The Active Hybrid Solar Panel integrated with Fresnel Lens Concentrator

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Abstract. Prototype of a hybrid solar panel equipped a Fresnel lens concentrator, and a solar tracking system has been developed. This hybrid solar panels is a combination of conventional solar cells and thermoelectric generators. Solar cells work to convert solar radiation, whereas thermoelectric generator converts solar heat into electrical energy. A Fresnel lens, a refractive lens type, is used as a solar concentrator, whereas the solar drive system uses solar azimuth data. This prototype is equipped by INA219 sensor as a measure of electric current and output voltage of solar panels. The temperature gauge uses a DS18B20 sensor, and the GY 49 MAX44009 light sensor is a light intensity detector. Solar panel drive uses MG995 servo motor and RTC module. All measured parameters are stored in the Secure Digital (SD Card) module. Through optimization, the obtained slope angle of the solar panel is 10°. Meanwhile, the optimized distance of the Fresnel lens to the solar panel is 0.2 F. The addition of Fresnel lens resulted increasing 23.83 % of the output power of hybrid solar panelin Rawamungun - East Jakarta area.

1. Introduction

Indonesia has abundant solar energy, suitable to be used as an alternative source of electricity that is environmentally friendly. The converting solar radiation into electrical energy requires a photovoltaic effect on solar panels. However, the length of solar radiation on solar panel causes an increase in the solar panel’s temperature, consequently the efficiency of solar panel decreases. The increase in solar panel’s temperature can be utilized as electrical energy using thermoelectric generator (TEG). TEG converts thermal energy into electrical energy so that the efficiency of solar panels also increases [1-2]. Another effort to produce greater solar panel output power by focusing solar radiation using Fresnel lens concentrators that the solar radiation's intensity increases (3-4). Plastic Fresnel lens has several advantages; there are small volume, clear, lightweight, stable polymers with optical characteristics that are close to glass materials, large production capacity, low cost, and effectively increase energy density.

This paper describes the development of hybrid solar panels, solar cell-thermoelectric generator, equipped by a Fresnel lens as a concentrator. The solar panel is completed with a solar drive system so that it can move actively following the sun’s position[5].

2. Methods

Hybrid solar panels consist of a polycrystalline solar panel size of 17cmx11cm, and SP1848-27145 Thermoelectric-generators (TEG). Fresnel lens, a type of refractive lens, is used as solar concentrators.
Whereas the solar drive system uses solar azimuth data. Three types of sensor are used as prototype output measuring devices, there are INA219 sensor, DS18B20 sensor, and MG-49 Sensor. The INA219 sensor functions to measure output current and voltage of solar panel, the DS18B20 sensor functions as a temperature gauge, and the MG-49 sensor functions as a solar radiation gauge. The microcontroller, as a control system, uses Arduino Uno R3, while the solar panel drive uses MG995 servo motor and RTC module. The Secure Digital (SD Card) module is used to store all measured parameters.

![Diagram of the system design](image1)

**Figure 1.** (a) The schematic system design (b) The solar panel holder and optimization of slope angle (c) The Prototype of hybrid solar panel without fresnel lens and completed by fresnel lens

The solar panel holder is made of acrylic material with a maximum length and width of 30 cm and 20 cm, respectively. The holder is adjustable according to the size of solar panel. At the bottom of solar panel, a TEG and heat sink are added, arranging them in series. TEG is intended to utilize the waste heat of solar panels during exposure to sunlight radiation into additional electrical charges.

The prototype movement uses an MG995 type servo motor, which can support a maximum torque load of 10 kg. The servo motor moves according to the horizon coordinate system, based on the solar azimuth database for one month. The used sample database is the average solar azimuth in July 2019 in South Tangerang and Rawamangun regions; there are 119.77° and 119.98°. This number is rounded to ≈ 120°.

This study’s procedures begin with optimization of slope angle, sensor’s characterization, optimization of fresnel lens distance, design of control system, and data acquisition. The characterization’s results of INA219 sensor, DS18B20 sensor, and SP1848-27145 TEG have been presented in a previous paper [2]. The schematic design and developed prototype of hybrid solar panel are shown in Figure 1.

3. Results and Discussions
This following are presented the results of slope angle optimization, the MG-49 sensor's characterization, optimization of Fresnel lens distance, and the measurement of device output.
3.1. **Optimization of the solar panel's slope angle**

The slope angle ($\theta$) optimization of solar panels uses angular variations of 10°, 15°, 20°, and 25° to the negative x-axis, according to schematic in Figure 1b. Data is collected by measuring the output of static solar panel, both voltage, and current. Data acquisition was done three times, from 09.00 to 15.00 o'clock in 60 minutes interval. The average measurement results can be seen in Figure 2.

![Figure 2. Graph of the solar panel's slope angle optimization](image)

Figure 2 shows the maximum solar panel power of 635.23 mW, obtained at a angle of 10°. Thus, this angle is used as the slope angle of solar panel. This result is in accordance with the previous research [6].

3.2. **Optimization of distance of Fresnel lens to the solar panel**

The Fresnel lens used in this prototype has not known yet its focus distance (F), that it is necessary to measure it. Because a Fresnel lens is a convex lens, a sample, brown paper, was placed at a certain distance from the lens until the paper burns. Then the distance is considered as the focal point of the lens. The measurement results show that the lens focus distance is 29 cm. Figure 3a shows the difference of light focused by Fresnel lenses in the varying distances.

![Figure 3. (a) the difference of light focused by Fresnel lenses(b) Graph of Fresnel lens distance to the solar panel](image)

The next step is optimization of Fresnel lens distance to the surface of solar panel, by measuring output power of solar panel at distance variations of 0.2 F, 0.4F, 0.6F, 0.8F and F [3]. This measurement results describe in Fig. 3b. Based on Fig 3, the solar panel has a maximum output power
of 574.73 mW at a distance of 0.2 F. At that distance, the light produced can hit the entire surface of the solar panel compared to other positions.

3.3. Characterization of MG-49 sensor
Sensor characterization is carried out to determine sensitivity and accuracy of MG-49 sensor. The light source is a lamp fitted a dimmer that its intensity can be controlled. The sensor measurement results of light intensity are then compared with the output luxmeter. The results of MG-49 light sensor characterization is illustrated in Fig. 4a.

![Graph showing characterization of MG-49 sensor](image)

Figure 4. Characterization of MG-49 sensor

It appears that the graph is linear. The relationship between sensor output and luxmeter is described in equation (1), and has slope of 1.0118.

\[ y = 1.0118x + 6.0559 \]  

(1)

Which x is the actual voltage (lux) measured by luxmeter, and y is the output of MG-49 sensor (lux). The average relative error of measurement is 6.68%. These results indicate that the sensor accuracy is quite high and precisely used to measure the intensity of solar radiation.

3.4. Output of active hybrid solar panel
Data output acquisition of active hybrid solar panel equipped Fresnel lens was conducted at 10.00-14.00 in 15-minute intervals for two consecutive days, on rooftop of HasyimAsjarie Building in Rawamangun, East Jakarta. Physical parameters measured are current, voltage, temperature, and solar radiation intensity of the solar panel using characterized sensors. The same measurement was made on hybrid solar panel without Fresnel lens as a comparison data. The measurement result of hybrid solar panel integrated Fresnel lens for two days are depicted in Fig 5a.
Figure 5a shows that the largest output power, 1902.28 mW, occurred at 12:45 WIB on the first day. The weather condition was sunny, and the light intensity was 83728.36 lux. The top and bottom surfaces of solar panels have temperature of 40.25° and 36.06°, respectively. There are differences in both curves' pattern at 11.00-12.00 due to weather condition. The weather was cloudy, and the wind blows quite strong on the first day. It has an average light intensity of 4.5% lower than the second day.

The power's increasing due to Fresnel lens is depicted in Fig 5b. Figure 5b describes output power difference of hybrid solar panels with Fresnel lens and without Fresnel lens on the second day. It appears that the pattern of both curves is the same, the maximum light intensity of 79626.89 occurs at 12:30, but the maximum power value is different. Fresnel lens is proven to increase the output power of 23.8%.

4. Conclusions
Through optimization, the slope angle of solar panel equals to 10°, and the distance of Fresnel lens to the solar panel is 0.2 F, with F equals to 19 cm that is focal distance of Fresnel lens. The use of Fresnel lens on hybrid solar panels resulted an increase in output power of 23.83% in Rawamangun, East Jakarta.

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