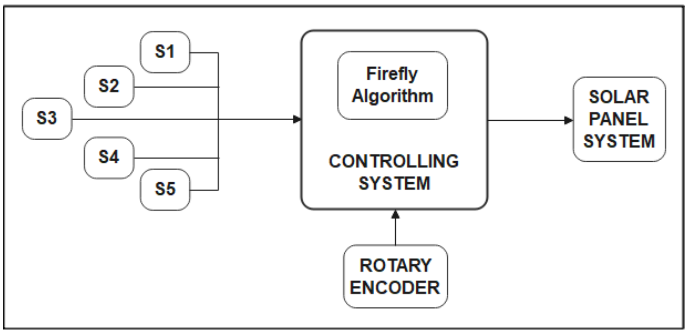

Figure 2. Block Diagram System

The magnitude of the angle of movement of solar panels is detected by a rotary encoder and translated into electrical pulses. The electric pulses are fed back to the controller. If the angle of movement detected by the rotary encoder corresponds to the Firefly algorithm's mathematical calculations, the motor stops moving the solar panel. This system will run continuously. The positions of the five light sensors are shown in Figure 3.

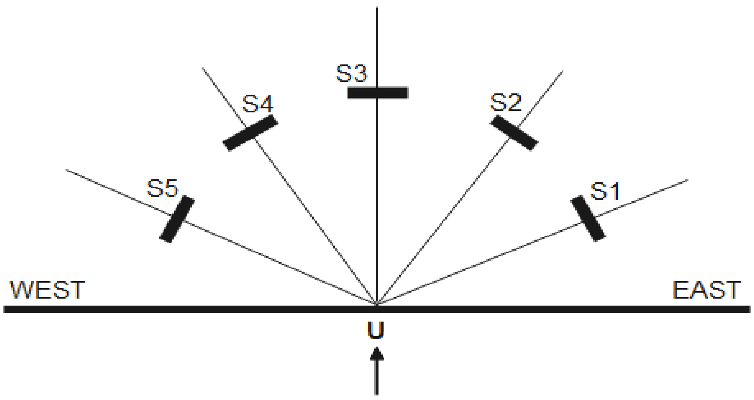

Figure 3. Sensors Angle Direction

2.4 Implementation of Firefly Algorithm on Single-Axis Solar Tracker System for Solar Panel 100 Wp

The Firefly algorithm will be translated in programming form on the controller based on the following pseudo code.

2.4.1 Firefly Algorithm

Objective function f(x), x = (x1,x2,…xn) T
Initialize a population of fireflies xi , (i=1,2,…n)
Brightness Ii at xi determined by f(xi)
Define light absorption coefficient γ
While(t<Max Generation)
For i = 1: n all n fireflies
    For j = 1: i all n fireflies
        Light intensity I_i at x_i is determined by $f(x_i)$
        If (I_j>I_i)
        Move firefly i towards j in all d dimensions
        end if
        Attractiveness varies with distance r via exp[-γr]
        Evaluate new solutions and update light intensity
    end for j
end for i
Rank the fireflies and find the current best
end while
Post process results and visualization

The firefly algorithm workflow in the controller system is shown in Figure 4.

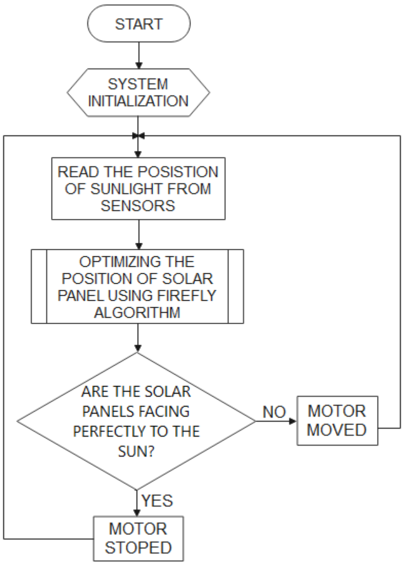

Figure 4. Flowchart of Firefly Algorithm Implementation on 100Wp Solar Panel Tracker System

There are five light sensors with different directions (total angle 120°), to determine the position of the sun. The intensity of sunlight is received by the light sensor, converted into an electrical signal, and sent to the control system to be read as sun position data. The Firefly algorithm embedded in the controller system will move the position towards the solar panel so that it always corresponds to the position of the sun. Mathematical modeling of the solar tracker positioning in the controller system to be optimized by the firefly algorithm is described as follows:

1. Read the sun position data obtained by each light sensor.
2. Carry out the clustering process: (a) If sensor 1 (S_1) has the highest value, then I_0 = (-) 720 and k=1 ; (b) If sensor 2 (S_2) has the highest value then I_0 = (-) 360 and k = 2 ; (c) If sensor 3 (S_3) has the highest value then I_0 = 0 and k = 3 ; (d) If sensor 4 (S_4) has the highest value then I_0 = (+) 360 and k = 4 ; (e) If sensor 5 (S_5) has the highest value then I_0 = (+) 720 and k = 5.
   I_0 represents the movement of the number of pulses from the rotary encoder to reach the facing position of the solar panel perpendicular to the sun with the maximum value of 720.
3. Observing the response and mathematical testing of the system formed, then the initial data is used in the formula Equation 5.

$$I = I_0 + (S_{k+1} - S_{k-1})\ x\ 0{,}3 \quad (5)$$

Where I is the light intensity of the fireflies and I_0 is the initial intensity. S_{k+1} is a sensor on the east side of the sensors which has an optimal position. S_{k-1} is a sensor located on the west side of the sensors which has an optimal position. And 0.3 is a constant based on the characteristics of a rotary encoder.

4. Determine the variables for the optimization process as follows: (a) Population of fireflies (n) is from all the light captured by the light sensor varies on the amount of 10, 25, and 50; (b) The absorption coefficient γ [0,1] is set to 0. ; (c) Random numbers α in the range [0,1] are set to 0.1, 0.4 and 0.8; (d) Varied iteration is set at 10, 20 and 50. Then the firefly algorithm formulas work to find the optimal values by comparing each value of absorbed light intensity using these predetermined variables.
5. Get the maximum absorption of light intensity generated by the optimization process of the Firefly algorithm by observing changes in the value of the population, iterations, and the range of random numbers.

The optimal value obtained by the Firefly algorithm controls the movement of the solar panel so that it faces perfectly at the angle and direction of sunlight. The angular movement of the solar panel will be detected by an electric pulse detector. If angular movement is detected corresponds to the mathematical calculation of the firefly algorithm. Then the solar panel stops moving because it has got the best position to absorb solar energy optimally.

3. Results and Discussion

Several tests were carried out on the single-axis solar tracker system to analyze the performance of the control system in optimizing using the firefly algorithm, as follows:

3.1 Performance of Firefly Algorithm

The performance test aims to understand the effect of determining the number of firefly populations and the number of iterations and the size of the random search space on the firefly algorithm's ability to obtain the best light intensity value. Performance testing of the Firefly algorithm uses the following parameters: (a) Population of fireflies (n) with some variation (10; 25; 50). (b) Light absorption coefficient [0,1] γ is 0,4. (c) Random parameter [0,1] α varies at 0,1; 0,4; 0,8. (e) Iteration varies at 10, 20 and 50. (f) A setpoint is 720.

Table 1. Firefly Algorithm Performance Test in Finding the Best Light Intensity

n	α	Iteration = 10		Iteration = 20		Iteration = 50	
		Gbest	time (s)	Gbest	time (s)	Gbest	time (s)
10	0,1	638,09	0,49	638,21	0,79	638,72	1,46
	0,4	638,34	0,49	638,83	0,79	640,86	1,46
	0,8	638,68	0,49	639,67	0,79	643,72	1,46
25	0,1	677,16	1,50	677,32	3,99	677,66	7,96
	0,4	677,64	1,50	678,29	3,99	679,63	7,96
	0,8	678,28	1,50	679,59	3,99	682,26	7,96
50	0,1	699,05	6,34	699,20	12,00	699,48	22,00
	0,4	699,22	7,00	699,65	12,00	699,83	22,00
	0,8	699,66	7,00	700,95	12,22	705,40	22,00

It can be seen in Table 1 that changes in the firefly population (n), random numbers (α), and the number of iteration greatly affect the optimization process of the firefly algorithm. If the population or iteration values or random parameters used are greater, then the light intensity value obtained will be even greater. At a population value of 50, a random parameter of 0.8, and an iteration of 50, the light intensity value obtained is closest to the setpoint value. Firefly Algorithm's best light intensity value (Gbest) represents the number of rotary encoder pulses, where each pulse is equal to 0.1^0. It can also be noted that the large population of fireflies and the large number of iterations affect the execution time. The larger the firefly population and/or the more iterations, the system takes more time to execute. At 10 iterations, a population of 50 takes 7 seconds to execute. At 20 iterations, a population of 50 takes 12 seconds to execute. And at iterations of 50, population 50 takes up to 22 seconds of execution.

3.2 The Accuracy of Solar Panel Tracking's Angle to The Sun's Position Using Firefly Algorithm

The research took place in Malang during June - July 2021 with relatively sunny weather conditions throughout the day. The measuring process of the angle of the sun's position starts from 06.30 to 16.30. It becomes a reference for the solar panel tracking accurate test.

Table 2. Accuracy of Solar Panel Tracking's Angle to The Sun's Position Using Firefly Algorithm

Time (WIB)	Sun's Position (x°)	PV Position (x°)	Error (%)
6:30	15	16	6,67
7:30	30	31	3,33
8:30	45	45	0,00
9:30	60	60	0,00
10:30	75	75	0,00
11:30	90	89	1,11
12:30	105	106	0,95
13:30	120	120	0,00
14:30	135	136	0,74
15:30	150	149	0,67
16:30	165	164	0,61
Average Error			1,28

Table 2 shows the angular position of the sun in real time and the angular position of the solar panel using firefly algorithm. The calculation value of the firefly algorithm is based on Equation 5. Solar panels can track the angle of the sun's position by referring to the optimization value of the firefly algorithm. The optimal value will control the solar panel movement to track precisely the angular position of sunlight. The average test error is 1.28%.

3.3 Energy Output per Hour Based on Solar Panel Position to The Sun

Figure 5 shows the measurement results of the absorbed solar energy per hour between the static position solar panels and the tracking solar panels with a control system using the firefly algorithm. Each test was conducted using different identical solar panels simultaneously.

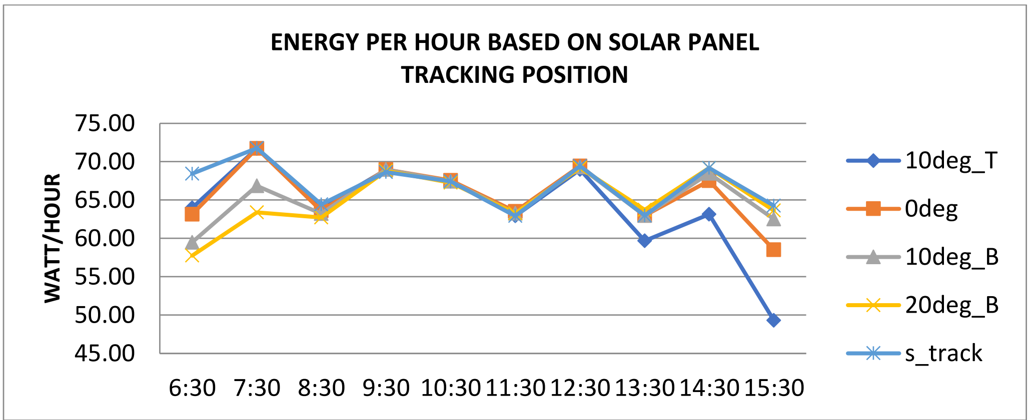

Figure 5. Energy Output Per Hour Based on Solar Panel 100 Wp Position to the Sun

Static solar panels produce maximum energy absorption only at a certain time based on a selected facing angle position to absorb solar energy. For example, if the solar panel is set at an angle of 10^0 to the west, the largest absorption of solar energy is 69.30 watts/hour at 12.30 WIB. At that time the angle of the solar panel is perpendicular to the position of the sun. But in the morning the solar panels with an angle of 10^0 to the west have very low energy absorption. This is because the solar radiation angle is outside the maximum range of the solar panel capture angle (30^0).

On the other side, tracking solar panels with a control system using the Firefly algorithm, will always track the position of the sun and absorb energy continuously. It can be seen that the energy per hour produced at each test time has a maximum value. It ranges from 62.93 Watt/hour to 71.77 Watt/hour.

3.4 Energy Output per Day Based on Solar Panel Position to The Sun

Figure 6 shows the measurement results of the total solar energy absorbed per day between static position solar panels and tracking solar panels with a control system using the firefly algorithm. If the solar panel is positioned at a static angle of 10^0 to the east, the maximum absorption of solar energy is 640.2 Watt/day. If the solar panel is positioned at a static angle of 0^0 (perpendicular to the earth), the maximum absorption of solar energy is 656.9 Watt/day. If the solar panel is positioned at a static angle of 10^0 to the west, the maximum absorption of solar energy is 625.6 Watt/day. If the solar panel is positioned at a static angle of 20^0 to the west, the maximum absorption of solar energy is 649.6 Watt/day.

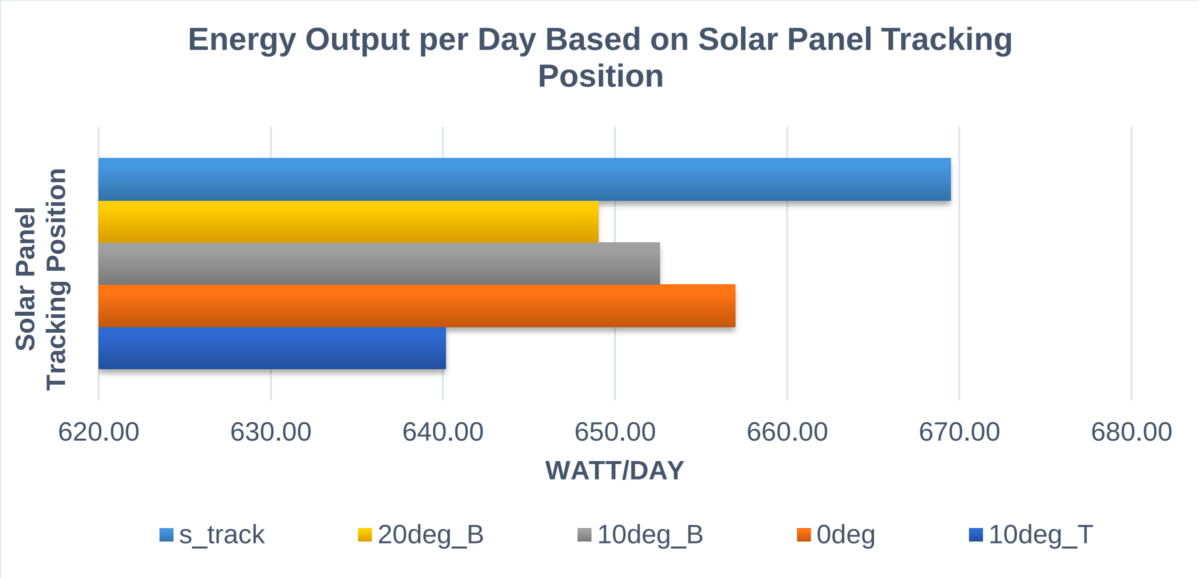

Figure 6. Energy Output per Day Based on Solar Panel Position to The Sun

When the solar panel system works to track the sun's position throughout the day with optimization using the firefly algorithm, the maximum absorption of solar energy is 669.5 Watt/day. The energy needed to drive the solar panel motor is 3.36 Watt/day. So, the total energy obtained is 666.14 Watt/day. It can be seen that the solar tracker system optimized by the firefly algorithm is able to produce the most optimal absorption of solar energy per day.

4. Conclusion

The optimization process by applying the firefly algorithm on a single axis solar tracker system has succeeded in driving a solar panel 100 Wp to track the sun's position precisely with an average error of 1.28%. It can be concluded that the Firefly algorithm is feasible to solve optimization problems on solar trackers. The best value and closest to the setpoint (705.40 of 720) is obtained when given the largest population of fireflies, the highest random number, and the most iterations. But, it makes the execution time slower. The total energy obtained by the Single Axis Solar Tracker with The Firefly Algorithm (after deducting the energy to drive the motor) is 666.14 Watt/day, greater than the best energy obtained by static solar panel.

System performance can be improved by using a controller with a larger memory capacity and higher response speed. To get optimal tracking on a single axis solar tracking system so that the solar panel system can absorb sunlight and convert it into electrical energy as much as possible, we still use the basic firefly algorithm. Furthermore, research on solar tracker optimization problems in order to produce maximum electrical energy can also be carried out by applying a novel strategy for the firefly algorithm (an improved method for the basic firefly algorithm) or by applying a hybrid algorithm between firefly algorithm and other optimization algorithms, taking the advantages of each algorithm.

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