Optimizing Single Axis Tracking for Bat Algorithm-based Solar Cell

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Abstract

Adding the solar tracking control system was an attempt to increase the efficiency of solar panels. The solar tracking control system was a control system that follows the sun position. The purpose of this solar tracking system was to position the cross-section always to face the sun. The Single Axis system in solar tracking was intended to follow the sun's angle or solar azimuth angle from the east to the west. There needed a control optimization to get the position as desired. Optimization often used artificial intelligence to obtain the automatic best optimization, such as Bat Algorithm (BA). This research compared several methods: without control, using PID control, using PID-Auto control, and using PID-BA control. The simulations showed that the smallest elevation angle deviation was found in the PID-BA controller. In conclusion, PID-BA was the best controller in this research. This research could be used as a future reference with other controllers to get the most optimized controller.

Keywords
Bat Algorithm, Firefly Algorithm, Solar Tracker, Photovoltaic, PID Controller

1. Introduction

Solar Power Plant, with its modular system and is easy to move, is a considerable solution as an alternative power plant [1]. Adding the solar tracking control system was an attempt to increase the efficiency of solar panels. The solar tracking control system is a control system that follows the sun position [2]. The purpose of this solar tracking system is to position the cross-section always to face the sun. During sunrise or sunset, the elevation angle is 0°. The maximum elevation angle is 90° when the sun is directly overhead. The solar azimuth angle is the sun's angle position calculated from the north. The solar azimuth angle is 0° in the north, 90° in the east, 180° in the south, and 270° in the west. Currently, Artificial Intelligent (AI) is often used to develop various sciences such as micro-hydro control [3][4], DC motor speed control [5], vehicle steer control [6], and wind turbine blade control [7]. Several use Ant Colony Optimization (ACO) method [8][9][10], Firefly Algorithm (FA) [11][12][13], and Bat Algorithm (BA) [14]. Previous research used Particle Swarm Optimization (PSO) [15]. Thus, this research used BA artificial intelligence as the tuning in the PID controller.

2. Photovoltaic

2.1. Parameters

Photovoltaics is a solar tracking system load produced specifically for Indonesia. The DC motor parameters are $J = 3.2284 \times 10^{-6}$ kg.m^2, $b = 3.5077 \times 10^{-6}$ Nms, kb = 0.0274 Vsec/rad, kt = 0.0274 Nm/Amp, R = 4 Ω, and $L = 2.75 \times 10^{-6}$ H [16]. The gear transmission system is a spur gear with two teeth: M1B12 model (12 teeth and 10 gr mass) and M1A20 model (120 teeth and 1.32 kg mass). The PV dimensions are 670 x 1040 x 35 mm with 7.5 kg mass, J1 = 0.0022642 kg.m^2, JT1 = 0.0023185 kg.m^2, J2 = 0.0222231 kg.m^2, JT2 = 0.0222774 kg.m^2.

2.2. DC Motor Transfer Function

Using the Laplace Transformation, the equation below was obtained [17][18]:

$$\mathrm{LsI(s) + RI(s) = V(s) - Ks\theta(s)} \tag{1}$$

DC motor transfer function without load:

$$\frac{\theta(s)}{V(s)} = \frac{K}{s((Js+b)(Ls+R)+K^2)} \tag{2}$$

$$\frac{\theta(s)}{V(s)} = \frac{0.0274}{8.878x10^{-12}s^3+1.291s^2+0.0007647308s} \tag{3}$$

2.3. Single Axis Tracking

Single Axis Tracking is a device to maximize the utilization of the sun in the solar cell by following the sun direction from the east to the west, rotating according to the vertical turning axis. The vertical turning axis in solar tracking is intended to follow the solar azimuth angle (γ) that is calculated from the east to the west. Figure 1 below shows the photovoltaic of the vertical axis tracking.

Figure 1. Single Axis Solar Tracking

Based on the picture above, during the equinox, the sun rises precisely from the east and sets accurately in the west, regardless of latitude, and thus, form a 90° azimuth angle when the sun rises and 270° angle when the sunsets.

$$y = arc\cos\left\{\frac{\sin\delta\cos\varphi - \cos\delta\sin\varphi\cos HRA}{\cos a}\right\} \quad (4)$$

Generally, the solar tracking system is classified into two: single-axis solar tracking and dual-axis solar tracking. The single-axis solar tracking is divided into vertical and horizontal axis solar tracking.

2.4. Vertical Axis Transfer Function

Photovoltaic of load torque value was obtained from the solar cell panel inertial moment multiplied by the turning angle acceleration. The turning angle acceleration is from the gear1 angle acceleration. Below is the equation of the solar cell panel inertia moment in vertical axis transfer function.

$$J_1 = \frac{1}{2} m_{pv}(L^2 + W^2)(\frac{N_2}{N_1})^2 \quad [kg.m^2] \quad (5)$$

The equation of the vertical rotating-axis PV solar tracker inertia moment:

$$J_{T2} = J_{st} + J_2 \quad [kg.m^2] \quad (6)$$

$$J_{T2} = 2.71684x10^{-5} + J_2 \quad [kg.m^2] \quad (7)$$

Vertical axis solar tracker transfer function:

$$\frac{\theta(s)}{V(s)} = \frac{K}{s((JT2s+b)(Ls+R)+K^2)} \quad (8)$$

3. Method

3.1. PID Controller

The PID controller is a combination of proportional, integral, and derivative controllers. In this method, tuning is conducted in closed-loop, where the reference input uses step function. This method only uses a proportional controller. The increase in Kp from 0 value up to critical Kp is aimed to obtain continuous oscillation output with the same amplitude [19][8]. The critical Kp value is called the ultimate gain. Tu, or the ultimate period, value is obtained after the system output reaches a continuous oscillating state [17][20][21][22].

3.2. Bat Algorithm (BA)

Based on the equation of bat echolocation from the previous discussion, below is the pseudocode from bat algorithm that was developed by Yang [23]:

```
Objective function f(x), x = (x_1, ..., x_d)^T
    Initiate the bat population x_i, (i = 1,2, ..., n) and v_i
    Define the frequency f_i in x_i
    Initiation of wave emission rates r_i and hardness level A_i
    while (t < maxium iteration)
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Generate new solutions by adjusting the frequency
Update speed and location
      if (rand > r_i)
       choose the solution among the best solutions
       generate local solutions among the best solutions
      end
      if (rand < A_i & f(x_i) < f(x_*))
       accept a new solution
       update r_i and A_i
      end
Sort each bat and choose the new x_*
End
```

Figure 2. Bat Algorithm Pseudocode

3.3. PV Optimization Design

Figure 3 displays the transfer function of the PV equation and parameters.

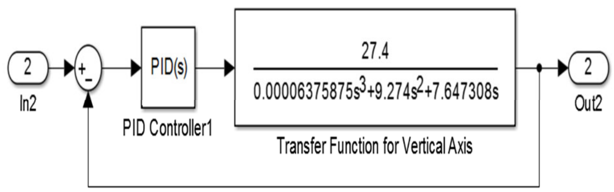

Figure 3. Single-axis Simulation

4. Result

Figure 5 illustrates the design without control, with PID control, with PID-Auto control, and with PID-BA control.

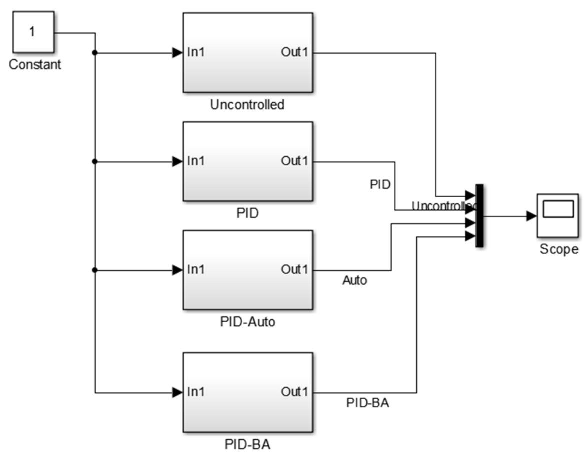

Figure 4. Control Design of Single Axis in PV

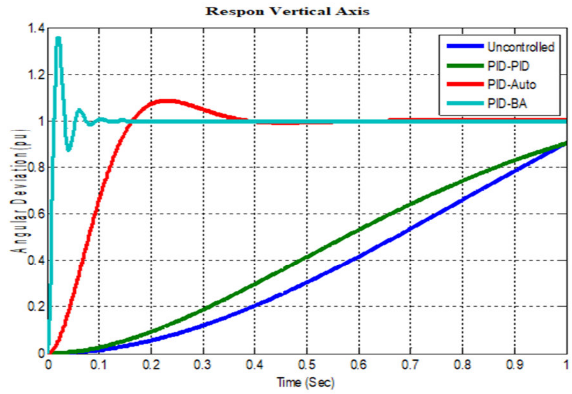

Figure 5. Single Axis Response Angle

Figure 5 presents the vertical angle deviation in simulation without control that was 46.021, with PID that was 90.356, with PID-Auto that was 4.763, and with PID-BA that was 19.734. Without control had 13.023, PID had 9.033, PID-Auto had 0.487, and PID-BA had 0.073.

The constants from the vertical axis simulation were Kp, Ki, and Kd constants, as depicted in Table 1.

TABLE I
PID Constants in Vertical Axis

	Unc.	PID	PID-Au	PID-BA
Kpv	-	1	4.053	56.321
Kiv	-	1	0.060	0.753
Kdv	-	0	2.385	81.227
Overshoot	46.021	90.356	4.763	19.734
Undershoot	21.181	82.743	0.471	1.193
Settling time	13.023	9.033	0.487	0.073

The table above informs that the smallest overshoot in the single-axis was found in the PID-Auto controller for 4.763 pu. The smallest undershoot in the single-axis was found in the PID-Auto controller for 0.471. The fastest settling time in the single-axis occurred in the PID-BA controller for 0.073 seconds.

5. Conclusion

The simulation results showed the smallest angle deviation in the single-axis was in the PID-BA controller for -0.07°. Therefore, it can be concluded that the PID-BA controller was the best in this research. This research could be used as a future reference with other controllers to get the most optimized controller.

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