

**AUTOMATIC DUAL-AXIS SOLAR TRACKER DEVELOPMENT BY USING FRESNEL LENS**

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**ABSTRACT**

The worldwide demand for energy is increasing exponentially, while reserves of fossil fuel have begun to deplete. Sustainable energy solutions are becoming more and more common today. Sustainable energy contributes to the efficient collection of energy, efficient storage and efficient converting energy into work. Among these sources of renewable energy, solar energy typically offers great potential for transformation into electricity for daily uses, thanks to its availability and low-cost process. The objective of this research is to develop dual-axis solar tracker by using Fresnel lens. The lower energy absorption and seasonal variation dependence on some geographical locations, however, are the big challenges in identifying suitable applications using solar energy as the heat source. In order to overcome this, research into high-efficiency concentration technology for solar energy is necessary and practical. In this research, Fresnel lenses were chosen due to their advantages such as low length, light weight, low-cost mass production and flexibility in the capture of solar energy. The overall efficiency of the Fresnel lens solar concentrator is around 51% based on the performance analysis of the Fresnel lens solar concentrator and the production of steam.

**Keywords:** *Sustainable energy, Renewable energy, Solar concentrator, Solar tracker, Fresnel Lens*

**1. INTRODUCTION**

Over the last two decades the number of solar energy systems applied in daily use has increased. A lot of studies were conducted to discover the method to increase the solar panel's efficiency. Common photovoltaic technology in the solar panel system seems to have lower performance if being compared to concentrating solar power (CSP) technology. If the solar tracker is being used on electrical boat, it must be capable to capture more energy in order to expand the battery life span to ensure it can work on a long period of time. Although the battery can be charged by the solar tracker through solar charger, the standard lifetime batteries are still insufficient and need to add a secondary power source. Solar energy concentration technology with Fresnel lens is an efficient way to fully utilize sunlight to prolong the lifespan of the batteries.

While CPV cells have reached 20-30 percent efficiency (approximately), this still means that up to 70 percent of the energy could end up as heat. Most will be mirrored, but 30-50 per cent of the direct light energy going into concentrated heat will still be there [1]. The more effective the Fresnel lens is in focusing the light, the greater the problem of preventing heat build-up and the higher the CPV cell equilibrium temperature. The reality is that conditions with high ambient temperatures also has certain disadvantages for solar panels. It is one of the major causes of drop-in efficiency, and if not properly considered, may reduce energy yields. Fresnel lens are used to increase the efficiency output of the solar

tracker. This Fresnel lens is intended to be mounted with the solar tracker as a concentrator in photovoltaic applications. Following the edge ray principle, a suitable shape and position of Fresnel lens must be correctly determined to obtain the optimum result. Meanwhile, solar tracker is used to extend solar battery efficiency. Solar trackers have two varieties, single axis and solar tracker with dual axis. The solar tracker's movement is limited for single axis that can only move in one direction. Dual axis solar tracker is used for this analysis as it can travel horizontally and vertically and capable of making the solar tracker to move based on the sun's location.

High operating temperatures induce a loss of efficiency in solar photovoltaic and thermal panels. A phase-change material will be introduced in this project to maintain the temperature of the panels close to ambient. PCMs are materials undergoing reversible phase transition, depending on their temperature. In the process, they absorb or release heat. The heat and mass transfer modeling of computational fluid dynamics (CFD) in a system composed of impure phase change material is located at the back of a solar panel. In recent years, in addition to water and air, phase change materials (PCM) were also considered as passive-based cooling applications for photovoltaic panels. To determine the correct PCM for the PV panel for the given climatic conditions, different PCMs with different melting temperatures and latent heat fusion need to be examined for.

## 2. CONCENTRATING SOLAR POWER (CSP)

Concentrating solar power (CSP) technology utilizes focused sunlight. CSP technology uses mirrors to concentrate the sun's energy and convert it into high-temperature heat to generate electric power. The thermal energy concentrated in a CSP technology can be stored and used to produce electricity when it is needed, day or night. In this project, a Fresnel lens is used as the medium for concentrating the sunlight into photovoltaic cell.

Fresnel lenses are made from substrates like acrylic to polycarbonate to vinyl, based upon the required application. Acrylic is the widely recognized substrate because of its high transmittance in the visible and ultraviolet (UV) uses, yet polycarbonate is the substrate highly beneficial in a brute environment due to its resistance from impact and high temperature. A Fresnel lens offers better performance in focusing compared to conventional lenses, depending on the type of the usage.

### 2.1 *Fresnel lens*

The working principle of a Fresnel lens is that the direction of light does not change inside a medium. Instead, the light is just refracted at the surfaces of the medium. Subsequently, the material in the focal point of the lens serves just to expand the weight and absorption inside the system. The Fresnel lens refracts light from an object and creates an image in the focal plane that is distorted by aberrations due to imperfect prism tips and grooves being made. Applications such as photovoltaic electricity generation are often equipped with Fresnel lenses and precise tracking must be used to keep the lens focused on the solar panel. Figure 2.1 presents a cross section of a spherical Fresnel lens in comparison to a cross section of a conventional spherical plano-convex lens of equivalent power.

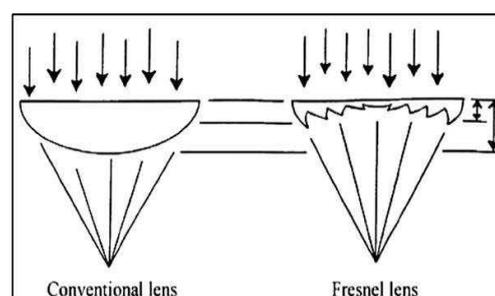


Figure 2.1: Conventional lens and Fresnel lens

Xie et al. [2] also indicated that for collecting and extracting concentrated solar radiation in the form of heat, electricity or both, Fresnel lenses could be combined with hybrid photovoltaic or thermal absorbers. Efficiency of approximately 50 percent could be achieved by using thermal absorbers and low operating temperature, and satisfactory electrical output could be obtained by considering photovoltaic being used. Trip Anagnostopoulos et al. [3] states that Fresnel lenses were suitable for lower volume and weight solar radiation concentrations, lower focal length and lower cost compared to ordinary thick lenses. It was found that the collection of 60-80% of the solar radiation transmitted by the Fresnel lenses on linear absorbers leaves the remaining quantity to be distributed in the interior for illumination thermal building needs.

The information that had been collected are used in determining a suitable dimension of the Fresnel lens to be used. A flat-plane polycarbonate Fresnel lens was used in this project. The compatible size of the lens to be mounted on solar panel is 42cm × 19cm. The width is 0.3mm with focal length of 0.3m. Figure 2.2 below shows the design of Fresnel lens being used to conduct this research.



Figure 2.2: Fresnel lens

## 2.2 Solar Tracker

Solar Tracker is a necessary component in solar panels consisting of motors and drivers to move solar panels in accordance with the maximum point of solar radiation or in other words maintain the position of solar panels remain 90 degrees with the sun as shown in Figure 2.3.

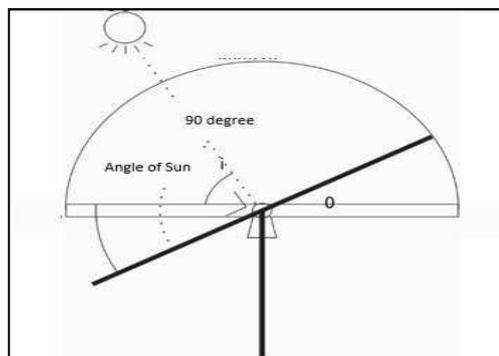


Figure 2.3: Angle of Solar Panel

There are many types of solar trackers, among them are installed with radiation sensors or trackers that based on time. The type of solar tracker used for this project are based on radiation sensors or closed-loop system. Closed-loop systems use light sensitive sensors to monitor the movement of the Sun and to dynamically position the photovoltaic concentrated Fresnel system. Closed-loop systems typically offer greater precision in monitoring. However, when the feedback signal gets lost due to

shadow on the sensor or clouds blocking the Sun, it will be the limitations. Closed-loop systems are favored in this study, since they are much simpler and economical. Oner et al. [4] concept of a spherical motor for a photovoltaic tracking device is powered by a microcontroller with the ability to travel on two axles. Electrooptical sensors such as Light Dependent Resistance (LDR) are mounted on top of the solar panel. A four-quadrant photodetector detects the sun's location, and a motor pushes the instrument base to hold the image of the sun in the middle of the four-quadrant photodetectors. A major characteristic of an LDR is that its resistance is decreasing in proportion to the increasing light intensity. Thus, a photo-effect is created as changes in the material's electrical resistance. The signal is transmitted to the motor moving processor, which in turn changes the tracker's position to get the maximum light intensity.

Active tracking systems are powered by small electrical motors and control module is required to control these. The control module or microcontroller which is commonly used nowadays is Arduino. Some microcontrollers are using Pulse Width Modulation (PWM) for controlling the movement of solar panel. An important use of PWM timers is motor control. The controller uses the signal to drive the servo motor at a controlled speed, operating at 12 V. A 555 timer along with Pulse Width Modulation (PWM) are used to implement Speed Control of DC Motor.

A DC motor with high torque gear transmissions was chosen to rotate the solar panel in order to achieve high resolution and low power consumption. To move the solar panel from position A and place it in position B, servo motors are used to actuate the joints as shown in Figure 2.4. Panning the angular movements of each joint is necessary to complete the task. The controller must forward PWM data to the solar tracker's motors. It gives the solar panel precise angular power which is impossible with a standard DC motor.



Figure 2.4: DC Servo Motor

### 2.3. Phase-change material (PCM)

PCMs are materials undergoing reversible phase transition, depending on their temperature. In the process, they absorb or release heat. The heat and mass transfer modeling of computational fluid dynamics (CFD) in a system composed of impure phase change material is located at the back of a solar panel [5]. PCM are materials that used store and release heat by changing phase from solid to liquid, and liquid to solid. PCM used in this project is paraffin. Paraffin is a derivative of petroleum and have a waxy state in room temperature. The melting point temperature range between  $-8^{\circ}\text{C}$  and  $40^{\circ}\text{C}$ . The ability to freeze without supercooling and excellent thermal storage capacity are the special features of paraffin. They are non-corrosive and are suitable to use with most materials.

## 3.0 ANALYSIS OF THE RESULTS

### 3.0 Solar Panel Voltage and Current Efficiency

To test the task of this project, solar tracker is placed in the open space where there is a maximum

intensity of sunlight. From the tasks performed, the results obtained from this project will be explained throughout with graphs and tables. The output of this project will be measured using multi-meters. This test is conducted from 8.00 am to 6.00 pm for 14 days to determine the average voltages and currents generated by solar tracker and Fresnel lens solar tracker. The results are as shown in the Table 1 below.

Table 1: Voltage output collection

Day	Fresnel Lens Solar Tracker (V)	Solar Tracker (V)
1	11.22	10.07
2	11.20	9.94
3	12.20	8.33
4	9.94	8.96
5	10.89	9.24
6	11.92	8.16
7	10.76	7.09
8	8.35	8.16
9	11.43	9.42
10	9.64	6.92
11	11.11	9.18
12	9.96	7.54
13	11.51	8.18
14	9.98	9.55
Average	10.72	8.62

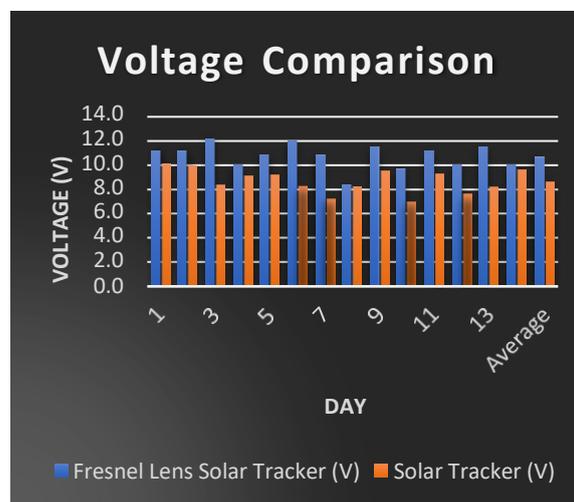


Figure 2.5: Comparison of voltage output

The result shows that the output for voltage between solar tracker and Fresnel lens solar tracker is constantly different. The solar tracker mounted with Fresnel lens produce a higher output voltage. The highest average of voltage produced when using Fresnel lens is 12.2 V, while normal solar tracker can only produce 10.07 V at most. The average voltage output efficiency of Fresnel lens solar tracker is around 24.4% compared to normal solar tracker as shown in Figure 2.5.

Table 2: Current output collection

Day	Fresnel Lens Solar Tracker (A)	Solar Tracker (A)
1	0.93	0.87
2	0.91	0.83
3	1.06	0.81
4	0.81	0.73
5	0.88	0.76
6	1.00	0.66
7	0.87	0.62
8	0.74	0.65
9	0.97	0.80
10	0.83	0.59
11	0.94	0.78
12	0.85	0.65
13	1.00	0.67
14	0.82	0.83
Average	0.90	0.73

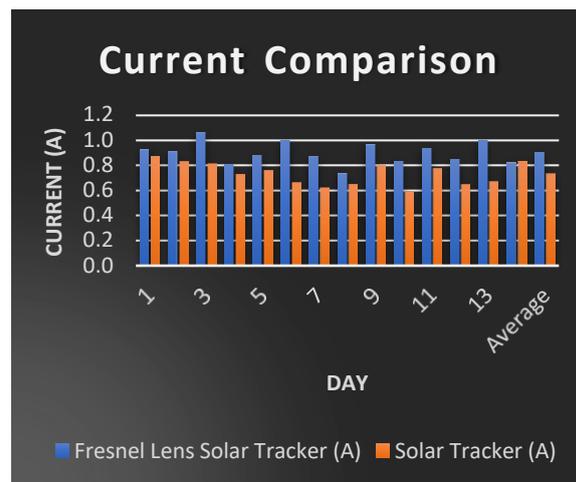


Figure 2.6: Comparison of current output

The result in Figure 2.6 shows the currents produced by solar tracker and Fresnel lens solar tracker. The solar tracker mounted with Fresnel lens produce a constantly higher current output compared to normal solar tracker. The highest average of current produced when using Fresnel lens on solar panel is 1.06 A as indicated in Table 2, while normal solar tracker can only produce 0.87 A at most. The average current output efficiency of Fresnel lens solar tracker is around 23.3% compared to normal solar tracker.

### 3.2 Solar Panel Power Efficiency

After the data of currents and voltages have been recorded, the value of power produced can be calculated by using the formula of power,  $P=VI$ . To determine the highest and the lowest power generated from the testing, the value of voltage is multiplied to the value of current to obtain the value of power in every hour from 8:00 am to 6:00 pm during the 14-days testing period. The analysis of the

results is shown in the Table 3.

Table 3: Power output collection

Day	Fresnel Lens Solar Tracker (W)	Solar Tracker(W)
1	12.53	9.76
2	11.81	9.11
3	14.60	7.43
4	11.47	7.63
5	11.50	8.33
6	13.43	7.65
7	11.18	5.53
8	8.10	7.22
9	12.74	8.49
10	10.49	6.49
11	12.22	8.22
12	10.77	6.92
13	13.20	7.60
14	11.52	8.90
Average	11.83	7.81

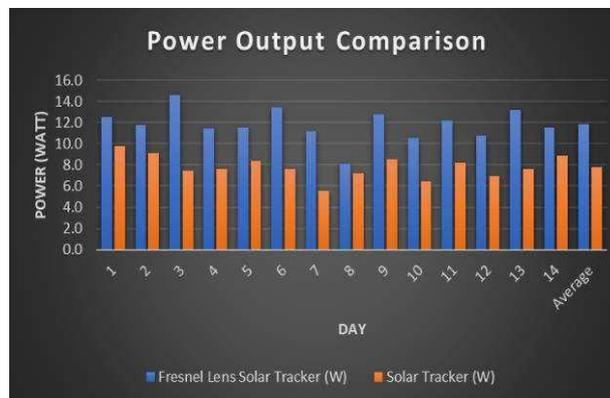


Figure 2.7: Comparison of power output

The result in Figure 2.7 shows the power outputs produced by solar tracker and Fresnel lens solar tracker. The solar tracker mounted with Fresnel lens produce a constantly higher power output compared to normal solar tracker. The highest average of power produced when using Fresnellens on solar panel is 14.6 W, while normal solar tracker can only produce 9.76 W at most. The average power output efficiency of Fresnellens solar tracker is around 31.5% compared tonormal solar tracker.

#### 4.0 CONCLUSION

Fresnel lens are designed as focusing devices and the study has focused on developing a sun tracking system with solar concentrating technology. The combination of solar tracker system with the Fresnel

concentrator are proven to be able to increase the performance of solar panel. Based on the results discussed in the previous chapter, the use of Fresnel lens on the solar tracker system will increase the energy efficiency of solar panel by 20.15%. The use of solar concentrating systems will compensate for the lower efficiency resulting from the unfavorable condition, such as cloudy weather. For various times of day and year, this value can vary. So, more research should be conducted to solve the matter. The longevity of this Fresnel lens is one of the benefits. It has been known that the Fresnel Lens has a lifespan of more than five years, which is an important feature for cost-effective implementation.

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