Solar Cell Output Optimization using Light Convergence Method

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Abstract. Light intensity is one of the many factors that can influence the power output of a solar cell. In this research, light convergence method is performed by using a Fresnel lens to increase the light intensity that are passes through the solar cells. 2 solar cells are used for this research. One of them is paired with a Fresnel lens positioned perpendicularly at a distance of 5cm. The output from both solar cells are then compared. The solar cell paired with the Fresnel lens contains a higher power output by up to 40.29% at 13.10 o’clock in the afternoon compared to a normal solar cell. However therein lies a decrease in power output at 10.00 – 10.30 o’clock and 13.30 – 14.00 o’clock by up to -30.65% because shadows from the Fresnel lens relative to the sun’s position affects the light intensity a solar cell receives. Results from 3 days’ worth of tests shows that at 10.00 – 14.00 o’clock, the solar cell paired with a Fresnel lens retain a higher average power output of around 6.08% compared to a solar cell without one.

1. Introduction
Solar energy is the ultimate source of nearly all the different types of energy on Earth. It is unique in that it can be directly converted to electric power upon contact with certain materials commonly referred to as solar cells. There are a few factors that affect the power output of a solar cell namely temperature, materials, light intensity, and etc [1]. Because of these factors, solar cells’ have a low efficiency that ranges only from 7.1% to 46%.

The purpose of this research is to optimize the power output of solar cells based on one of the affecting factors, specifically, light intensity. A higher amount of light intensity a solar cell receives results in a higher power output [3-4]. The method used in this research is the light convergence method. A method that concentrates light to a point in a solar cell using mirrors or lenses [5]. The resulting lights will be concentrated on the solar cell, increasing the light intensity that passes through the solar cells, which in turn improves the power output.

In other researches, the media that are used for light convergence includes reflectors and convex lenses. The usage of a reflector for converging light can increase the power output of solar panels as high as 25% when installed perpendicularly to the solar cell [6]. Whilst the use of 30 convex lenses with a distance of 15cm from the solar cells can also increase the output of a solar cell as high as 26.67% [7].

In this research, Fresnel lens will be used as the media for light convergence because a Fresnel lens is relatively smaller in surface area compared to a reflector or a convex lens and can be purchased for a lower price.

2. System Design
2.1. Hardware Design
This research makes use of 2 solar cells with the same specifications. One of the solar cells will be paired with a Fresnel lens that can converge light into the solar cell.
The use of a Fresnel lens that has a larger surface area than the solar cell ensures the amount of light that the solar cell receives will also increase in accordance with the surface area of the Fresnel lens. The more substantial the light intensity will result in higher power output from the solar cell in accordance with the following equation.

\[
V_{oc} = \frac{n k T}{q} \ln \left( \frac{X I_{sc}}{I_o} \right)
\]  

Where
- \(V_{oc}\) = Open Circuit Voltage (Solar cell voltage when I = 0)
- \(n k T/q\) = Thermal voltage (Equation of voltage towards temperature (0.02586V when 26.85 Celsius))
- \(X\) = Light Intensity (1kW/m²)
- \(I_{sc}\) = Short Circuit Current (Solar cell current when V = 0)
- \(I_o\) = Solar Cell Current in Dark Conditions

2.2. Method of Finding Light Convergence Point
Because the distance between the Fresnel lens and solar cell directly impacts the light convergence. A test is required to find the best light converging point. The pursuit of the convergence point is done by adjusting the distance between the Fresnel lens and solar cells at the time when the sun is at its peak, then specify which distance the Fresnel lens converges light optimally so that the resulting output of the solar cell is also maximized.

3. Results and Discussions
3.1. Test Results of Finding Light Converging Point
The testing of convergence is done to find the best distance between the Fresnel lens and solar cells, in which to maximize the value of the solar cell’s power output.

Testing is done at 11:44 – 12:04 o’clock because those are the times when the position of the sun is at its peak. The data for timing is obtained from the website https://www.suncalc.org, a website that calculates the position of the sun.
Testing is done by adjusting the distance between the Fresnel lens and the solar cell, from 1cm until 10cm. The voltage and current output are calculated for every centimetre of difference. Results from the tests can be seen from the following Figure 3.

![Figure 2. Sun’s Positional Data from Date of Testing](image1)

![Figure 3. Data Showing Results of Light Convergence Point Testing](image2)

**Table 1. Results of Light Convergence Point Testing**

| Distance Between Fresnel Lens and Solar Cells (cm) | Voltage (Voltage) | Current (Ampere) | Electrical Power (Watt) |
|--------------------------------------------------|------------------|------------------|------------------------|
| 1cm                                              | 6.2              | 0.066            | 0.4092                 |
| 2cm                                              | 5.891            | 0.073            | 0.43004                |
| 3cm                                              | 5.665            | 0.079            | 0.44754                |
From the result of Table 1, it can be seen that the highest output is 0.5006 watt with a distance of 5 cm between the Fresnel lens and the solar cell. It can be concluded from the data above that the distance of 5 cm is the best possible distance for the light converging method because the power output is at its’ highest compared to other distances.

3.2. Results of Tests
Tests are done by using 2 solar cells with the following specifications:

Table 2. Solar Cell Specifications

| Dimension | Voltage | Current | Open-Circuit Voltage (Voc) | Maximum Load Voltage |
|-----------|---------|---------|---------------------------|---------------------|
| 70x55x3mm | 5.5V    | 100mA   | 8.2V                      | 6.4V                |

One of the solar cells is paired with a Fresnel lens separated at a distance of 5 cm to converge light onto the solar cell. Temperature sensors connected to the microcontroller are implanted on both solar cells to calculate their temperature. Then, the two solar cells are placed where they will be exposed directly to the sunlight from 10.00 – 14.00 (UTC+07:00). Afterwards, calculation of Open-Circuit Voltage (Voc) and Short-Circuit Current (Isc) for the output of the solar cells are done every 5 minutes using a multi-meter. The tests operate at 10.00 – 14.00 o’clock (UTC+07:00).

3.2.1. Results of Solar Cell Power Output

![Figure 4. Graphics of Solar Cell Output](image)
From Figure 4 we can see the difference in power output from the solar cell that is paired with the Fresnel lens and the solar cell without it from 10.00 to 14.00 o’clock. Results from the entirety of the tests show an improvement in the solar cell’s power output, with an average improvement of around 1.61% or 0.008135 Watt. The biggest improvement occurs at 13.15 o’clock where the increase of power is 9.75% or 0.041 Watt. However, a decrease in output also happens as far as -30.66% or -0.10697 Watt at 10.00 – 10.20 o’clock and 13.55 – 14.00 o’clock, which may happen because of the position of the sun leaning in the East or West creating the possibility of partial shading towards the solar cell that can cause a decrease in power output.

3.2.2. Results of Solar Cell Temperature Tests
Temperature measurements of solar cells are also done to see if the pairing of Fresnel lens would also impact the temperature of the solar cell and if it would impact the output of the said solar cell.
From Figure 5 it can be seen that the solar cell that is paired with a Fresnel lens possess a higher temperature for the majority of the time compared to the solar cells without it. This happens because the Fresnel lens concentrates light towards the solar cell which causes more light to hit the solar cell resulting in an increased temperature.

It can also be seen that at 10.00 – 10.20 o’clock when the difference in temperature is significantly higher, the value of the open-circuit voltage that is measured decreases. This is consistent with the theory where the higher the temperature of the solar cell, the lower the voltage of the solar cell.

4. Conclusion

The conclusion from this research is, that the pairing of a Fresnel lens for a solar cell can increase the power output of a solar cell by 9.75%, with an average increase of 1.61% when testing is done at 10.00 – 14.00 o’clock. The Fresnel lens that is used must have a surface area that is bigger than the surface area of the solar cell to ensure that it can pass through a higher amount of light intensity. If the position of the sun is in the east or the west such as at 10.00 – 10.30 o’clock or 13.30 – 14.00 o’clock then partial-shading will occur to the solar cells paired with the Fresnel lens causing the power output of the solar cell to decrease by up to -30.66%. The placement of the Fresnel lens can also impact the temperature of the solar cells. This happens because of the higher intensity of light being accepted by the solar cells, which also causes higher temperature. Consistent with equation (1), the higher the temperature of the solar cell, then the lower the open-circuit voltage from the affected solar cell.

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