The comparison of dual axis photovoltaic tracking system using artificial intelligence techniques

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ABSTRACT

In this paper, the efficiency of photovoltaic panels is improved by adding a sun tracking system. The solar tracking system is used for tracking the sun so that photovoltaic always faces the sun. This system uses a dual axis consisting of horizontal rotation axis and a vertical rotation axis. The horizontal rotational axis motion is to follow the azimuth angle of the sun from north to south. Then, to follow the sun's azimuth angle from east to west is the vertical axis motion. Both types of movements are controlled using a PID controller that is optimized with an artificial intelligence approach, namely particle swarm optimization (PID-PSO), firefly algorithm (PID-FA), imperialist competitive algorithm (PID-ICA), bat algorithm (PID-BA), and ant colony optimization (PID-ACO). Experiments of various approaches were carried out and the corresponding performance compared. The experimental results show that PID-BA performs best in terms of settling time and overshoot. The results also allow the comparison of different PID controller and the calculation of the fastest completion time.

Keywords:
Bat algorithm
Dual axis photovoltaic tracking system
PID controller

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1. INTRODUCTION

The use of renewable energy such as solar energy and wind energy is very fast [1]-[4]. However, solar energy is very promising to be used as electricity generation [5]. Several techniques have been done to obtain optimal electricity using photovoltaics. One of the techniques to get electric power is the addition of tracking control systems to photovoltaic (PV) systems. It has been added to obtain the maximum power point from the PV and direct the PV towards the sun. Tracking power point in a photovoltaic system has been investigated to track the PV system's maximum power points using the fuzzy logic controller [6], [7]. Solar panels also need control of tracking the position of the sun so that they always precisely follow the position of the sun. This solar tracking system is used to track the horizontal rotation axis and vertical rotation axis [8], [9]. The horizontal axis is the axis used to track the sun's height angle and the vertical axis is the axis following the angle of the sun's azimuth. Control optimization is needed so that the position is exactly as desired.

A study which was conducted by [10], [11] analyzed about the benefits of using sun-tracking versus using fixed modules. They concluded that there was a gain of 30-50% higher than using fixed modules. In
need of that best performance of that gain then the authors proposed an empirical study on comparing several artificial intelligence methods that will be used on the experiment. These artificial methods will optimize the movement of PID controller. Artificial intelligence (AI) has been often used in system optimization and has contributed a lot to research. Among them are used for control and optimization of vehicle steer [12], controls on motor speed, frequency control on micro-hydro [8], speed control on wind turbines, and dual axis tracking photovoltaic control. The artificial intelligence method used is particle swarm optimization (PSO) [13], firefly algorithm (FA) [14], imperialist competitive algorithm (ICA) [15], [16], bat algorithm (BA) [17], and ant colony optimization (ACO) [18]. In this paper, PID-PSO, PID-FA, PID-ICA, PID-BA, and PID-ACO are used to track sunlight to get the maximum power point from PV. For optimization often used artificial intelligence to get the best optimization automatically [13] but it has different result of each artificial methods. In this study, several methods chosen to carry out in this research were PSO, FA, dan fuzzy logic controller (FLC). Those methods will be tested and measured to discover best result among methods so that they will obtain maximum power point. The results also allow the comparison of different PID controller and the calculation of the fastest completion time.

2. DUAL AXIS TRACKING MODEL

Solar-azimuth-elevation tracking consists of a horizontal rotation axis to track the sun's height ($\alpha$) from north to south and a vertical axis of rotation to track the sun's azimuth angle ($\gamma$) from east to west as shown in Figure 1. The azimuth angle is the angle formed by the sun clockwise from north to south [19]. The azimuth angle depends on the latitude and time of the year and has an equation like (1) [20]. The elevation angle is the horizontal angle of the sun. The angle of the sun's height depends on the latitude and time of the year like (2).

$$\begin{align*}
    y &= \arccos \left( \frac{\sin \delta \cos \varphi - \cos \delta \cos \varphi \cos HRA}{\cos \alpha} \right) \\
    \alpha &= \arcsin(\sin \delta \sin \varphi - \cos \delta \cos \varphi \cos(HRA))
\end{align*}$$

2.1. Parameters of system

This research was conducted in Indonesia with DC motor parameters such as Table 1, and spur gear parameters like Table 2. Table 3 is the PV model parameters.
Table 1. The parameters of DC motor

| DC motor Parameters | Value             |
|---------------------|-------------------|
| J (kg.m²)           | 3.2284x10⁻⁶       |
| b (N.m.s)           | 3.5077x10⁻⁶       |
| kb (V/sec.rad⁻¹)    | 0.0274            |
| kt (Nm.Amp⁻¹)       | 0.0274            |
| R (Ω)               | 4                 |
| L (H)               | 2.75x10⁻⁶         |

Table 2. Spur gear

| Type      | Number of teeth | Mass (gr) |
|-----------|-----------------|-----------|
| M1B12 model | 12              | 10        |
| M1A20 model | 120             | 1320      |

Table 3. NPS100W PV model

| PV parameters | Value |
|---------------|-------|
| Dimension(mm)  | 10    |
| Mass(kg)       | 1320  |
| J1 (kg.m²)     | 0.0022642 |
| JT1 (kg.m²)    | 0.0023185 |
| J2 (kg.m²)     | 0.0222231 |
| JT2 (kg.m²)    | 0.0222774 |

2.2. DC motor model

By using the transform of Laplace, (4) is DC Motor model without load.

\[ L_s I(s) + R I(s) = V(s) - K s \theta(s) \]  

\[ \frac{0(s)}{V(s)} = \frac{K}{s((Js+b)(Ls+R)+K^2)} \]  

\[ \frac{0(s)}{V(s)} = \frac{0.0274}{0.878x10^{-12}s^3+1.291s^2+0.0007647308s} \]  

2.3. Horizontal axis model

The inertia moment of the solar cell and the turning angle acceleration affects the torque value of photovoltaic loads. As shown in (9) is the inertia moment of the horizontal axis rotary sun. Tracking the horizontal axis rotary sun like (10).

\[ J_1 = \frac{1}{2}m_pvL^2N_2^2 \]  

\[ J_{T1} = J_{st} + J_1 \]  

\[ J_{T1} = 2.71684x10^{-5} + J_1 \]  

\[ \frac{0(s)}{V(s)} = \frac{K}{s((JT2s+b)(Ls+R)+K^2)} \]  

\[ \frac{0(s)}{V(s)} = \frac{0.0274}{6.375875x10^{-11}s^3+0.0092745s^2+0.0007647308s} \]  

2.4. Vertical axis model

As shown in (11) represents the inertia moment of a vertical rotary axis. The inertia moment of the vertical rotary axis of the PV tracker is (14) and the transfer function of the vertical rotary axis solar tracker is (15).

\[ J_1 = \frac{1}{2}m_pv(L^2 + W^2)N_3^2 \]  

\[ J_{T2} = J_{st} + J_2 \]  

\[ J_{T2} = 2.71684x10^{-5} + J_2 \]  

\[ \frac{0(s)}{V(s)} = \frac{K}{s((JT2s+b)(Ls+R)+K^2)} \]
\[
\frac{f(s)}{V(s)} = \frac{0.0274}{6.126285 \times 10^{-8}s^2 + 9.646175 \times 10^{-6}s^2 + 0.00075076s}
\]  

(15)

2.5. PID controller

PID controller is a simple controller that has three controller parameters, namely proportional (Kp), integral (Ki), and derivative (Kd) gain. The PID controller can be tuned using the Ziegler-Nichols method, using the self-tuning method, and using the artificial intelligence method [21].

2.6. Particle swarm optimization (PSO)

The PSO is an optimization algorithm that mimics the collective behavior of birds [22], [23]. In this paper, optimization is done to find the PID parameters value so that the PID can produce azimuth angles and sun elevation angles. So that the PV can produce maximum power points. The parameters of PSO are shown in Table 4.

2.7. Firefly algorithm (FA)

The FA algorithm is an optimization algorithm that mimics the collective behavior of fireflies [24], [25]. In this paper, PID parameters are searched by using FA so that PID can produce azimuth angles and sun altitude angles. So that the maximum power point is obtained. The FA parameters are shown in Table 5.

| Table 4. Parameters of PSO | Table 5. Parameters of FA |
|---------------------------|---------------------------|
| PSO Parameters            | FA Parameters             |
| Value                     | Value                     |
| Number of Particles       | Alpha (\(\alpha\))       |
| 30                        | 0.25                      |
| Maximum of iteration      | Beta (\(\beta\))         |
| 50                        | 0.2                       |
| Number of Variables       | Gamma (\(\gamma\))       |
| 3                         | 1                         |
| C2 (Constant of Social)   | Dimensi                   |
| 2                         | 3                         |
| C1 (Constant of Cognitive) | Fireflies Number          |
| 2                         | 50                        |
| W (Inertia Momentum)      | Maximum of iteration      |
| 0.9                       | 50                        |
| Kph_pso, Kpv_pso          | Kph_fa, Kpv_fa            |
| 0-300                     | 0-300                     |
| Kih_pso, Kiv_pso          | Kih_fa, Kiv_fa            |
| 0-100                     | 0-100                     |
| Kdh_pso, Kdv_pso          | Kdh_fa, Kdv_fa            |
| 0-100                     | 0-100                     |

2.8. Imperialist competitive algorithm (ICA)

The ICA is an optimization algorithm that mimics socio-political behavior [15]. In this paper, ICA is used to determine PID parameters, then PID will determine the azimuth and the sun's height angle. So that the maximum power point is obtained. The parameters of ICA are shown in Table 6.

| Table 6. Parameters of ICA |
|----------------------------|
| ICA-Parameters             | Value      |
| Countries Number           | 50         |
| Imperialists Number        | 6          |
| Colonies Number            | 44         |
| Revolution rate            | 0.3        |
| Coefficient of Assimilation (\(\beta\)) | 2        |
| Coefficient of Assimilation (\(\gamma\)) | 0.5       |
| Zeta \(\zeta\)             | 0.01       |
| Kph_ica, Kpv_ica           | 0-300      |
| Kih_ica, Kiv_ica           | 0-100      |
| Kdh_ica, Kdv_ica           | 0-100      |

2.9. Bat algorithm (BA)

Bat algorithm (BA) is a stochastic global optimization algorithm based on bat echolocation mechanism and very good characteristics [26], [27]. Some simulation results show that the bat algorithm model has a good performance in the optimization function. The parameters of BA are shown in Table 7.

| Table 7. Parameters of BA |
|---------------------------|
| ICA-Parameters             | Value      |
| Countries Number           | 50         |
| Imperialists Number        | 6          |
| Colonies Number            | 44         |
| Revolution rate            | 0.3        |
| Coefficient of Assimilation (\(\beta\)) | 2        |
| Coefficient of Assimilation (\(\gamma\)) | 0.5       |
| Zeta \(\zeta\)             | 0.01       |
| Kph_ica, Kpv_ica           | 0-300      |
| Kih_ica, Kiv_ica           | 0-100      |
| Kdh_ica, Kdv_ica           | 0-100      |

2.10. Ant colony optimization (ACO)

ACO is algorithm that mimic the behavior of dead ants and sort the ant’s larvae. The ACO algorithm provides relevant partitions of data without the knowledge of the initial cluster center. There are ant agents that randomly move on two-dimensional grids where in the grid there are randomly scattered objects, and the size of the grid depends on the number of objects. Ant agents that are selected or allowed to
move in the grid, will take objects and also drop objects that are affected by the similarity and density of objects [28]. The standard ACO used are shown in Table 8.

### Table 7. Parameters of BA

| BA Parameters       | Value |
|---------------------|-------|
| Population Size     | 35    |
| Noise / Loudness    | 0.5   |
| Pulse / Pulse rate ratio | 0.6 |
| Alpha (α)           | 0.9   |
| Gamma (γ)           | 0.9   |
| Amount of Iteration | 50    |
| Kp_{h_ba}, Kp_{v_ba} | 0-300 |
| Ki_{h_ba}, Ki_{v_ba} | 0-100 |
| Kd_{h_ba}, Kd_{v_ba} | 0-100 |

### Table 8. Parameters of ACO

| ACO Parameters       | Value  |
|----------------------|--------|
| Node                 | 100    |
| Max_I               | 50     |
| Alpha (α)           | 1      |
| Beta (β)            | 2      |
| Rho                 | 0.1    |
| C                   | 100    |
| Kp_{h_aco}, Kp_{v_aco} | 0-300 |
| Ki_{h_aco}, Ki_{v_aco} | 0-100 |
| Kd_{h_aco}, Kd_{v_aco} | 0-100 |

### 3. RESULTS AND DISCUSSION

The sun’s declination is the angle between the equator and the line drawn from the center of the earth to the center of the sun. Solar declination results in four seasons in the subtropical regions of both the northern hemisphere and the southern hemisphere. Transfer function is made into MATLAB simulink equation as follows. Control design of motor DC without load by design, uncontrolled, PID-PSO, PID-FA, PID-ICA, PID-BA, and PID-ACO as shown in Figure 2. Design PID Controller for the simulation of dual axis shown in Figure 3, while designs of uncontrolled, PID-PSO, PID-FA, PID-ICA, PID-BA, and PID-ACO shown in Figure 4. Angular response results motor DC; Uncontrolled, PID-PSO, PID-FA, PID-ICA, PID-BA, and PID-ACO shown in Figure 5, Horizontal Axis; Uncontrolled, PID-PSO, PID-FA, PID-ICA, PID-BA, and PID-ACO shown in Figure 6, and Angular Vertical Response Axis; uncontrolled, PID-PSO, PID-FA, PID-ICA, PID-BA, and PID-ACO shown in Figure 7. The results of the assessment in detail shows in Tables 9-11.

![Figure 2. Design control of motor DC without load](image)

![Figure 3. Design of PID controller for dual axis simulation](image)
Figure 4. Design of dual axis control at PV

Figure 5. Respons Motor DC

Figure 6. Angular response horizontal axis
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The motor DC response results in Table 9 can be explained that of the 6 models, the worst model in tracking the position of the sun is an uncontrolled model. The highest overshoot value in PID-PSO is 1.754 pu and the lowest value in PID-ICA is 1.271 pu. The highest undershoot value in the PID-ACO is 0.836 pu and the lowest value in uncontrolled is 0.005 pu. The PID-ICA undershoot lasts only 0.001 seconds. The fastest completion time on PID-ICA is 0.143 s and the longest in uncontrolled is 1.442 s.

| Unc  | PID-PSO | PID-FA | PID-ICA | PID-BA | PID-ACO |
|------|---------|--------|---------|--------|---------|
| Kpm  | 8.468   | 34.145 | 13.499  | 60.203 | 79.487  |
| Kmm  | 14.908  | 3.079  | 1.353   | 9.845  | 7.326   |
| Kdm  | 0.133   | 0.231  | 0.220   | 0.163  | 0.325   |
| Overshoot (pu) | 1.754 | 1.636 | 1.271 | 1.374 | 1.734 |
| Undershoot (pu) | 0.566 | 0.596 | 0.534 | 0.836 |
| Settling time (s) | 1.442 | 0.184 | 0.143 | 0.193 |

The horizontal response results in Table 10 can be explained that of the 8 models, the worst model in tracking the position of the sun is an uncontrolled model. The highest overshoot value in PID-PSO is 49.100 pu and the lowest value in PID-BA is 25.912 pu. The highest undershoot value in the uncontrolled is 22.300 pu and the lowest value in PID-ACO is 10.473 pu. The PID-BA undershoot only lasts 0.019 seconds with a small difference in value, so it can be ignored. The fastest completion time on PID-BA is 0.241 s and the longest in uncontrolled is 11.890 s.

| Unc  | PID-PSO | PID-FA | PID-ICA | PID-BA | PID-ACO |
|------|---------|--------|---------|--------|---------|
| Kph  | 212.400 | 83.264 | 101.076 | 93.764 | 94.347  |
| Kih  | 27.100  | 49.521 | 0.608   | 0.5784 | 2.118   |
| Kdh  | 152.000 | 8.852  | 92.423  | 85.763 | 73.231  |
| Overshoot (pu) | 46.100 | 41.765 | 13.841 | 12.723 | 10.473 |
| Undershoot (pu) | 22.300 | 14.773 | 0.246  | 0.534  | 0.836   |
| Settling time (s) | 11.890 | 0.184 | 0.143 | 0.193 |

The vertical response results in Table 11 can be explained that of the 9 models, the worst model in tracking the position of the sun is an uncontrolled model. The highest overshoot value in PID-PSO is 46.490 pu and the lowest value in PID-BA is 19.734 pu. The highest undershoot value in the uncontrolled model is 21.180 pu and the lowest value in PID-ACO is 1.193 pu. The fastest completion time in PID-BA is 0.073 s and the longest in uncontrolled is 9.230 s.

In terms of the fastest completion time for both horizontal and vertical, the movement of PID controller using bat algorithm (BA) was the fastest among other artificial intelligence methods to point out the position [29]. Also did the simulation using PID-BA and compared it using uncontrolled. They concluded...
that PID-BA were better than the uncontrolled because the smallest elevation angle deviation was found in PID-BA controller. They suggested to use PID-BA for optimizing the result.

| Table 11. Vertical axis results |
|-------------------------------|
|                      | Unc | PID-PSO | PID-FA | PID-CA | PID-BA | PID-ACO |
| Kvp                 | -   | 287.2   | 134.05 | 124.89 | 56.322 | 134.053 |
| Kv                  | -   | 21.40   | 0.063  | 0.374  | 0.753  | 0.060   |
| Overshoot (pu)      | 46.02 | 46.49   | 40.830 | 35.823 | 19.734 | 24.473  |
| Undershoot (pu)     | 21.18 | 20.48   | 14.474 | 12.384 | 1.193  | 3.762   |
| Settling time (s)   | 9.23  | 0.18    | 0.152  | 0.181  | 0.073  | 0.462   |

4. CONCLUSION

In this study dual axis photovoltaic tracking system is briefly described and the comparison of PID controller system using artificial intelligence is summarized. From the results and discussion, the result shows that among seven models, PID-BA was slightly better than the other methods in tracking the position of the sun. PID-BA can point at the fastest position even though it has a slightly undershoot smaller than PID-ACO on the horizontal axis.

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