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Dual-axis solar tracker system utilizing Fresnel lens for web-based monitoring

Humairoh Ratu Ayu, Rifki Mohamad Kurniawansyah, Amir Supriyanto, Junaidi
Department of Physics, Faculty of Mathematics and Natural Sciences, Lampung University, Bandar Lampung, Indonesia

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ABSTRACT

Solar energy produced using solar panels is a renewable source of electricity. Over the years, several studies have been developed in the field to increase the performance efficiency of these panels. Therefore, this study aims to develop dual-axis solar tracker with the addition of Fresnel lens to improve performance efficiency. The system implemented consisted of multisensors, servo motors, Fresnel lenses, Arduino nano, and NodeMCU ESP32. In the experiments, proposed tracking system with and without Fresnel lens were evaluated to compare the output of both setups. The results showed that the maximum power of dual-axis solar tracker with and without the device was 13.60 W and 15.78 W, respectively, at the same radiation intensity, temperature, and time. These findings showed that the proposed tracking system could increase the maximum power efficiency of solar panels by 16.03%. Furthermore, the maximum value was obtained when dual-axis solar tracker with Fresnel lens moved from E to W at 23° to the horizontal.

Corresponding Author:

Humairoh Ratu Ayu
Department of Physics, Faculty of Mathematics and Natural Sciences, Lampung University
Bandar Lampung, Indonesia
Email: humairoh.ratu@fmipa.unila.ac.id

1. INTRODUCTION

Population density and the amount of electrical energy required in a region are closely correlated. Global energy consumption had tenfold at the end of the 20th century, while industrial activity had expanded by a factor of 20 [1]. Moreover, the average yearly growth rate of global primary energy consumption was 2.1%, compared to 1.6% for population increase worldwide. This demonstrates how primary energy use is increasing far more quickly than population increase [1], [2].

In Indonesia, the country has traditionally relied on fossil fuel-based energy sources, such as coal, oil, and gas. However, this causes the depletion of fossil fuels and the dangerous impact of their use on the environment [3]. Emissions and greenhouse gas impacts rise with energy use [4]. The quantity of CO_2 produced either directly or indirectly contributes to global warming and produces an atmospheric greenhouse gas effect. With the global greenhouse gas effect, for instance, rising by 23% between 2005 and 2018, environmental issues including temperature rise resulted [5]. This has led to the government shifting away from the method in favor of promoting renewable energy sources, including solar energy.

Several studies around the world have been dedicated to enhancing the efficiency of solar energy use. These efforts have led to significant progress, such as a 4.6% increase in the output power efficiency of solar cells using phase change materials (PCM) [6]. Other innovation includes the development of a photovoltaic thermal phase change material (PVT-PCM) [7] and the implementation of a spiral flow configuration [8]. Furthermore, the application of the Proteus tracking system simulation has shown a 24% improvement compared to static system [9]. Photovoltaic windows also showed an efficiency of 19.17% [10], with thermal control water spraying cooling showing 16.65% [11]. The use of solar tracking using the MPPT algorithm has further increased efficiency by 16.46% [12], with automatic tracking tilt angel optimization of solar panel with a soft computing process achieving excellent results [13].

Significant advancements have been made in the field of solar tracking system for solar panels. For instance, focused on optimizing photovoltaic plant design with horizontal single-axis tracking from east to west [14]. Several studies have also compared the performance of static solar panels with a single-axis tracking system on a hot climate region close to the equator. The results showed that the average output power of the single-axis was 11% higher [15], 15% [16], 18-25% [17], 24% [9], and 25-30% [18], with a maximum energy of 37.63% [19]. Furthermore, comparing solar panel tracking system for single axis and double axis with the fixed system, it was found that the efficiency of the double axis tracking system was higher than the single axis, with percentages of 81.68% and 32.17%, respectively [20].

Previous studies have shown that dual-axis solar tracking system is superior [21] compared to the single-axis [22], [23], static system [24]–[26], and static solar panel oriented optimally [27]. Several developments in the design of a prototypical dual-axis tracker have been carried out, such as using light dependent resistor (LDR) [28], Fresnel lenses [29], programmable logic controllers (PLC) [30], field-programmable gate array (FPGA) [31], geared dc servomotors [32], microcontroller [33], intelligent fuzzy controller [34], [35], proportional integral derivative (PID) controller [36], plasmon resonance sensors [37], and adaptive neural fuzzy inference system controllers [38], which can increase the efficiency of solar panel performance.

Based on previous reports, the double-axis tracking system is considered more effective in improving the performance of solar panels compared to single-axis or stationary system. Furthermore, the rapid development of technology helps to facilitate the real-time monitoring of parameters influencing the efficiency of solar panel performance, such as current, voltage, temperature, and intensity. Several studies have monitored various internet of things (IoT)-based photovoltaic (PV) system using predetermined parameters [39]–[41]. Apart from that, the use of solar panels for IoT-based smart farming has been carried out [42]. However, of the several studies that have been conducted, there are no studies that focus on monitoring the movement of solar panels in two directions following the direction of the sun's movement using additional website-based Fresnel lenses. The system developed can move in two directions, namely from east to west and rotational movement clockwise or counterclockwise, with changes in angle, which aims to increase the efficiency of solar panels.

2. RESEARCH METHOD

2.1. Scientific methods

Solar cell used in this study was the polycrystalline type with a capacity of 20 Wp and dimensions of 45 cm long and 35 cm wide. Meanwhile, Fresnel lens had dimensions of 55 cm long and 45 cm wide, with lens focus of 70 cm. The optimal distance for the placement of Fresnel lens in dual-axis solar tracker system was 13.36 cm, which was determined based on (1) and (2), as illustrated in Figure 1. Based on Figure 1, it is obtained as (1) and (2) [43].

$$\tan\alpha = \tan\beta \tag{1}$$

$$\frac{1}{2}\frac{P_1}{l} = \frac{1}{2}\frac{P_2}{(l-x)} \tag{2}$$

Where P_1 is the length of the lens (cm), P_2 is the length of the solar panel (cm), l is the focal distance of the Fresnel lens (cm), and x is the ideal distance between the Fresnel lens and the solar panel (cm).

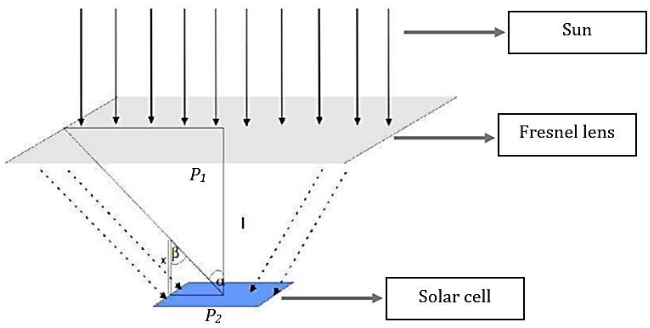


Figure 1. Absorption of sunlight using a Fresnel lens

2.2. Solar tracker techniques

Dual-axis solar tracker design with horizontal and rotational orientation was used in the procedures. The primary axis with horizontal orientation consisted of three positions, namely, when the sun was in the west direction, perpendicular to solar panel, and in the east direction. Furthermore, the initial position of solar panel was horizontal, parallel to the x-axis, and moved in the direction of the sun's movement. The maximum movement of solar tracker on each side was only up to 55°. When the sun was in the west, as in Figure 2(a) and the LDR sensor detected the radiation intensity, solar panel moved east to west (E to W), with an angle ranging from 0° to 55°. The presence of the sun in the east, as shown Figure 2(a) led to the movement of solar panel from west to east (W to E), with an angle range between 0° to –55°. The secondary axis was a rotational motion based on the radiation intensity detected by the LDR sensor. The movement of solar panel was clockwise or counterclockwise, with a rotation angle ranging from 0° to 180°, as shown in Figure 2(b).

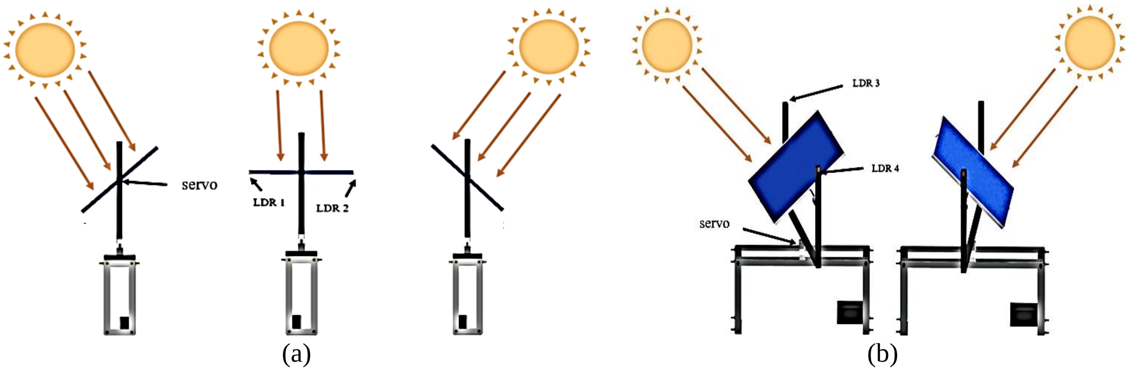


Figure 2. Schematic diagram of sun tracking: (a) primary axis and (b) secondary axis

2.3. Mechanical and electrical structure

This section explained the mechanical and electrical structure of the proposed dual-axis solar tracker. The tracking system design with Fresnel lens is shown in Figure 3. Adjustment of the coordinate system was carried out using two actuators, driven by the MG995 servo motor and installed on the tool according to the rotation axis, namely the primary (east-west) and the secondary (rotational motion) axis. The servo motor for the primary axis was placed on one of the vertical sides of the solar panel, as shown in Figure 4(a). The servo motor for the secondary axis was positioned on a metal joint that could move rotationally, as shown in Figure 4(b). ACS712 current, voltage sensor, and MPU6050 sensor [44] were placed on the back of solar panel, as shown in Figure 5(a). The electrical components in the tracking system are presented in Figure 5(b).

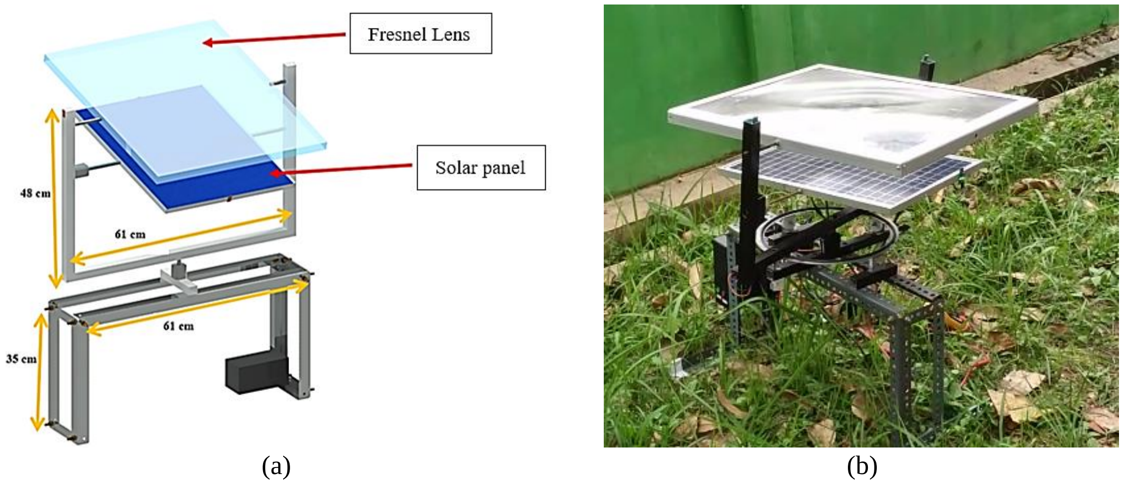


Figure 3. Solar tracker: (a) design and (b) prototype

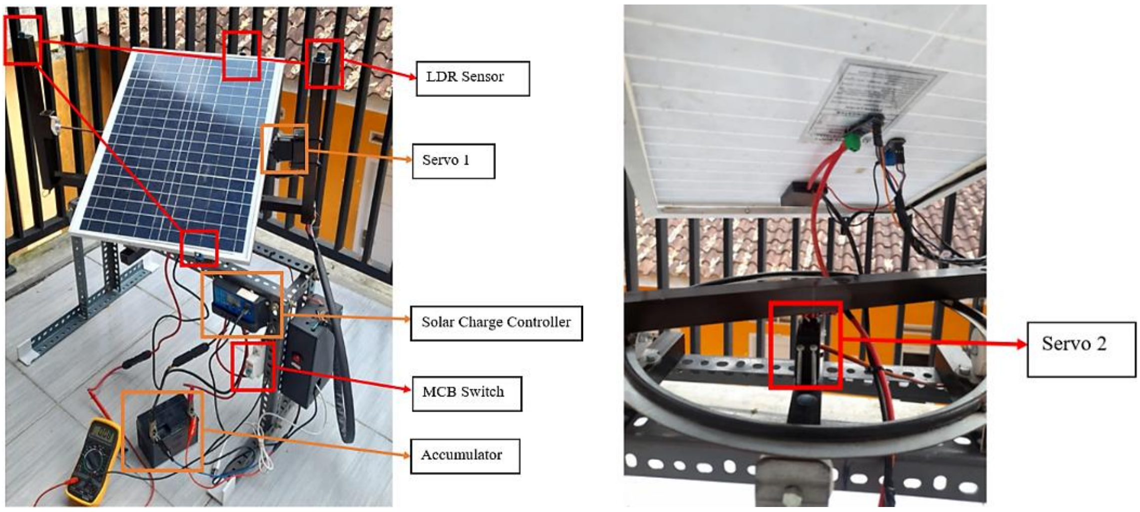
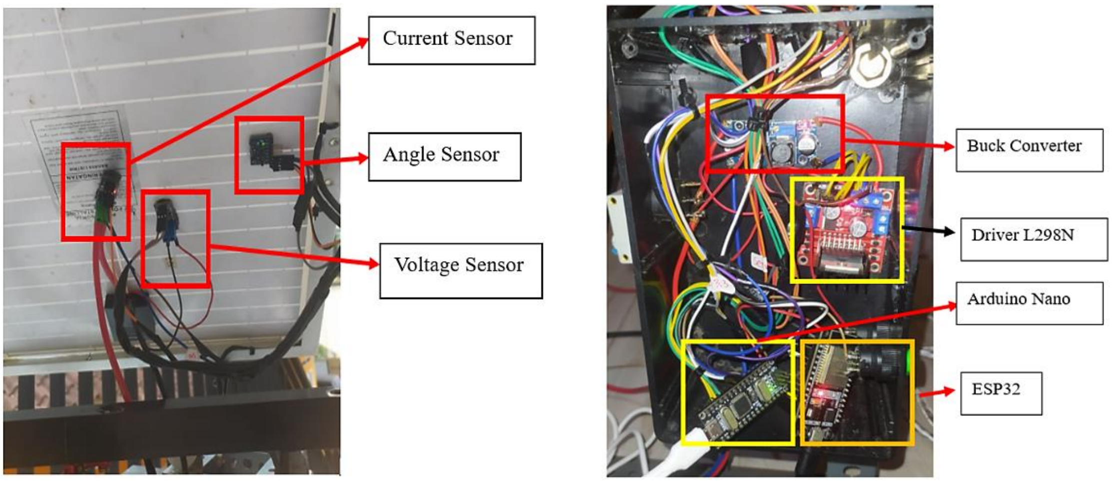


Figure 4. Prototype of (a) dual-axis solar tracker and (b) servo configuration



(a) (b)

Figure 5. Tracking system: (a) the installation of sensors and (b) the electronic components

Furthermore, the battery had a maximum voltage of 12.7 V and a maximum current of 5 A. Dual-axis tracking system used Arduino Nano and NodeMCU ESP32 as the central unit of solar tracker. The LDRs sensors were connected to the analog pins of the Arduino Nano, while the current, voltage, and angle sensors were connected to the analog pins of the NodeMCU ESP32. An input voltage of 3.3 V was given to the ACS712 and MPU6050 current sensors, while the voltage sensor was 5 V. To control the servo motor, an L298N motor driver attached to an Arduino Nano was used. In this study, the NodeMCU ESP32 also functioned to send all sensor data to website through the available WiFi.

The electronic circuit of the proposed tracking system is presented in Figure 6. The strategy for determining solar tracker movement to the east-west or rotation based on the light intensity received by the four LDR sensors is shown in the flow diagram in Figure 7. Apart from the flowchart, the strategy proposed was to be divided into four criteria to determine the movement of solar tracking system on the primary and secondary axes.

Photovoltaic cells stimulated electrons when photons hit solar cell, thereby producing an electric current when connected to a voltage source. The maximum power generated from solar panel could be calculated by measuring the voltage in open circuit conditions (VOC), current in short circuit conditions (ISC), and fill factor (FF) [12] and written in (3).

$$P_{out} = V_{oc} I_{sc} FF \qquad (3)$$

The increase in solar panel power (η) was determined by comparing the power produced by solar panels with and without Fresnel lens [43] and shown in (4).

$$\eta = \frac{P_2 - P_1}{P_1} x100\% \tag{4}$$

Where P_1 and P_2 are solar panel power produced and without Fresnel lens, respectively.

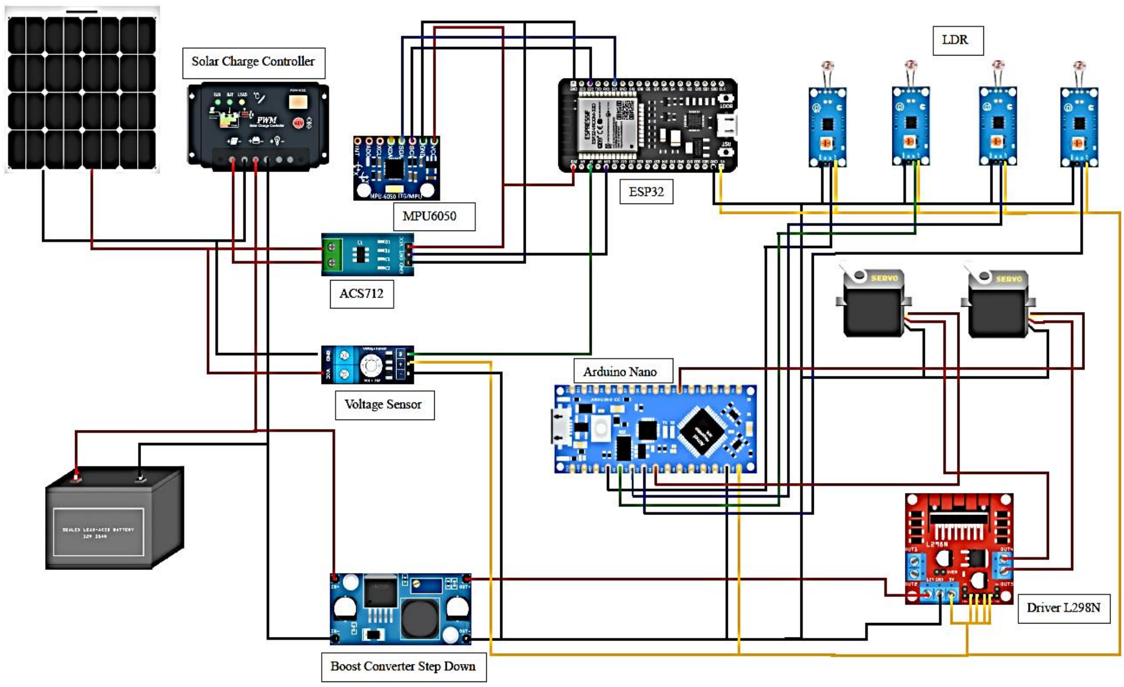


Figure 6. The overview of electronic circuit of the solar tracking system

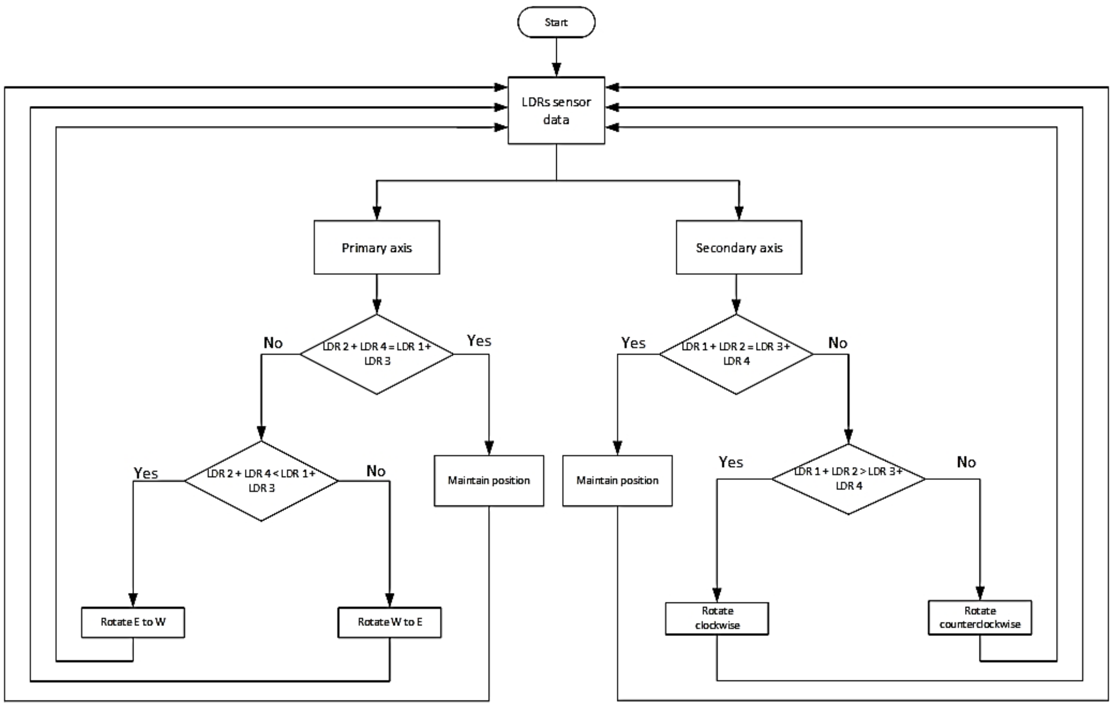


Figure 7. Flowchart of the proposed solar tracking strategy

3. RESULTS AND DISCUSSION

3.1. Effect of Fresnel lenses on the output power of solar panels

Solar tracker testing with and without Fresnel lens was conducted for five days every 30 minutes from 08.30 to 16.30. The experiment result without the device showed that the maximum output power ranged from 13.04 W to 13.60 W at the same temperature and time, namely 30.2 ºC and 13.30 local time as shown in Figure 8. Meanwhile, testing with Fresnel lens produced a higher maximum output power compared to the other variant, ranging from 15.32 W to 15.90 W at 13.30 with temperatures varying between 30.2 ºC to 33.6 ºC as illustrated in the graph in Figure 9.

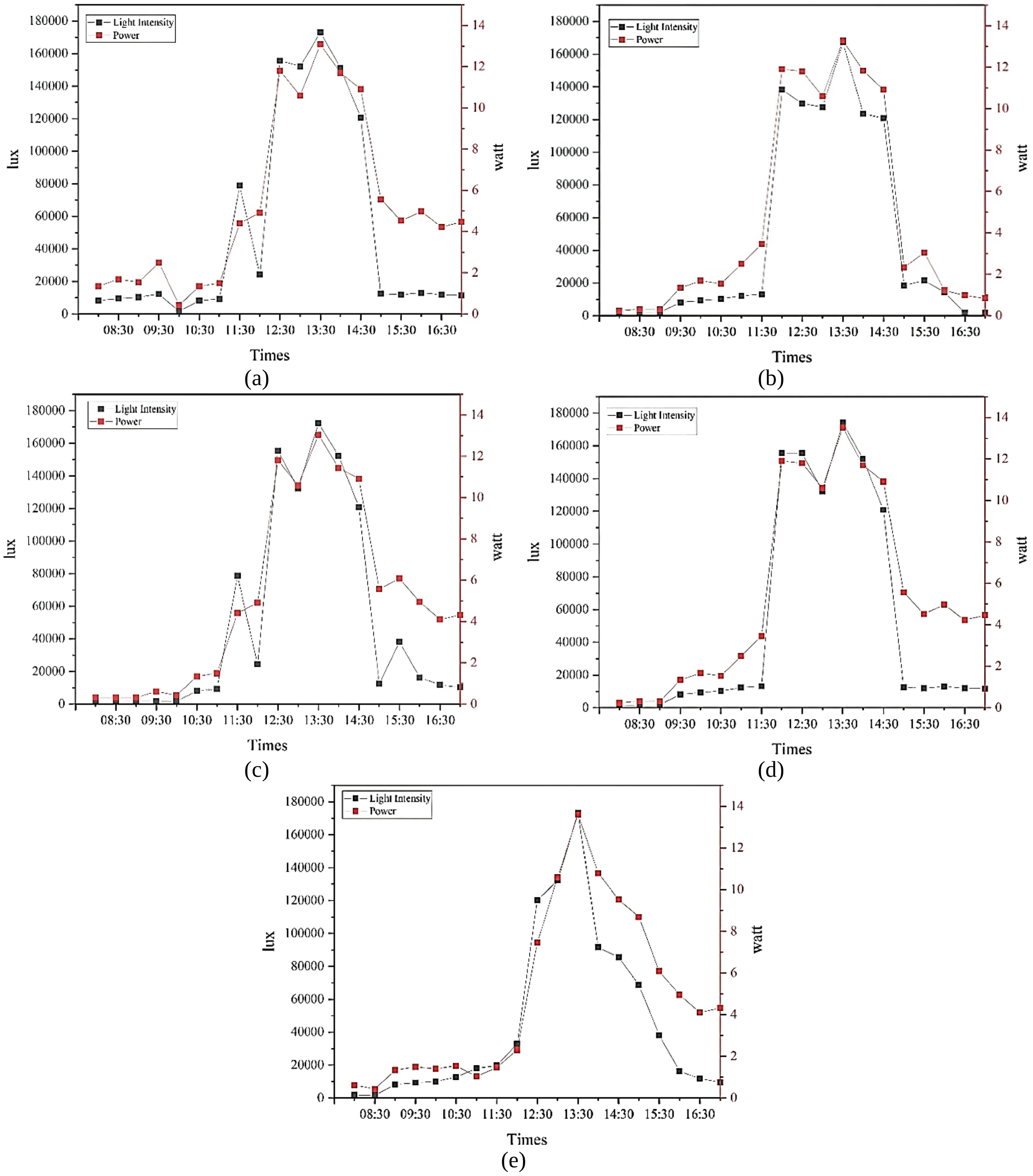


Figure 8. Maximum power of dual axis solar tracker without Fresnel lens, (a) day-1, (b) day-2, (c) day-3, (d) day-4, and (e) day-5

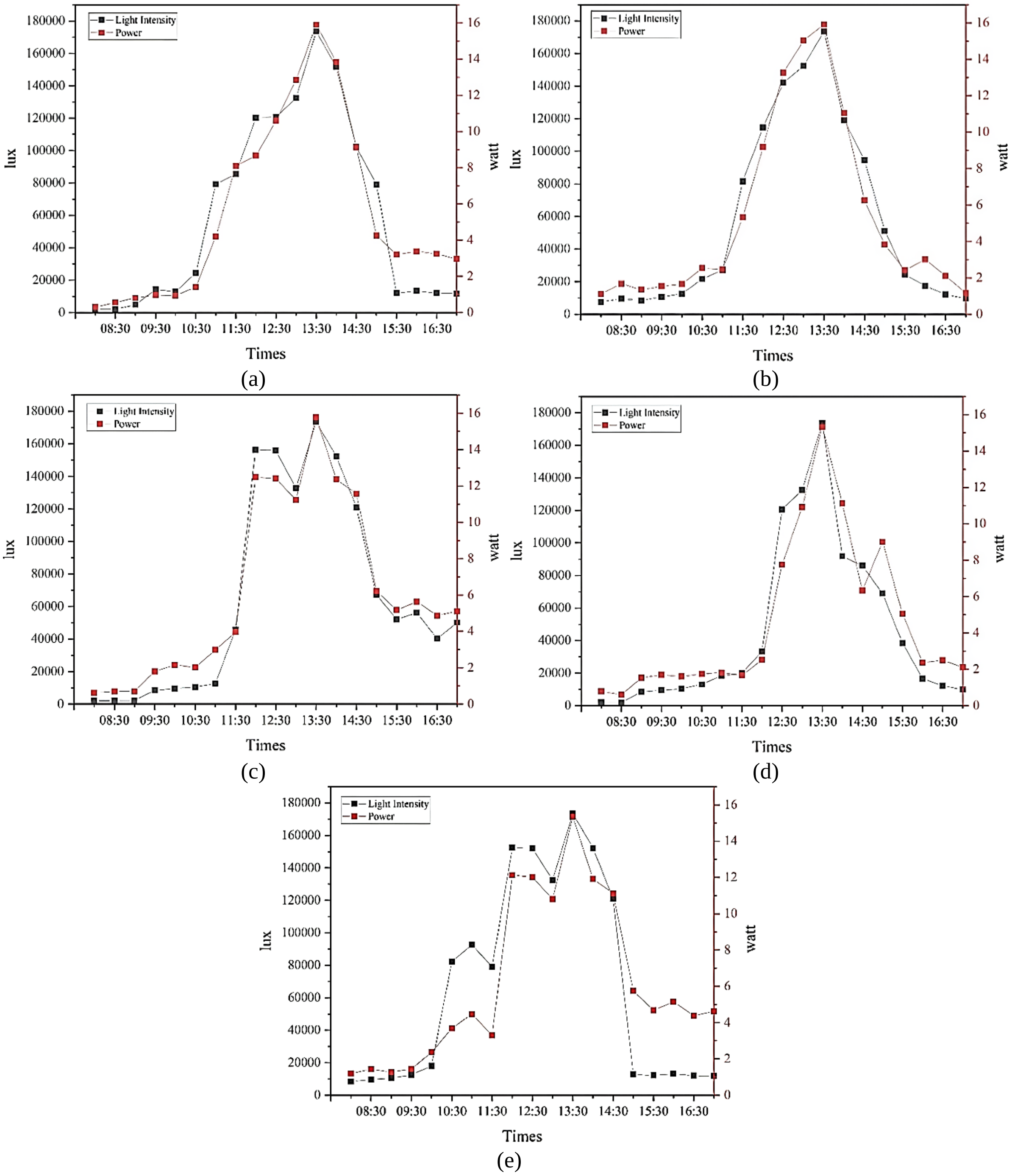


Figure 9. Maximum power of dual axis solar tracker with Fresnel lens, (a) day-1, (b) day-2, (c) day-3, (d) day-4, and (e) day-5

The maximum power of solar panel without Fresnel lens produced during testing was 13.60 W with solar intensity of 173,200 lx and an environmental temperature of approximately 30.2 ^{o}C. Meanwhile, the maximum power of solar panel with the device was obtained at 15.90 W with solar intensity of 173,178 lx and an environmental temperature of approximately 33.6 ^{o}C. Under the same conditions, when the sun's intensity was 173,200 lx, and the temperature was 30.2 ^{o}C at 13.30, the output power produced by solar panels with and without the device was 15.78 W and 13.60 W, respectively. These results proved that a tracking system with Fresnel lens could increase the output power by 16.03%. These results were consistent with [43] and [45] who obtained energy values of 5.67% and 16.64%, respectively. The results of monitoring current, voltage, power, and angle values from solar tracking system are showed on website in real-time, as shown in Figure 10.

3.2. Effect of tilt angel on the output power of solar panels

Based on the results of tests carried out in Bandar Lampung, Indonesia, the sun's movement throughout the day from east to west caused solar panels to move in two directions. In the morning, the devices moved from west to east with an angle ranging from 0° to –55°. Meanwhile, during the day, solar panels moved from east to west, with an angle range of 0° to 55°. The movement of the devices at a certain angle affected the resulting output power. During five days of observations, maximum power was obtained at an average angle of 28° for solar tracker without Fresnel lens and 27.2° with Fresnel lens which is displayed in Figures 11(a) and 11(b). The maximum power obtained by solar tracker was 13.60 W without Fresnel lens formed at an angle of 28°. Meanwhile, a value of 15.90 W was obtained by adding Fresnel lens at an angle of 23°. The two designs reached maximum power when solar panel moved from east to west. Other studies produced optimum solar PV energy in South-West Nigeria at 20° [46] and in Athi River, Kenya at an angle of 15° [47]. Different study locations also influenced the sun's position, which caused differences in the optimum angle obtained in solar tracker system.

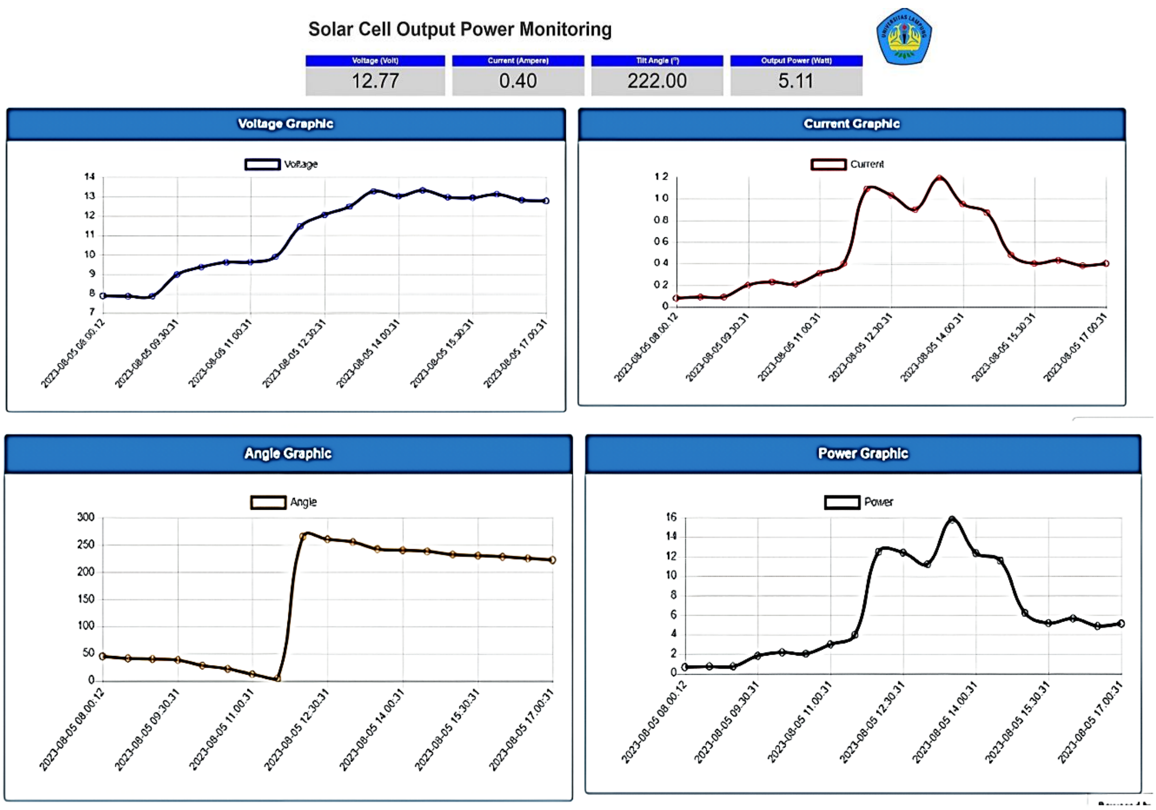
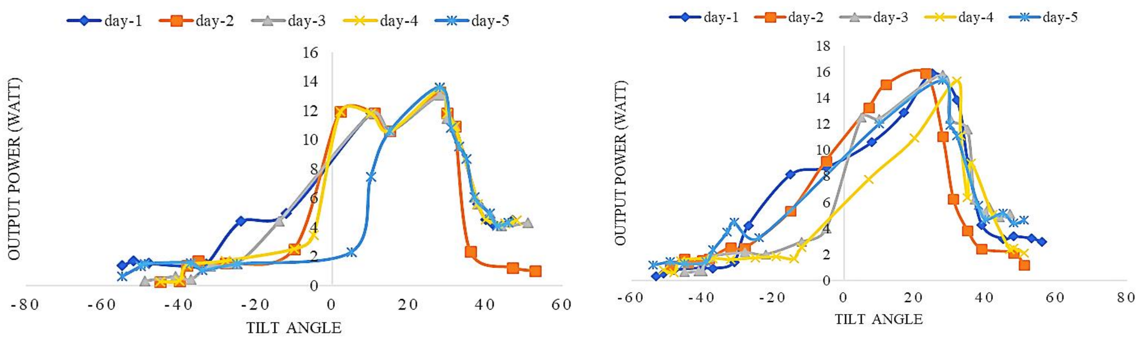


Figure 10. Monitoring system via website



(a) (b)

Figure 11. The effect of tilt angle on the output power of solar panels (a) without Fresnel lens and (b) with Fresnel lens

4. CONCLUSION

Dual-axis solar tracking system with Fresnel lens was applied to increase the output power of solar panels. The tracking system design was proposed to follow the sun trajectory using the digital logic design of LDR participation through the primary and secondary axes. The analytical results suggest that a dual-axis solar tracker that uses a Fresnel lens is preferable to one without. The output power with Fresnel lens increased by 16.03% compared to the experiment without Fresnel lens under the same conditions, namely when the sun's intensity was 173,200 lx, and the temperature was 30.2 ºC at 13.30. Meanwhile, the maximum power obtained using Fresnel lens was 15.90 W when solar tracker moved from E to W at an angle of 23º.

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BIOGRAPHIES OF AUTHORS

Humairoh Ratu Ayu is a lecturer in Physics Department at the Universitas Lampung, Bandar Lampung, Indonesia. She received her bachelor and magister degrees from Universitas Lampung and Universitas Diponegoro in 2012 and 2016, respectively. She is currently managing editor of the JTAF and JEMIT, she also joins instrumentation peer group. Her research interests include the field of embedded system, artificial intelligence, intelligent control, renewable energy, and internet of things. She can be contacted at email: humairoh.ratu@fmipa.unila.ac.id.

Rifki Mohamad Kurniawansyah is a physics graduate in 2023 at the Universitas Lampung, Bandar Lampung, Indonesia. He is also a member of the robotic club. His research interests include the field of mechatronics and intelligent control. He can be contacted at email: rifki.mohamad191011@students.unila.ac.id.

Amir Supriyanto is a senior lecturer in Physics Department at the Universitas Lampung since 1991. He is head of electronics laboratory. He was deputy Dean of Students and Alumni Affairs on 2019. His research interest includes the field of renewable energy, control system, and its application. He can be contacted at email: amir.supriyanto@fmipa.unila.ac.id.

Junaidi is a lecturer in Physics Department at the Universitas Lampung, Bandar Lampung, Indonesia since 2008. He received his bachelor, magister and doctoral degrees from Universitas Lampung and Universitas Gadjah Mada in 2006, 2012, and 2016, respectively. He has published more than 100 journal papers in the fields nanotechnology, nanowires, embedded system, and intelligent control. He is head of Phyiscs Master's Study Program at the Universitas Lampung and editor in chief of the JTAF. He can be contacted at email: junaidi.1982@fmipa.unila.ac.id.