Fresnel lenses and auto tracking to increase solar panel output power

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ABSTRACT

This solar panel, which is equipped with microcontroller-based auto-tracking, is also equipped with a Fresnel lens to obtain more optimal power because the Fresnel lens has the property of bending or refracting light rays that pass through it so that it can focus sunlight. The Fresnel lens focuses sunlight radiation onto the solar panels. To determine the magnitude of the influence of Fresnel lenses on increasing the power produced by solar panels, two solar panels of the same size (11 cm × 11 cm) were moved by auto-tracking using the same axis. One solar panel is not fitted with a Fresnel lens, and the other is fitted with a Fresnel lens measuring 30 cm × 30 cm, where the distance between the Fresnel lens and the solar panel is 5 cm. Measurements of the output power of both solar panels were carried out simultaneously, namely from 08.00 to 18.00 West Indonesia Time (WIB). The power output of both solar panels was measured in 30-minute intervals, resulting in 21 measurements. Solar panels using Fresnel lenses produce an output power that is 105.306% more significant than that of those without Fresnel lenses.

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1. INTRODUCTION

The output power of solar panels depends on the solar radiation received by the solar panels. The more solar radiation a solar panel receives, the more power it produces, and conversely, the less solar radiation a solar panel receives, the less power it can produce. To ensure maximum power produced by solar panels, the position of the panels must always be perpendicular to the direction of sunlight. Therefore, a system was created so that the solar panels always follow the direction of the sun's movement automatically. This system is based on a microcontroller that moves the solar panels automatically following the direction of sunlight. Jumaat *et al.* [1] uses 5 light dependent resistor (LDRs) as light sensors for single-axis auto tracking solar panels. Arif *et al.* [2] use 3 LDRs as light sensors for auto-tracking solar panels so that they move vertically and horizontally following the movement of the sun's rays according to the strength of the light received by the LDRs. The auto-tracking designed and created in [2] uses four LDR light sensors that move the solar panels from east to west or vice versa, and also from north to south and vice versa, so that this auto-tracking is in the form of a double axis.

Another way to maximize the power produced by solar panels is to use Fresnel lenses, which can focus sunlight radiation onto the solar panels. Research conducted by Sheikholeslami *et al.* [3] uses a Fresnel lens to focus sunlight onto solar panels without additional automatic tracking. In the paper by Mohaimin *et al.* [4], the distance between the Fresnel lens and the solar panel can cause a decrease in the output voltage of the solar panel. The other research method was carried out by Muladi *et al.* [5] only uses one solar panel; the Fresnel lens is installed on top of the solar panel. In this paper, dual-axis auto tracking and a Fresnel lens were used to obtain maximum results by adjusting the distance of the Fresnel lens to the solar panel so that the entire surface of the solar panel is exposed to solar radiation originating from the refraction of sunlight through the Fresnel lens.

2. METHOD

The research was carried out in this research is seen in Figure 1. This system design concept is carried out where two polycrystalline solar panels are the same size (11 cm × 11 cm) with a power of 2 WP (16 volts, 0.125 ampere) placed side by side on one axis. These two solar panels move on their axis through two driving poles, which follow the direction of the sun's rays perpendicularly. This movement is called auto-tracking. A Fresnel lens measuring 30 cm × 30 cm is installed on top of the first solar panel, while the Fresnel lens is not installed on the second. Measurements of the input and output power produced by the two solar panels were carried out in one day, namely 08.00 to 18.00 West Indonesia Time (WIB), with measurements every 30 minutes. By comparing the output power produced by these two solar panels, it is possible to assess the efficiency level resulting from using Fresnel lenses.

2.1. Movement of solar panels

Two bipolar stepper motors drive the solar panels via a microcontroller, where the movement of the panels is based on the direction of sunlight (auto-tracking) [6]. Four LDRs are used to determine the direction of movement of the solar panels, where 2 LDRs (LDR-1 and LDR-2) are used as sensors to move the panels east-west. The other 2 LDRs (LDR-3 and LDR-4) are sensors. To orient the solar panels in a north-south direction. Figure 2 is a block diagram of the solar panel auto-tracking created. The work of the auto-tracking system is depicted in Figure 3.

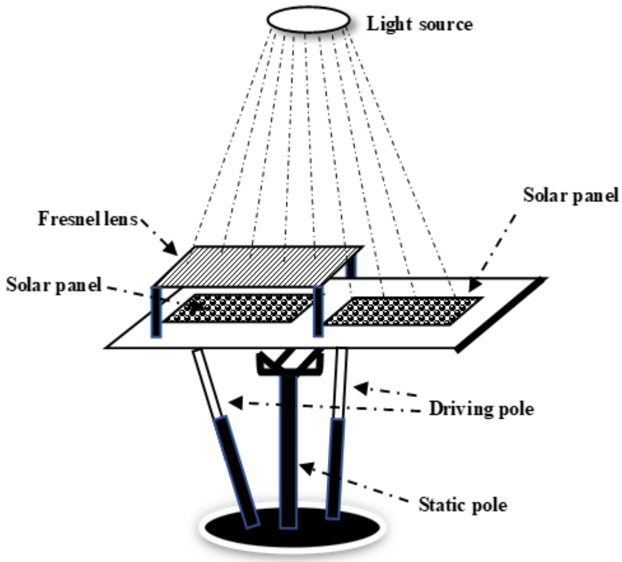

Figure 1. Concept of system design

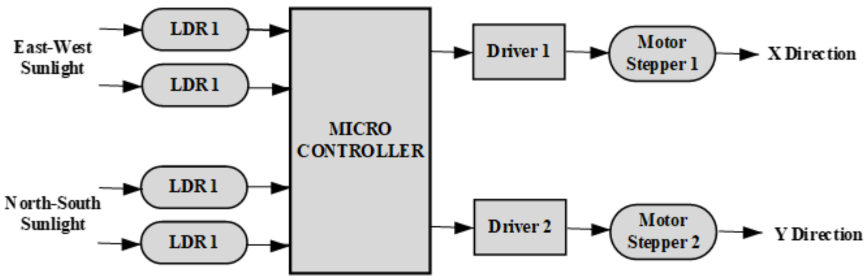

Figure 2. Block diagram of auto tracking

The LDR-1 and LDR-2 sensors receive light from sunlight and provide information on the intensity of the light received by each LDR 1 and LDR 2 to the microcontroller. The microcontroller continuously moves the solar panel towards east and west until the light strength received by LDR-1 and LDR-2 is the same. In this position, the solar panels are perpendicular to the direction of the sun's rays in the east and west directions. Once achieved, the system will perform the same action for LDR-3 and LDR-4. The microcontroller will receive a substantial amount of light from the LDR-3 sensor and LDR-4 sensor. Then, the microcontroller moves the solar panel north and south continuously until the sensor receives the light strength. LDR-3 and LDR-4 are the same size, which means that the slope of the north-south side of the solar panel is perpendicular to the direction of the sun's rays [7]–[15]. Once the east-west and north-south conditions are the same, the system will stop for 45 minutes, then re-read the four sensors and do the same thing again to detect the same amount of light received by LDRs -1, 2, 3, and 4. Tracking in this way lasts until 18.00 WIB, then stops, and the microcontroller moves the solar panel back to its initial position towards the east side.

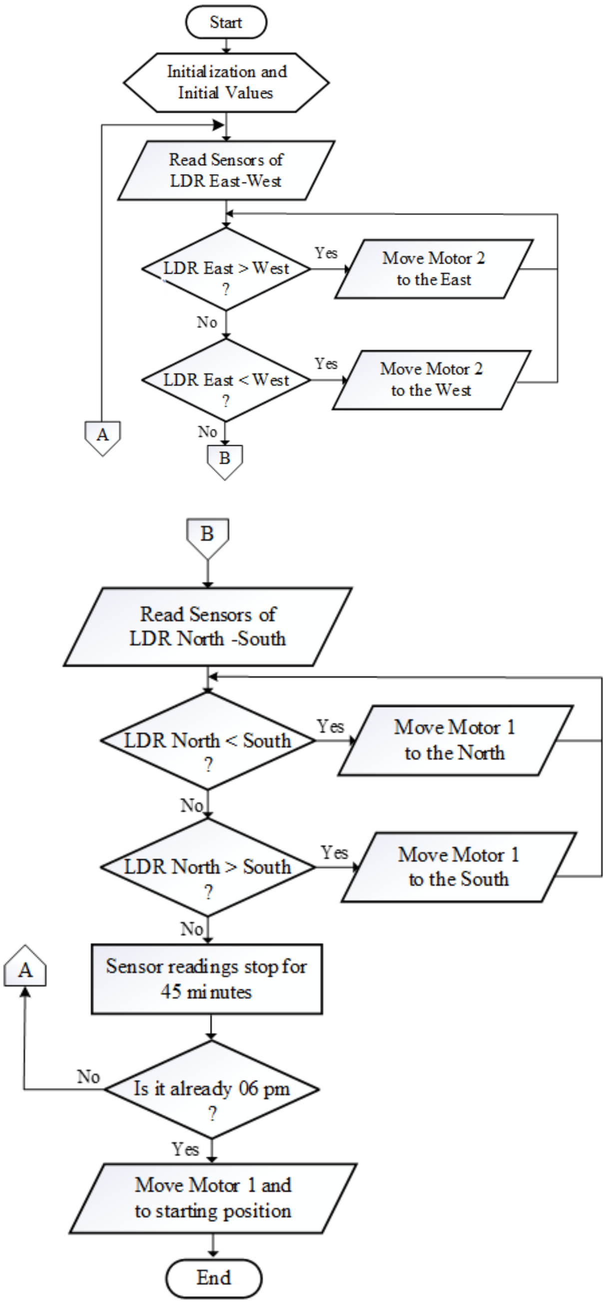

Figure 3. Flowchart of auto tracking

2.2. Determining the distance of the Fresnel lens to the solar panel

Figure 4 shows the Fresnel lens layout placed on a solar panel at a distance of 5 cm above the solar panel. The power produced by the solar panel was measured at a distance of 4, 5, 6, 7, and 8 cm from the Fresnel lens. Table 1 shows the results of measuring the power produced by solar panels at these distances. The maximum power produced by solar panels is obtained at a distance of 5 cm from the solar panels, namely 1.31219 Watts with a voltage of 16.6 Volts; this occurs because at this distance, the entire surface of the solar panels is exposed to sunlight.

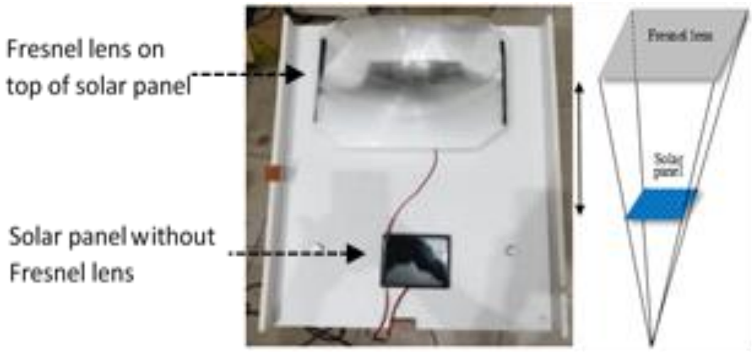

Figure 4. Position the Fresnel lens above the solar panel

Table 1. Power measurement results at various distances

Fresnel lens distance (cm)	Voltage (V)	Power (W)
4	14.3	0.973762
5	16.6	1.312190
6	10.3	0.505190
7	8.2	0.320190
8	6.3	0.189000

2.3. Measurement stages

Measurements are made on several quantities that affect the power produced by solar panels. Measurements are carried out in the following stages:

- Measurement of the strength of light received by a solar panel without a Fresnel lens and with a Fresnel lens.
- Calculate the solar panel's input power (Pin) without a Fresnel lens and with a Fresnel lens.
- Measurement of the voltage and current produced by a solar panel without a Fresnel lens and a Fresnel lens with a 100 ohm or 5-watt resistor load.
- Calculate the output power (Pout) of the solar panel without a Fresnel lens and with a Fresnel lens.

2.4. Measurement pattern

Figure 5 shows a block diagram of the input and output power measurement pattern for both solar panels, both for solar panels installed with Fresnel lenses and solar panels without Fresnel lenses. The flowchart in Figure 6 shows that this power measurement was carried out 21 times in 1 day, starting from 08.00 to 18.00 WIB, with a period of every 30 minutes. This is done by measuring the current and voltage output from the two solar panels. The solar panel output power amount is obtained by multiplying the current and voltage for each measurement.

2.5. Determining results

The solar panel output power obtained without a Fresnel lens is compared with the output power obtained from a solar panel with a Fresnel lens installed. To obtain objective results, the same load is installed on the output of both solar panels. From the results of this comparison, the solar panel that produces greater output power is the best model [16]–[27].

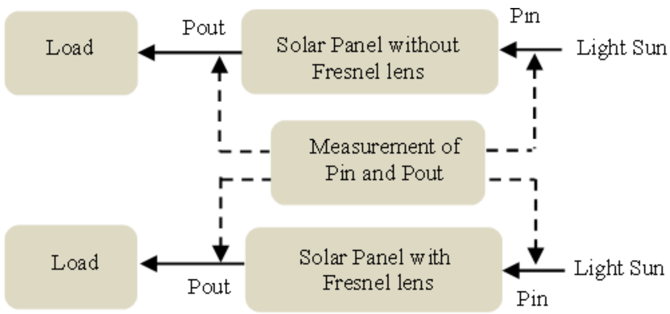

Figure 5. Block diagram of measurement pattern

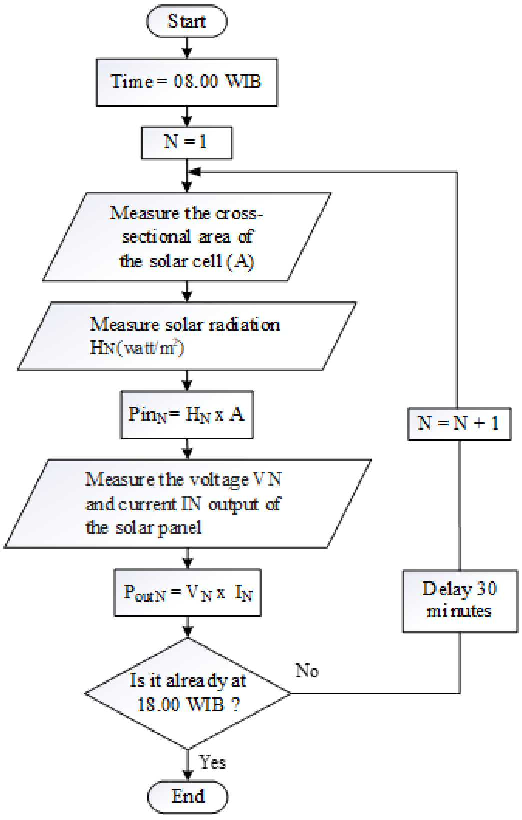

Figure 6. Flowchart diagram of solar panel output power measurement patterns

3. RESULT AND DISCUSSION

Figure 7 shows the overall system circuit as a double-axis auto-track solar panel system control circuit. As the central controller, the microcontroller controls the movement of the two solar panels simultaneously so that the solar panels are always in a perpendicular position to the direction of sunlight. This is done based on input from four LDRs, sensors for detecting sunlight intensity. Based on input from these 4 LDRs, the microcontroller drives the two solar panels via two driving poles driven by two stepper motors. The solar panel output power obtained without a Fresnel lens is compared with the output power obtained from a solar panel with a Fresnel lens installed. Greater output power at the same load in both measurement models is best. Figure 8 is the physical form of the device that has been designed, where the microcontroller continuously adjusts the direction of the solar panel until all LDR sensors provide the same output voltage value. In this condition, it is ensured that the direction of the solar panel faces the direction of the sunlight perpendicularly.

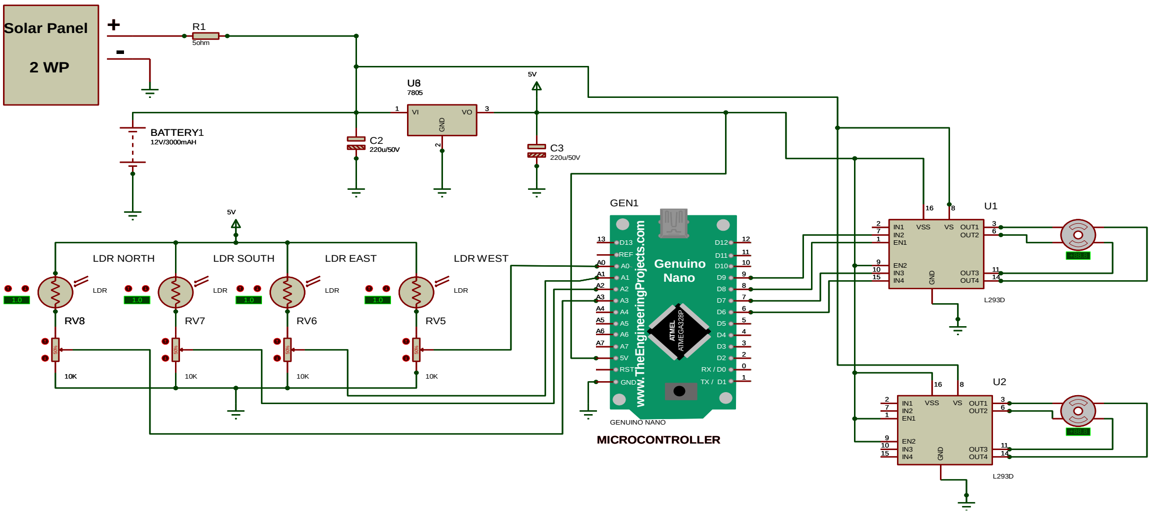

Figure 7. Circuit of overall system

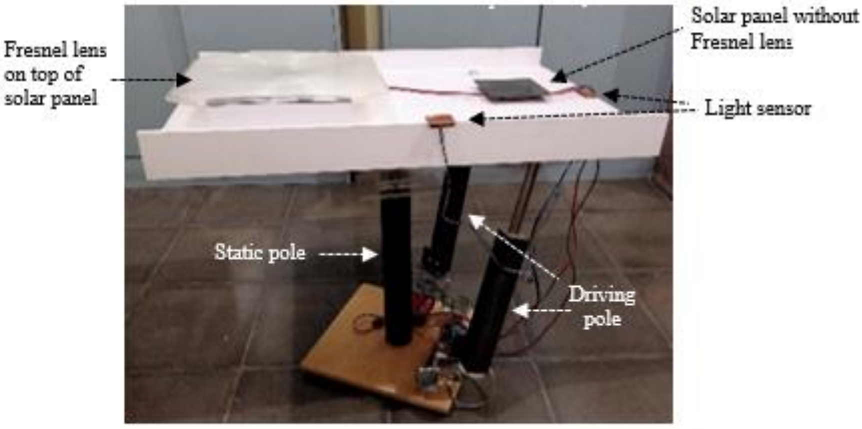

Figure 8. Designed tools for research

The amount of solar radiation received by the two solar panels during the measurement time (21 measurements) starting at 08.00 WIB until 18.00 WIB is shown in Table 2, where the highest intensity of sunlight received by the two solar panels occurred at 13.00 WIB, namely 1,089.33 watt/m^2 received by solar panels without Fresnel lenses and 1.633.995 watt/m^2 received by solar panels equipped with Fresnel lenses. From the 21 measurements that were carried out, the difference in the intensity of sunlight between the two solar panels was obtained. The average percentage difference during 21 measurements was 52.042%; the intensity of sunlight received by solar panels equipped with Fresnel lenses was more significant than that received by solar panels without Fresnel lenses.

Table 2 can be depicted in graphical form as in Figure 9. The yellow graphic is the amount of solar radiation produced by solar panels with Fresnel lenses. In contrast, the blue graphic line is the amount of solar radiation produced by solar panels without Fresnel lenses. In each measurement 21 times, the amount of solar radiation produced by a solar panel with a Fresnel lens is more significant than that produced by a solar panel without a Fresnel lens. The greater the intensity of sunlight, especially during the day, the greater the solar radiation produced.

From the results of input power measurements on the two solar panels shown in Table 3, solar panels equipped with Fresnel lenses receive an average of 52.042% greater solar radiation than those without Fresnel lenses. The largest input power obtained by the two solar panels occurs when the sun is perpendicularly above the solar panel at around 13.00 WIB, the most significant input power on the solar panel equipped with a Fresnel lens is 1.225823 watts, and the most significant input power on the solar panel without a Fresnel lens of 2.461532 watts. The average percentage difference in the input power of a solar panel with a Fresnel lens compared to that of a solar panel without a Fresnel lens is 102.937%. The size of the solar radiation determines the amount of input power (Pin) from the solar panel. The greater the solar radiation, the greater the input power of the solar panel. Table 3 in graphic form is shown in Figure 10. In all measurements carried out (21 measurements), it can be seen that the input power of solar panels with Fresnel lenses (yellow line) is greater than the input power of solar panels without Fresnel lenses (blue line).

Table 2. Amount of light radiation on solar panels

Time	Light radiation (W/m^2)		Difference
(WIB)	without lens	with lens	(%)
08.00	543.3	573.9	5.63225
08.30	577.4	866.1	50
09.00	632.2	948.3	50
09.30	365.6	548.4	50
10.00	765.8	1148.7	50
10.30	856.7	1285.05	50
11.00	297.7	446.55	50
11.30	954.8	1432.2	50
12.00	978.4	1467.6	50
12.30	396.7	595.05	50
13.00	1089.33	1633.995	50
13.30	965.5	1448.25	50
14.00	478.5	717.75	50
14.30	874.3	1311.45	50
15.00	636.6	954.9	50
15.30	446.8	670.2	50
16.00	568.7	853.05	50
16.30	467.8	701.7	50
17.00	654.6	981.9	50
17.30	567.5	851.25	50
18.00	343.5	814.95	137.249
		Everage	52.042

Table 3. Input power of solar panel

Time	Pin (watt)		Difference
(WIB)	without lens	with lens	(%)
08.00	0.66764	0.864627	29.50497
08.30	0.649748	1.304736	100.8065
09.00	0.711415	1.428567	100.8064
09.30	0.41141	0.826137	100.8063
10.00	0.861755	1.730459	100.8064
10.30	0.964045	1.935864	100.8064
11.00	0.335002	0.672705	100.8063
11.30	1.074436	2.157538	100.8066
12.00	1.100994	2.210866	100.8064
12.30	0.446407	0.896413	100.8062
13.00	1.225823	2.461532	100.8065
13.30	1.086477	2.181716	100.8065
14.00	0.538456	1.081254	100.8064
14.30	0.98385	1.975634	100.8064
15.00	0.716366	1.438509	100.8064
15.30	0.502784	1.009623	100.8065
16.00	0.639958	1.285077	100.8065
16.30	0.526415	1.057076	100.8066
17.00	0.736621	1.479183	100.8065
17.30	0.638608	1.282366	100.8064
18.00	0.386541	1.227681	217.6069
		Everage	102.973

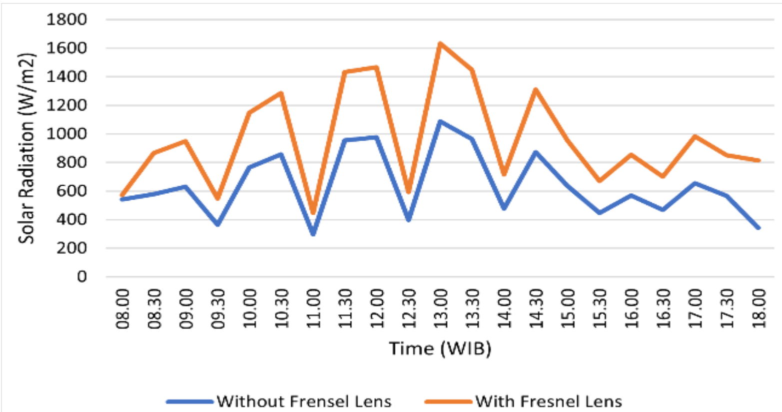

Figure 9. Solar radiation without and with a Fresnel lens

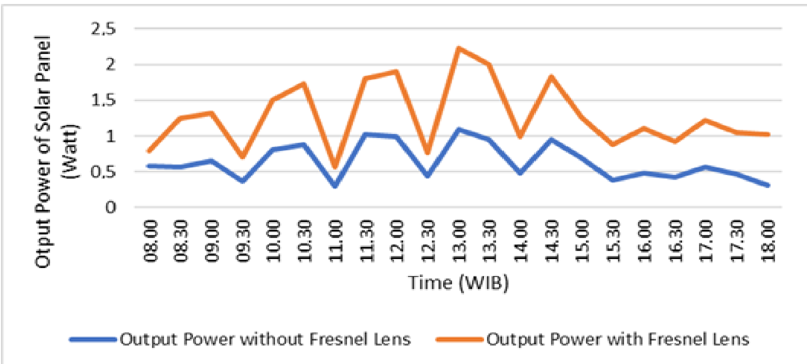

Figure 10. Graph of solar panel input power

Table 4 is the result of measuring the output power produced by the two solar panels. This output power is obtained due to the input power received by the solar panel see in Table 3. Likewise, in the results of measuring the solar panel input power, the most significant solar panel output power occurs when the sun is perpendicular to the solar panel, namely at 13.00 WIB. where at that time, the output power produced by solar panels with Fresnel lenses was 2.221714 watts and the output power produced by solar panels without Fresnel lenses was 1.085762 watts. The total power produced by a solar panel without a Fresnel lens for 10 hours is 13.3665 watts, so the amount of energy produced is 133.665 watt-hours (Wh). The total power produced by a solar panel equipped with a Fresnel lens for 10 hours is 26.8396 watts, so the energy produced is 268.396 Wh. Thus, the increase in energy produced by solar panels equipped with Fresnel lenses is 100.797% or 134,730 Wh. The average percentage difference in output power of solar panels installed with Fresnel lenses compared to those without Fresnel lenses is 105.306%. Table 4 in graphic form is shown in Figure 11, where the yellow line is the output power of a solar panel equipped with a Fresnel lens, and the blue line is the output power of a solar panel without a Fresnel lens. A significant difference occurred at 13.30 WIB. At that time, there was a difference of 110.9706 % between solar panels equipped with Fresnel lenses and solar panels without Fresnel lenses.

Table 4. Output power of solar panel

Time (WIB)	Pout (watt) without lens	Pout (watt) with lens	Difference (%)
08.00	0.574097	0.792429	38.03051
08.30	0.568880	1.248172	119.4087
09.00	0.645189	1.312190	103.3807
09.30	0.360429	0.708762	96.64400
10.00	0.812208	1.508762	85.76054
10.30	0.880762	1.726293	95.99994
11.00	0.297190	0.565762	90.37047
11.30	1.015048	1.807002	78.02133
12.00	0.987429	1.908573	93.28711
12.30	0.438857	0.765630	74.46002
13.00	1.085762	2.221714	104.6226
13.30	0.946714	1.997288	110.97060
14.00	0.474288	0.987429	108.19190
14.30	0.944030	1.836808	94.57094
15.00	0.690293	1.262088	82.83367
15.30	0.385714	0.880762	128.34590
16.00	0.485762	1.103088	127.08400
16.30	0.417189	0.920048	120.53510
17.00	0.567840	1.216002	114.14520
17.30	0.473338	1.055772	123.04820
18.00	0.315522	1.015048	221.70440
Total	13.36650	26.839600	
		Everage	105.30600

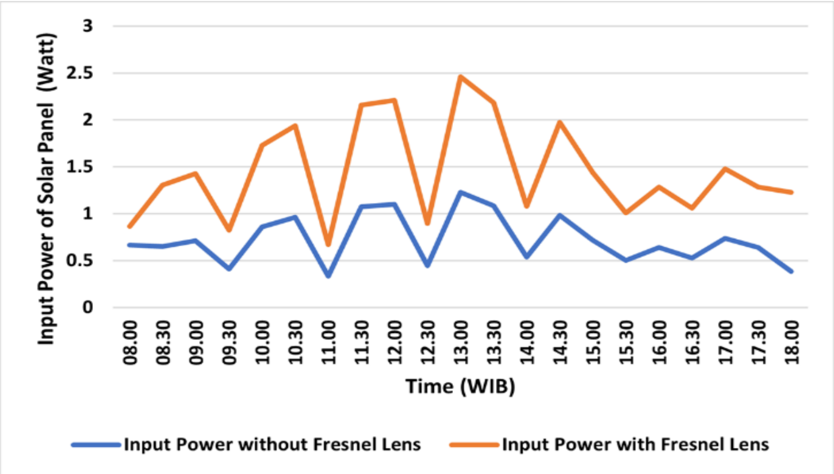

Figure 11. Output power of solar panel

4. CONCLUSION

This study optimized outcomes through the implementation of dual-axis auto-tracking, which involved altering the Fresnel lens's distance from the solar panel. Two 2 WP polycrystalline solar panels were positioned adjacent to one another along an axis and were manipulated perpendicularly by means of two driving poles. The initial panel was equipped with a Fresnel lens, whereas the subsequent panel lacked one. Daily input and output power measurements were conducted in order to evaluate the efficiency of the Fresnel lenses. The tests showed that a solar panel measuring 11 cm by 11 cm with auto-tracking and 2 degrees of freedom, along with a Fresnel lens measuring 30 cm by 30 cm (1:8) and placed 5 cm away, can add 105.306% more power and 100.797% more energy, for a total of 134,730 Wh. This is for a 2 WP solar panel.

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