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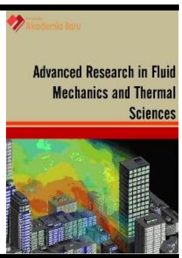

Investigation of Fresnel Lens Effect on Solar Panel Power Generation

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ABSTRACT

Solar panel power output can still be improved through various means. The aim of this paper is to investigate the effect on solar panel power generation due to Fresnel lens distance to the solar panel. The use of Fresnel lens is to magnify the light intensity from the sun to achieve higher solar collectability of solar panel which may increase power output. The Fresnel lens is to be positioned on top of the solar panel to concentrate the sunlight on to the solar panel. Voltages are measured by an electronic microcontroller with a 10-second interval while power output are determined by the product of voltage and load resistance connected to the solar panel. Immediate results were an instantaneous rise in voltage output but gradually decreasing with increase heat absorption in the solar panel. In the long run, voltage and power outputs were obtained at 0, 5, 10, 20, 30 and 40 cm Fresnel lens distance to the solar panel where all results saw the reduction in voltage and power generation from the solar panel incorporated with Fresnel lens compared to one without due to high ambient temperature. Because of this, it is deemed unfeasible to use Fresnel lens for solar power generation in hot areas such as those with equatorial or tropical climate.

Keywords:
Solar Panel; Fresnel lens effect; Temperature; Power output

1. Introduction

It is anticipated that by the year 2030, global electricity demand will double while solar electricity only supplies 0.015% of the world's electricity demands but costing 5 to 10 times more than conventional fossil fuels electricity [1]. Solar panel requires high light intensity to generate high solar power. There are several ways to increase light intensity collection on solar panel and one of them is by incorporating a concentrating solar collector such as Fresnel lens on top of the solar panel. Fresnel lens is a special solar concentrator convex lens in which the lens is considerably thinner and lighter than conventional convex lens. The idea is that the use of a convex lens (Fresnel lens) on top of the solar panel would increase solar light intensity by focusing sunlight into a smaller area. The use of

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concentrating solar collector is also a way to reduce the cost of PV conversion of energy as long as the concentrator is less expensive than the substituted solar cell [2].

Fresnel lens have varying applications depending on what is to be tested and this includes Fresnel lens as solar collector and concentrated photovoltaic among others. Concentrated photovoltaic is a major application and by utilizing Fresnel lens, the highest solar-electric conversion efficiency based on imaging Fresnel lens and non-imaging Fresnel lens are reported as over 30% and 31.5 ± 1.7% respectively [3]. Those without Fresnel lens have solar-to-electric conversion efficiency of about 3% [4]. These results were obtained Stretched Lens Array (SLA) application and dome-shaped prototype Fresnel lens application [5,6]. Another research was carried out using static linear Fresnel lens in which they have obtained a 4.8% solar-electric efficiency [7]. They have also found that only 69% of solar irradiation were direct radiation and 30% of that direct radiation were reflected back by the Fresnel lens and double glass protection thus achieving direct radiation-electric efficiency of 9.9%.

A geometric optical efficiency of 100% can be obtained for a linear photovoltaic concentrator when the sun is perpendicular to the lens [8]. However, the efficiency drops drastically to 50% with a 1° deviation when using a Fresnel lens with a 1.5° acceptance angle. An acceptance angle of 2° and 5° will have optical efficiency 60% and 70% respectively. This means that to obtain reliable efficiency at all times, the Fresnel lens must be able to track the sun. This fact is supported by Madhugiri and Karale [9] whom said that the main drawback of using solar concentrator was the need for dual-axis solar tracking to improve performance of these concentrators. Optical efficiency of 90% have been obtained by implementing compound parabolic concentrator (CPC) on solar panel in paraxial condition [10].

An improvement on Fresnel lens for high concentration photovoltaic system was proposed and designed [11]. By their design, an efficiency of 75% can be achieved when using with multiple wavelengths. This experiment uses a 1200X geometrical concentration equivalent to 1200 suns. Another research was able to achieve only 33% at 300-500 suns [12]. Earlier papers have also presented low optical efficiency of 23% at 5800 suns, 30% at 5800 suns, and 39% at 236 suns [13-16]. Nevertheless, in all cases, the solar concentration still increases from 1 sun to 1334, 1740, and 92 suns respectively with the use of point focus type Fresnel lens. These researches cover only the focal point of the lens.

A different paper experimented on different range from the focal point in which the results have indicated that the uniformity of irradiance distribution could be largely improved when the receiver plane is placed somewhat upwards or downwards the focus [17]. However, the concentration ratio is reduced from 120 suns to 8 suns when the plane moves upward by 4 cm from the focus. The results have also indicated that both current and voltage increase almost linearly with increasing concentration ratio.

However, the use of Fresnel lens not only magnifies light intensity but also the temperature. In many cases, this will have a negative effect on the power output of the solar panel. Based by calculations and experimentations, both had concluded that increase in temperature leads to a decrease in voltage output and a lower fill factor and also maximum power in general [18,19]. Another research has determined that the short circuit current is directly proportional to light intensity while voltage changes logarithmically with light intensity [20]. They had also found the relation to temperature was 0.6μA gain per °C for current and voltage reduction of 2.2mV per °C.

A different experiment was conducted by Omubo-Pepple *et al.,* [21] to distinguish voltage output between different ranges of temperature. Between 25°C and 35°C, voltage keeps increasing due to increase in light intensity across that temperature. Further increase in temperature, voltage output remains relatively constant but beyond 44°C voltage output begins to drop. This shows that high temperature is not favourable to performance of PV module. Some evidence has been compiled by

Cuce *et al.,* [22] in which they have obtained temperature dependency of fill factor for different PV modules. It was observed that the fill factor reduced from 0.71 at 15°C to 0.59 at 60°C with linear relationship. In their conclusion, they have stated that solar concentrating systems such as Fresnel lens and booster mirrors can be used to enhance photocurrent or current in general but cell temperature should be kept as low as possible to avoid substantial drop of voltage output.

Another experiment has also been carried out to determine feasibility of using solar tracking systems in hot regions [23]. In this research, it was found that the gain in electrical energy by tracking the sun is about 39% in case of cold city such as Berlin, Germany. Meanwhile, the gain in energy did not exceed 8% in case of a hot city such as Aswan, Egypt due to overheating of the PV panels. Power consumption of tracking systems were generally defined to be in the range of 5% to 10% thus making use of solar tracking not feasible in hot countries in general. Use of Fresnel lens required the support of tracking system to generate reliable power output.

In the above cases, the example used for the hot region was Aswan, Egypt which have a generally extreme dry with ranging temperature between 10°C to 45°C. The experiment was held for only one day at the hottest time of the year. For this paper, it will take place in Brunei which is hot and wet all year round with very short temperature ranges from 26°C to 28°C. Few researches on solar tracking capabilities to solar power output have been tested in the local region which have observed energy gain of 10% average with tracking compared to fixed panel but can be as high as 20% or even 30% [24-27].

2. Experimental Setup

The Fresnel lens used for this experiment has dimension 30 cm by 30 cm with focal length 20cm and the targeted solar panel has surface area of 12 cm x 12 cm. Take caution of temperature of solar panel as it may affect voltage generation. The first experiment is to record the immediate voltage output of the solar panel when Fresnel lens was just incorporated onto the solar panel. With this technique, light intensity will instantly rise while heat will be absorbed more slowly and therefore the observed voltage output will have higher light intensity and same temperature to ambient temperature. The Fresnel lens distance to the solar panel will be varied according to its focal length. The distance is measured by a long ruler while the voltage is measured using a multimeter across the solar panel. Figure 1 illustrates the position of the Fresnel lens above the solar panel and how the distance is determined.

The second experiment is comparing the voltage generation of the solar panel with and without Fresnel lens. In this experiment, there will be 2 solar tracking systems where one system is incorporated with a Fresnel lens and another one without. Both solar tracker systems will track the sun in one axis plane (East-West). In order to get good reading and analysis, the duration of the experiment will be for few hours of direct sunlight without or at least with minimum amount of cloud shading.

The hypothesis here is that the solar panel with the Fresnel lens will generate higher voltage due to magnified light intensity. However, high temperature magnified by the Fresnel lens will decrease efficiency of solar panel. Thus, the need to experiment on these theories when use in a hot country. The experiment will be held in Brunei which is hot and wet all year round with the average ambient temperature at 28°C. Several results are to be expected with different Fresnel lens distance from the solar panel. The distance of the Fresnel lens will be varied from 0, 5, 10, 20, 30 and 40 cm to the solar panel.

All measurements for the second experiment were taken automatically using a PIC electronic microcontroller. The controller measures the voltage across the solar panel and recorded it into a memory card with a 10-second interval to acquire very accurate voltage results over long duration of time. The power is determined by the product of voltage and load resistance at maximum power where in this case, the resistance is 55Ω. Figure 2 shows how the solar panel is connected to the microcontroller for the voltage to be measured. The experiment starts at about 0930 in the morning and ends at 1500 or 1600 depending on weather condition as this is where the highest output of the solar panel can be obtained.

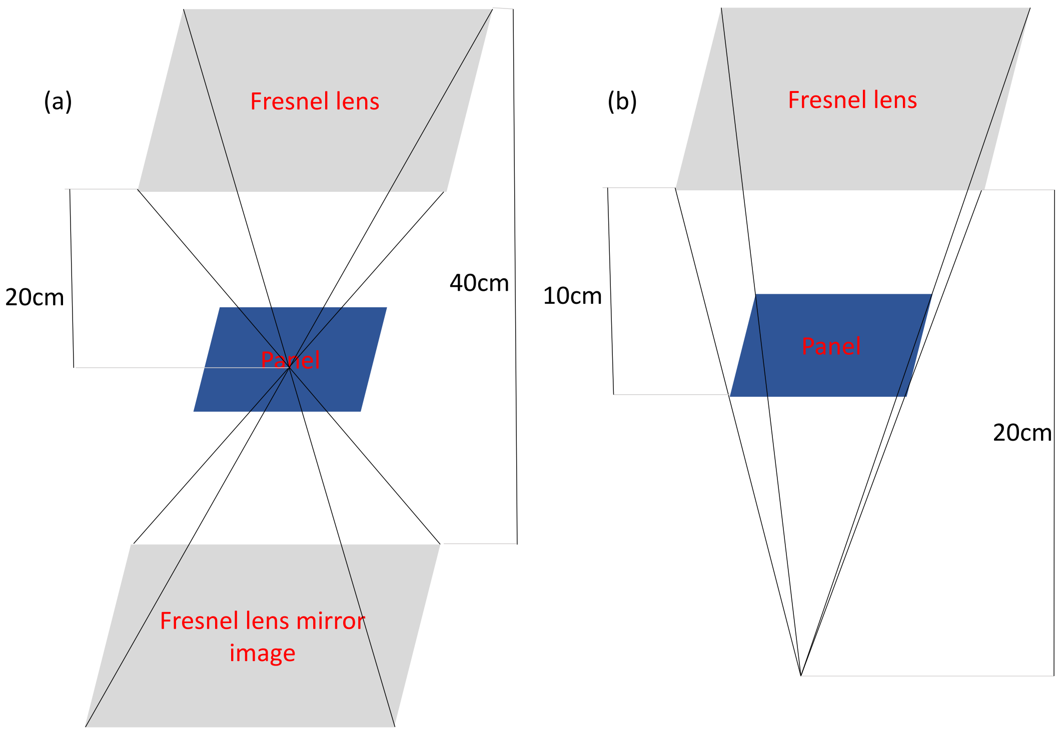

Fig. 1. (a) Fresnel lens at 20 cm from solar panel, focal length of Fresnel lens is at 20 cm; (b) Fresnel lens at 10 cm from solar panel. At 10 cm position, sunlight covers all surface area of solar panel

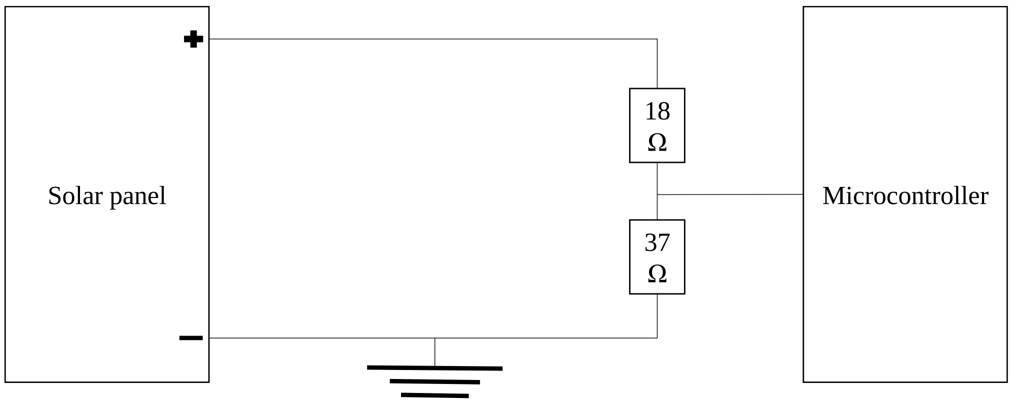

Fig. 2. Connection of solar panel to the microcontroller

3. Results

3.1 Instantaneous Voltage Output

The first experiment will be used to determine at which position the Fresnel lens above the solar panel will provide the highest voltage generation. The time of the experiment was recorded at noon when the sun is at its highest position and highest light intensity of the day. Also, at this time, the

Fresnel lens is the most perpendicular to the sun giving out a much more condensed and higher light intensity into the solar panel. Table 1 shows the voltage results for the first experiment.

Table 1
Instantaneous voltage measurement when Fresnel lens was introduced onto solar panel

Experiment condition	Instant voltage result (*V*)	Voltage output comparison to normal solar panel (*%*)
Without Fresnel lens	9.7	100
Fresnel lens at 0 cm, resting on solar panel	9.6	98.9
Fresnel lens at 10 cm, covering all areas of solar panel	10.5	108.2
Fresnel lens at 20 cm, at focal length	9.4	96.9
Fresnel lens at 40 cm, at double the focal length	8.5	87.6

From these immediate results, it is observed that voltage output is highest when sunlight magnified by the Fresnel lens covers the whole active surface area of the solar panel. The increase was by 8.2% compared to without Fresnel lens. No positive nor negative effect is observed when Fresnel lens rests on top of the solar panel while at focal length, reduction of voltage by 3% was observed. This is due to the fact that the sunlight is only concentrated into a very small area while the surrounding active are is shaded by the Fresnel lens. At more than twice the focal length, voltage is reduced by 12.3% due to full shading by the Fresnel lens.

3.2 Voltage and Power Output for Long-duration experiment

For the second experiment, the experiment will take long hours and as such, temperature will be taken into account. This will the main experiment for this paper. Several results were obtained according to the different distance of Fresnel lens from the solar panel where for this experiment, the distance to be taken were 0, 5, 10, 20, 30 and 40 cm.

3.3 Fresnel Lens Distance = 0 cm

Figure 3 shows the voltage output with measured temperature of the solar panel and Figure 4 shows the power output of the solar panel when Fresnel lens is at 0 cm above the panel. At 0 cm position, voltage outputs of both solar panel (with and without Fresnel lens) were almost identical. The highest difference in voltage observed was with a 9.3% reduction from normal solar panel (without Fresnel lens). However, at different point of time, temperature of solar panel with Fresnel lens was lower than normal and therefore it produces higher voltage with 5% increase from normal panel. The total power gain for both systems were almost equivalent which is about 99.6%. Temperature of solar panel with Fresnel lens has higher variance and higher average than the temperature of normal solar panel.

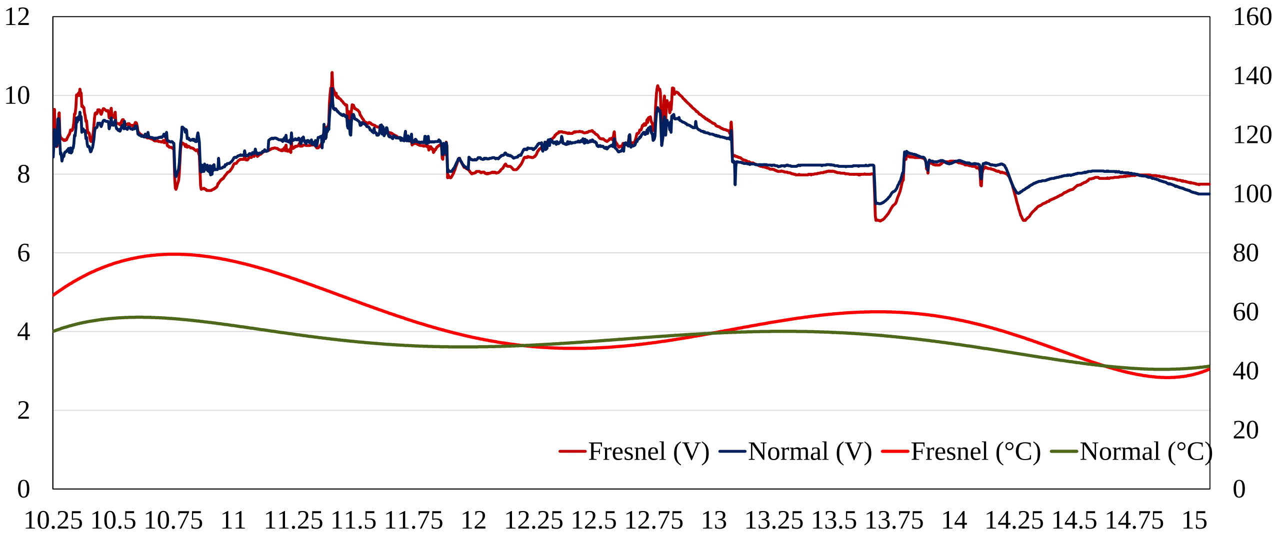

Fig. 3. Voltage output and temperature measured when Fresnel lens at 0 cm above the solar panel. Fresnel lens is resting on top of solar panel. Left y-axis represents voltage output (V) while right y-axis represent temperature in °C. The x-axis shows the time of the experiment in 24-hour format

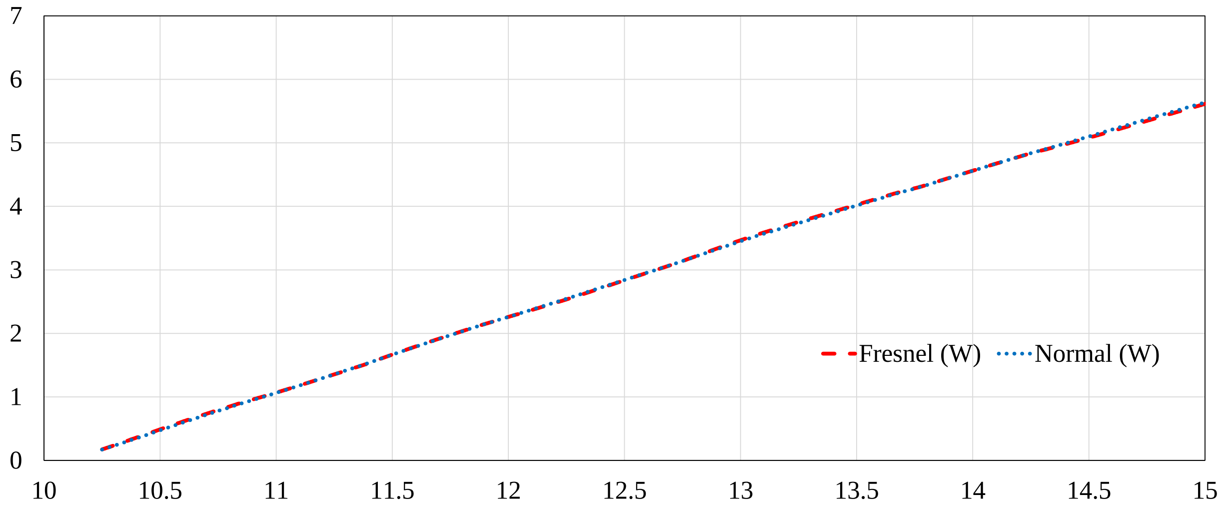

Fig. 4. Total power output (W) when Fresnel lens at 0 cm above the solar panel. Fresnel lens is resting on top of solar panel

3.4 Fresnel Lens Distance = 5 cm

At 5 cm position, irradiance hits less on the solar panel and more on its surrounding. Solar panel with Fresnel lens has lower voltage output compared to normal panel as evident from Figure 5. The difference in voltage observed had a 5-10% reduction of panel with Fresnel from normal solar panel. The total power of solar panel with Fresnel lens had 92.1% of normal panel as shown in Figure 6. Temperature of solar panel with Fresnel lens has much higher variance and higher average than the temperature of normal solar panel and even from previous 0 cm Fresnel lens distance. This is due to short distance and more compact area that causes low heat dissipation from the solar panel.

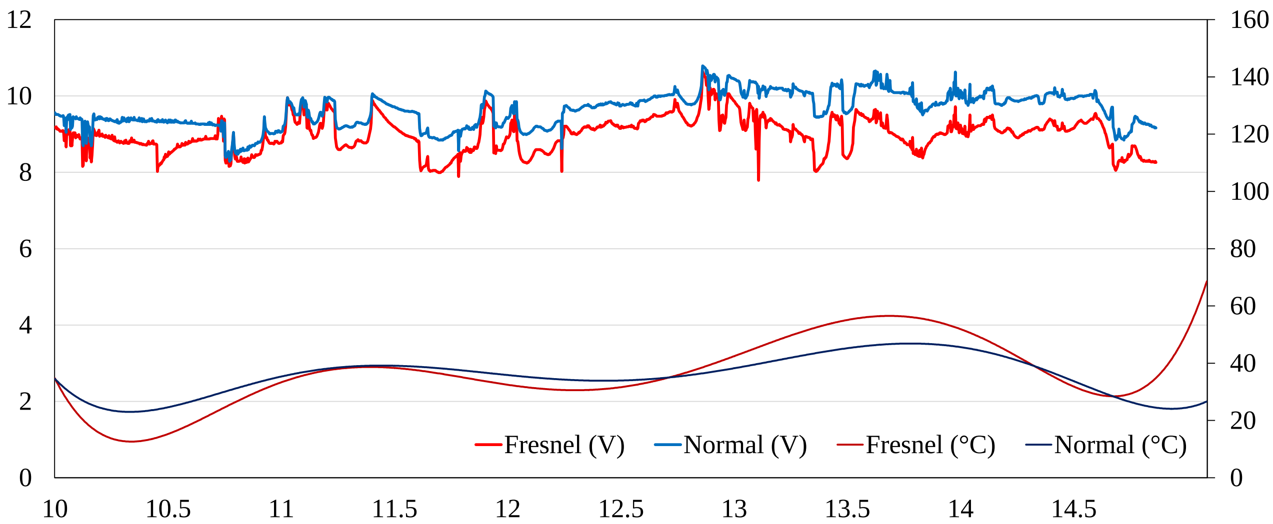

Fig. 5. Voltage output and temperature measured when Fresnel lens at 5 cm above the solar panel. Irradiance hits solar panel and the surrounding. Left y-axis represents voltage output (V) while right y-axis represent temperature in °C. The x-axis shows the time of the experiment in 24-hour format

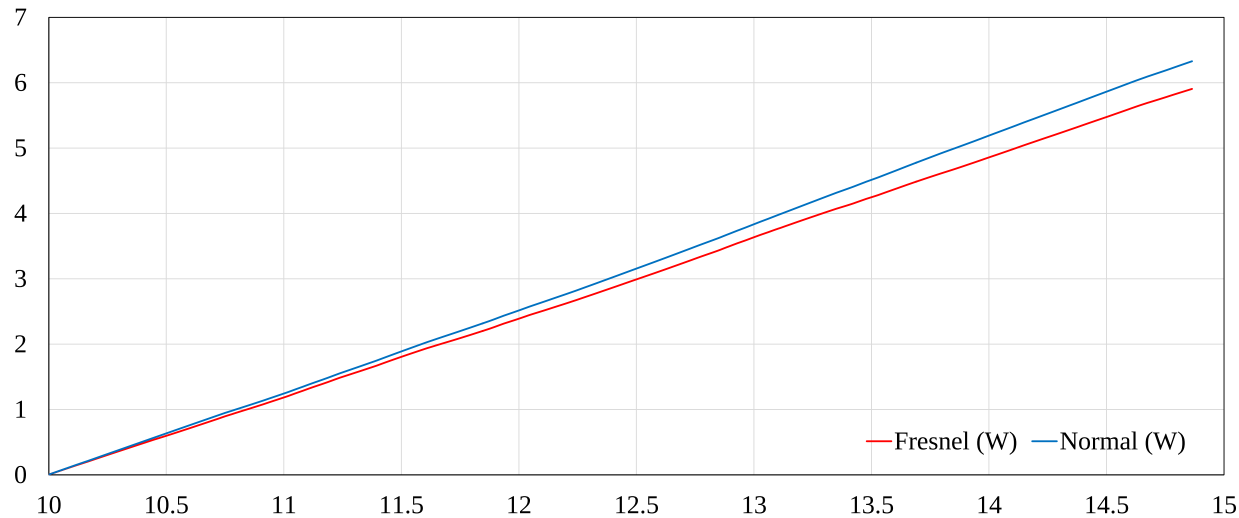

Fig. 6. Total power output (W) when Fresnel lens at 5 cm above the solar panel. Irradiance hits solar panel and the surrounding

3.5 Fresnel Lens Distance = 10 cm

At 10 cm position, irradiance hits fully on solar panel. In Figure 7, the voltage output from solar panel with Fresnel lens is lower than normal panel with a reduction of 5-15%. The variance is larger than previous where Fresnel lens distance at 5 cm and 0 cm. The total power for solar panel with Fresnel lens is 91.3% of normal panel total power as shown in Figure 8. Temperature of solar panel with Fresnel lens has lower variance than 5 cm Fresnel lens experiment but still a higher average temperature than temperature of normal solar panel. This is due to larger space for heat dissipation after the Fresnel lens and before the solar panel.

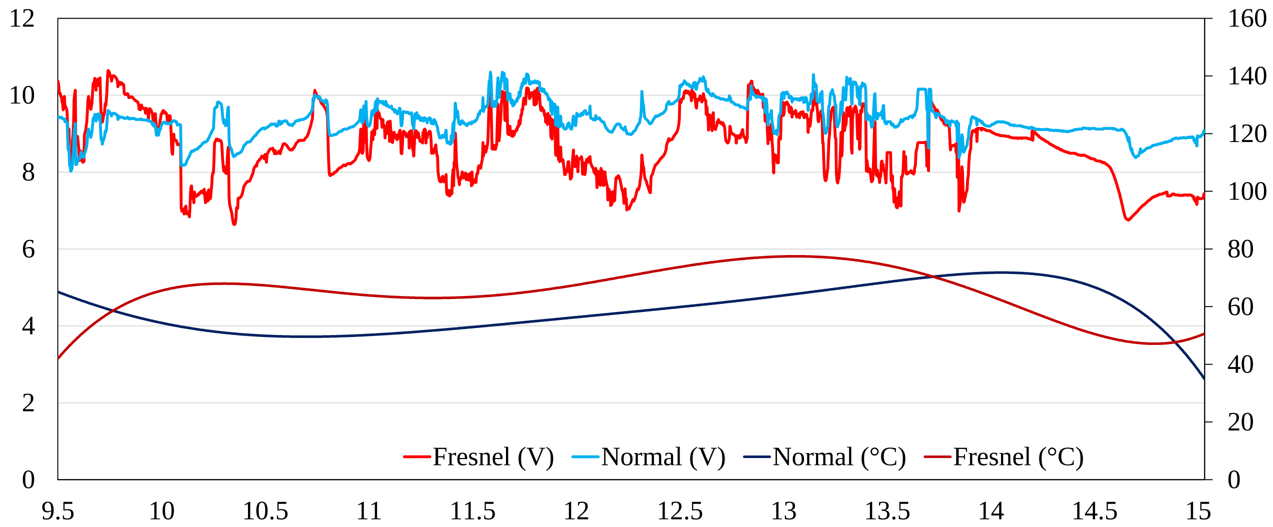

Fig. 7. Voltage output and temperature measured when Fresnel lens at 10 cm above the solar panel. All irradiance hits the solar panel. Left y-axis represents voltage output (V) while right y-axis represent temperature in °C. The x-axis shows the time of the experiment in 24-hour format

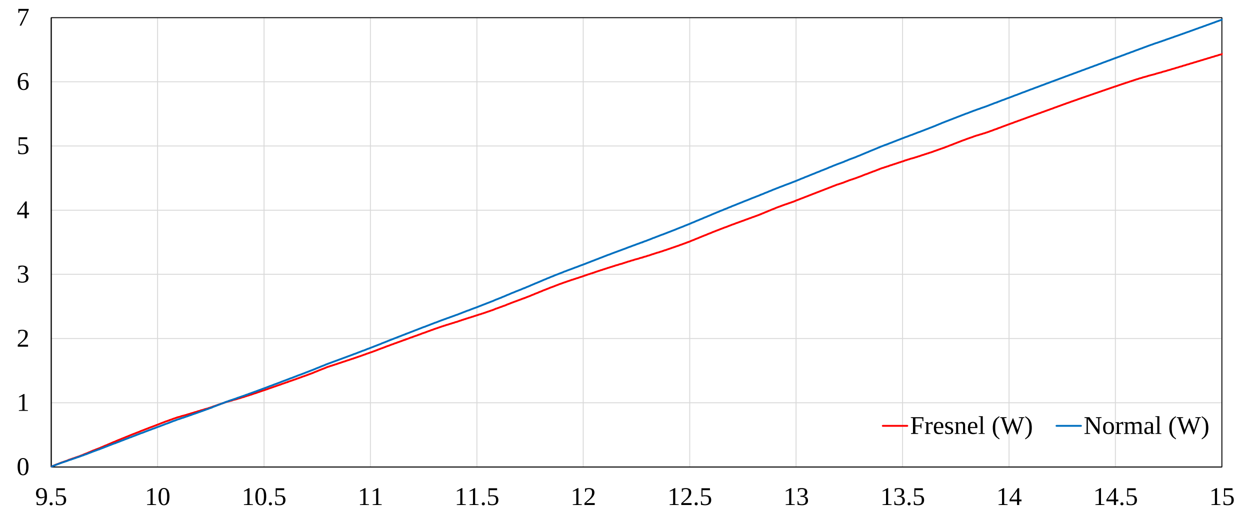

Fig. 8. Total power output (W) when Fresnel lens at 10 cm above the solar panel. All irradiance hits the solar panel

3.6 Fresnel Lens Distance = 20 cm

Fresnel lens at focal length, irradiance is very concentrated into one spot on the middle of the solar panel. However, after few seconds, the protective film layer on top of the solar panel started to melt from extremely high heat. Because some of the equipment, especially the solar panel, was lent from the institute, the experiment was discontinued to avoid damage to equipment. For Fresnel lens distance at focal length, only the instantaneous voltage experiment was run for Fresnel lens distance at focal length.

3.7 Fresnel Lens Distance = 30 cm

Figure 9 shows the voltage output and measured temperature of the solar panel when the Fresnel lens is 30 cm above the solar panel. Irradiance is beyond the focal length and is now 10 cm to the mirror image of the Fresnel lens at 40 cm. Irradiance fully covered the solar panel but inverted.

Voltage output from solar panel with Fresnel lens is lower by 2.0-16.8% from normal panel. The total power of solar panel with Fresnel lens is 93.4% of normal panel as evident from Figure 10. Temperature of solar panel with Fresnel lens has lower variance than 10 cm and 5 cm Fresnel lens experiments but still a higher average temperature than temperature of normal solar panel. This is due to much larger space than 10 cm experiment for heat dissipation after the Fresnel lens and before the solar panel.

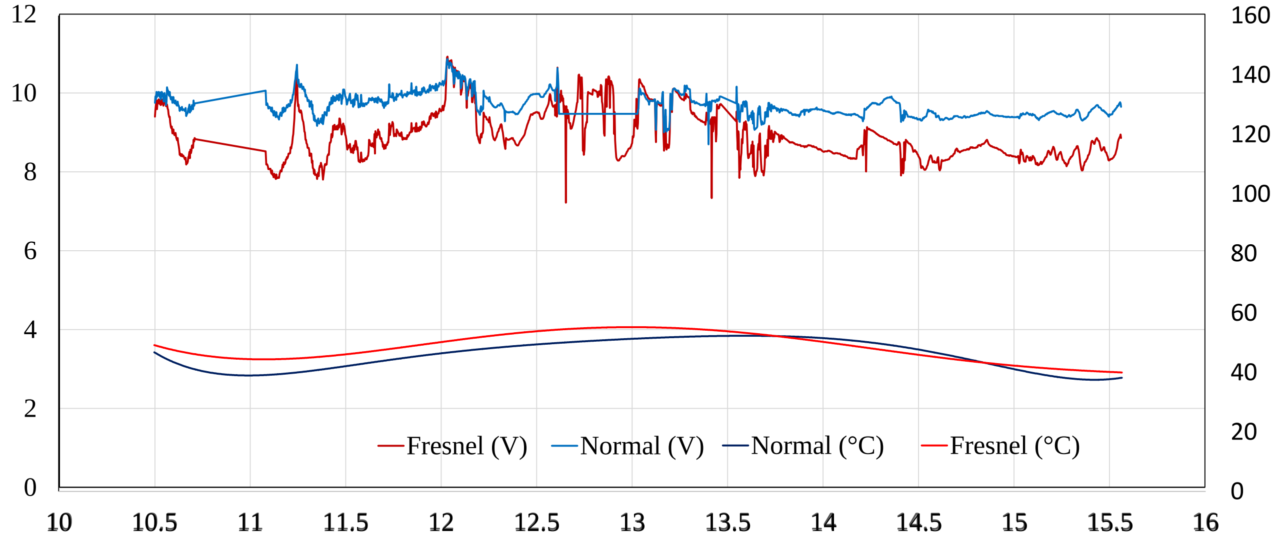

Fig. 9. Voltage output and temperature measured when Fresnel lens at 30 cm above the solar panel. Solar panel is fully covered with irradiance but inverted. Left y-axis represents voltage output (V) while right y-axis represent temperature in °C. The x-axis shows the time of the experiment in 24-hour format

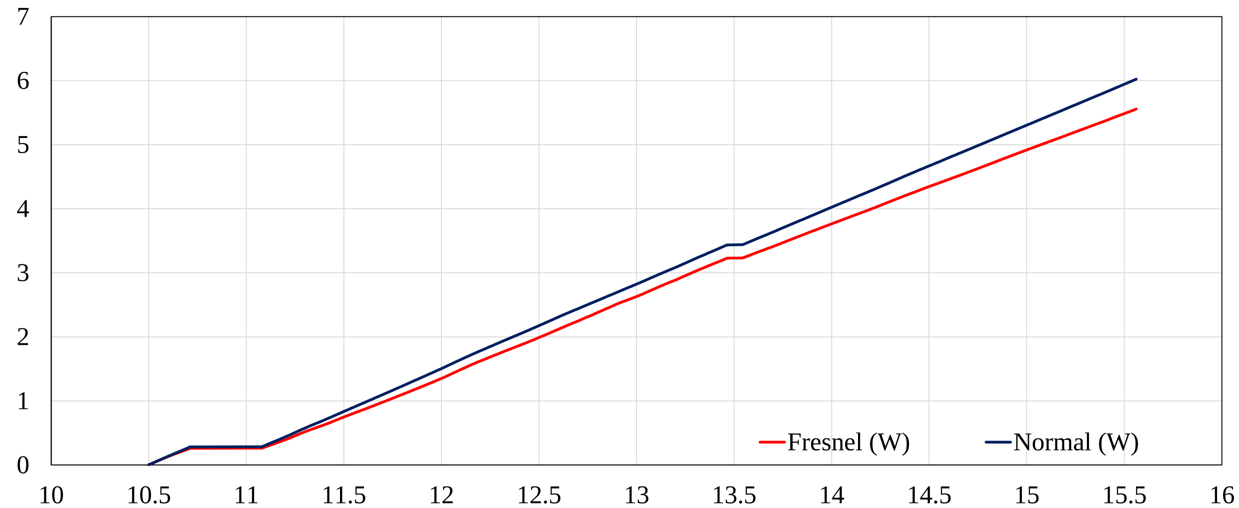

Fig. 10. Total power output (W) when Fresnel lens at 30 cm above the solar panel. Solar panel is fully covered with irradiance but inverted

3.8 Fresnel Lens Distance = 40 cm

At 40 cm position, irradiance is beyond the focal length and is now equal distance to the mirror image of the Fresnel lens at 40 cm. Irradiance covers the solar panel and also the surrounding but inverted. Voltage output from solar panel with Fresnel lens is lower by 5-20% from normal panel as shown in Figure 11. In Figure 12, it shows that the total power of solar panel with Fresnel lens is 95% from normal panel. Temperature of solar panel with Fresnel lens has lower variance than 10 cm and

5 cm Fresnel lens experiments but still a higher average temperature than temperature of normal solar panel. The 40 cm space between Fresnel lens and the solar panel provide sufficient space for heat dissipation to equalize the temperature close to the temperature of normal solar panel.

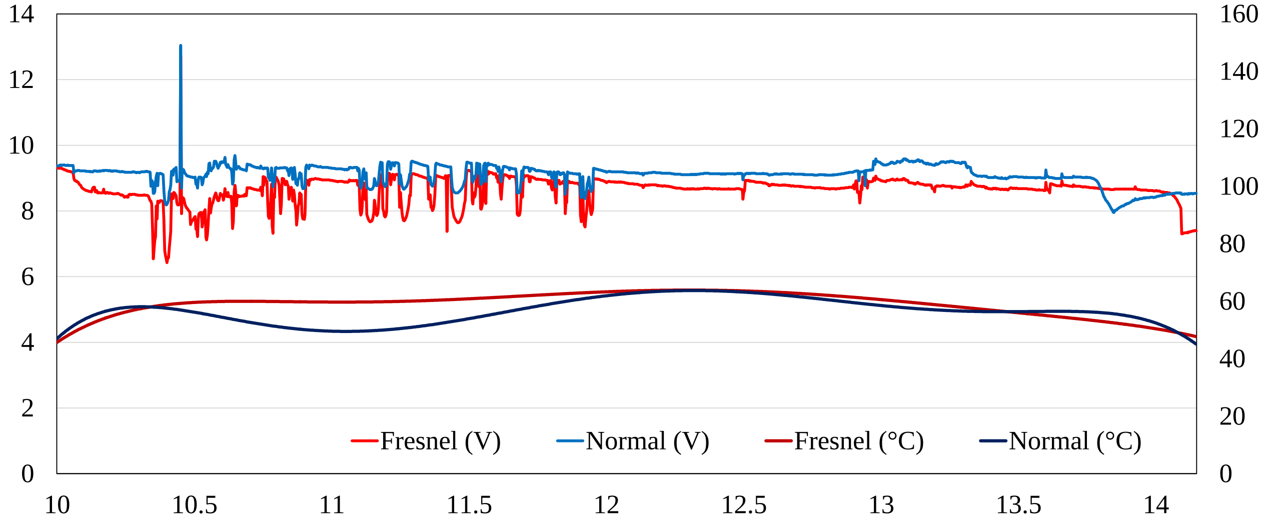

Fig. 11. Voltage output and temperature measured when Fresnel lens at 40 cm above the solar panel. Irradiance hits solar panel and the surrounding. Left y-axis represents voltage output (V) while right y-axis represent temperature in °C. The x-axis shows the time of the experiment in 24-hour format

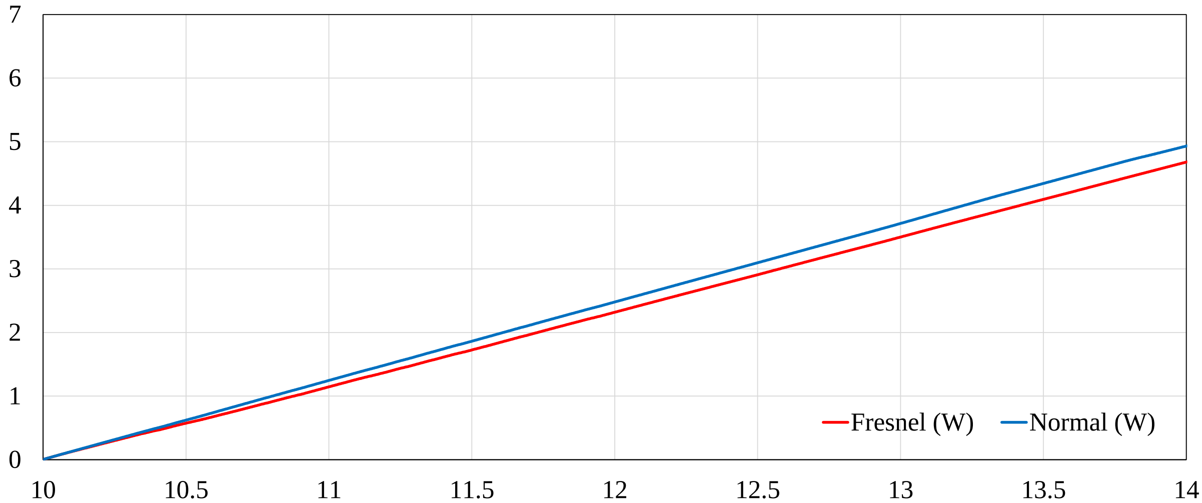

Fig. 12. Total power output (W) when Fresnel lens at 40 cm above the solar panel. Irradiance hits solar panel and the surrounding

3.9 Result Summary

The Fresnel lens distance from the solar panel have been observed to have significant effect on the voltage and power output of the solar panel. Indirectly, the Fresnel lens have an effect on the temperature of the solar panel which will also affect solar panel output. From the distance where irradiance coverage is fully on panel which is at 10 cm Fresnel lens distance, the power output is the lowest. Varying the distance up or down from this point lead to an increase in power output.

Temperature variance from normal solar panel temperature was observed to be at the highest at 10 cm distance and changing this distance reduce this variance. Even with the increase in sunlight intensity to the solar panel, power output did not reach a higher output from solar panel without

Fresnel lens. The increase in temperature due to the Fresnel lens have reduced the voltage and power output from the solar panel. Table 2 summarizes the power outputs of the solar panel with the Fresnel lens and their temperature variance for various distance of Fresnel lens from the solar panel.

Table 2
Power output results and other factors observed at different Fresnel lens distance

Fresnel lens distance to solar panel (cm)	Power output comparison to normal solar panel (%)	Temperature variance from normal solar panel temperature	Irradiance coverage from Fresnel lens
0	99.6	Lowest	Non- concentrated
5	92.1	High	Whole of solar panel and surrounding
10	91.3	Highest	Fully concentrated on solar panel
30	93.4	Medium	Whole of solar panel with surrounding and inverted
40	95.0	Low	Whole of solar panel but more to surrounding and inverted

4. Conclusion

The experimental data in using Fresnel lens at different distance have been presented in this paper. Immediate voltage results were an instantaneous rise in voltage output but gradually decreasing with increase temperature absorption with the highest output an increase of 8.2% at 10 cm Fresnel lens distance compared to solar panel without Fresnel lens. In the long run, voltage and power results were obtained for different distance of Fresnel lens to the solar panel. All results observed saw the reduction in voltage and power generation from solar panel incorporated with Fresnel lens with a decrease to 91.3% the lowest and 95.0% the highest, compared with solar panel without the concentrating medium. The major reason being the temperature sensitivity of solar panel. Other reasons include the shading of the solar panel by the Fresnel lens, the naturally high ambient temperature of the experiment site, and also the lack of cooling mechanism to remove excessive heat from the solar panel. Hence, it is deemed unfeasible to use Fresnel lens in solar power generation in hot areas such as those with equatorial or tropical climate.

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