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Influence of Diverging Lens on the Efficiency of a Solar Module under Low Intensity Solar Radiation

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ABSTRACT

The relevance of solar energy as a source of renewable energy cannot be over-emphasized at both household, local, national and global levels. Therefore, the utilization of optical devices such as lenses has been proposed to enhance solar module performance under sub-optimal solar conditions. The module's overall efficiency was determined by the cell efficiency and placement inside it, as well as the laminating materials employed. Diverging lenses in particular, have shown promise in reducing solar intensity and increasing angular tolerance. This study was carried out in Umuahia North to ascertain the impact of diverging lens on the efficiency of a typical solar module at a relative low solar intensity. This study used the experimental technique, secondary data, and an empirical research study. The study takes into account the shadow conditions, solar hour duration, and tilt angle. The study concluded that a diverging lens reduces the efficiency of a solar module by spreading incoming light rays away from the focal point, resulting in a lower intensity of light reaching the solar cells due to reduced focal concentration, increased reflection and dispersion, lower voltage and current generation, and potential mismatch under optimal operating conditions.

Keywords:
Diverging Lens,
Efficiency,
Solar Module,
Low Intensity,
Solar Radiation.

INTRODUCTION

Several renewable energy projects in many countries have demonstrated that renewable energy can directly contribute to poverty alleviation by providing a significant amount of energy required to start businesses and create jobs, particularly in rural communities that are not yet connected to the national grid (Federal Ministry of Environment, 2013). Several renewable energy technologies are currently in use to provide energy for cooking, space heating, lighting, cars, and other applications. The combination of energy efficiency, conservation, and renewable energy supplies should enable Nigeria to fulfill future demand without growing reliance on nonrenewable resources (Federal Ministry of Environment, 2013). In theory, solar energy might be viewed as a perfect energy source because it is free and virtually endless.

The increasing global demand for renewable energy has led to significant research and development in solar technologies (International Energy Agency, 2020). Solar modules are the basic components of solar energy systems, converting sunlight into electrical energy. However their efficiency is influenced by various environmental factors, including solar intensity (Green *et al.*, 2019). Low solar intensity, often encountered during early morning, late afternoon, or cloudy days, reduces solar module efficiency and energy efficiency (Upadhyay *et al.*, 2024).

The use of optical devices such as lenses has been proposed to improve solar module performance in suboptimal sunlight circumstances (Li et al., 2020). Diverging lenses in particular, have shown promise in reducing solar intensity and increasing angular tolerance (Xinzhong & Adam, 2018). However, the effect of diverging lenses on solar module performance at low sun intensities is poorly understood. As a result, the purpose of this research is to look at the impacts of diverging lenses on solar module efficiency at low solar intensities, specifically analyzing the link between lens focal length, solar intensity, and module efficiency.

According to recent reports, current photovoltaic (PV) cell installations remain tiny, accounting for approximately 0.1% of global total power generation, despite a 40% average yearly growth rate (Tyagi *et al.*, 2013). According to Mungai (2007), solar energy became acknowledged in Nigeria this century, but its growth was slow. People have gradually begun to learn how to use energy off grid in response to the failure of the nation's electricity supply, but due to the high manufacturing costs of PV cells and the enormous land area required to gather sunlight, solar power has the highest cost per Watt of any generation technique. Because power is only created when the sun shines, this pricey equipment lays dormant at night, in gloomy weather, or when trash and dust accumulate on its surface. Conventional solar modules lose considerable efficiency when exposed to relatively low sunlight intensity circumstances, which are prevalent in the early morning, late afternoon, or on cloudy days. Diverging lenses have been proposed as a way to reduce efficiency loss. However, the effect of diverging lenses on solar module performance at low sun intensities is uncertain.

Hence the study specifically analyzed the effect of diverging lenses on solar module efficiency at low solar intensities (200-400 W/m^2), determined the optimal lens focal length for maximizing solar module efficiency under low solar intensity, investigated the relationship between lens focal length, solar intensity, and module efficiency and evaluated the feasibility of diverging lenses in enhancing solar module performance in real-world scenarios.

MATERIALS AND METHODS

Study Area

The study was conducted within Secretariat Road, Umuahia North Local Government Area of Abia State in a relatively low shady conditions, solar intensity and with adjustable panel frames for regulating the tilt angle. Umuahia North is located on 131 m (430 ft) altitude and co-ordinates of 5^o 31’ 60’’ N and 7^o 28’ 60’’.

Materials

The following materials were used during the process of the experiment: solar panels, concave lens, head lump, multi-meter, volt-meter and photovoltaic cells.

Site Assessment

The following concepts and tips that were adhered to while performing the site assessment: Shading can be an issue for solar panels because it reduces the maximum power that can be generated. One of the most often used tools is the solar pathfinder, which shows the sun's direction throughout the year as well as how much sunlight each given place will receive. Sun hours are critical for determining how much radiance will be required to create the necessary efficiency watts. This statistic indicates the amount of hours a location will receive the most sunlight (Franklin, 2017). Hence, the study considered the efficiency of a common solar module at low sun intensity. The experiment commenced towards sun fall, precisely at about 4.30pm to 5.30pm. Readings were taken after 15 mins in these sequence: 4.30pm, 4.45pm, 5.00pm, 5.15pm and 5.30pm. The tilt angle of the panels is the setting required to provide maximum brightness. Ideally, the tilt angle corresponds to the latitude of the geographic region. It is advisable to have an adjustable panel frame as the sun hours continue to change with respect to the tilt in the rainy and dry seasons.

Standalone or Off-Grid Systems

Off-grid system refers to a system that is not related to the grid facilities. Off-grid PV systems refer to systems that are not connected to the main electrical grid (Weis, 2013). Off-grid systems, also known as standalone systems or small grids, are capable of generating power and running appliances independently. Off-grid solutions are appropriate for the electrification of small communities.

Figure 1: Off-grid Solar PV system

Experimental Procedure

The following experimental procedure were carried out: Suspension of two (2) panels at an angle of 45 ºC each, Placement of lens on the panels, Connection of measuring equipment to the solar panels, Taking of Readings at both voltage and the current at 15 minutes interval.

Figure 2: Fixing and Mounting of the Panels

RESULTS AND DISCUSSION

Results

Results of Timely Comparison between Lens and Without Lens Measured in Volts

Table 1 and Figures 1-3 shows the timely results for comparison between lens and without lens measured in volts. From the results on Table 1 and Figures 3-5, it could be observed that the results for lens increases in volts while that of without lens were decreasing. At the peak, 4.30 pm, the results for with lens was 19.8 volts while that of without lens was 18.6 volts, at 4.45 pm, it was 17.5 volts while that of without lens was 16.9 volts, at 5.00 pm, it was 22.4 which was the highest and 21.2 volts for without lens, at 5.15 pm, it was 21.9 volts for with lens and 19.5 volts for without lens and 20.9 volts for with lens and 18.9 volts for without lens. From the results, it could be deduced that diverging lens played potential role in production of light using solar module at a relatively low solar intensity; thereby reducing glare and diffusing light; optimized light for low intensity usage and application; for spread incoming light, creating a softer and more even illumination, which may benefit specific solar technologies optimized for low-intensity light; helped in light collection in cloudy state, lastly are useful research materials for solar testing.

Table 1: Timely Comparison between Lens and without Lens Measured in Volts

Time	With Lens (Volts)	Without Lens (Volts)
4.30 pm	19.8	18.6
4.45 pm	17.5	16.9
5.00 pm	22.4	21.2
5.15 pm	21.9	19.5
5.30 pm	20.9	18.9

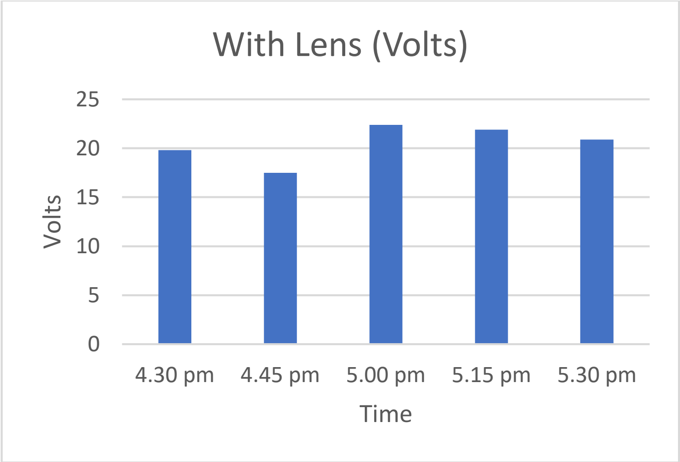

Figure 3: Lens Timely Result in Volts

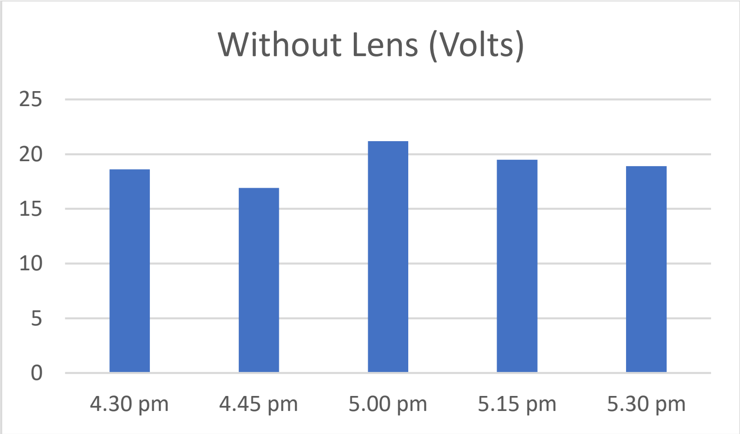

Figure 4: Timely Result for Without Lens in Volts

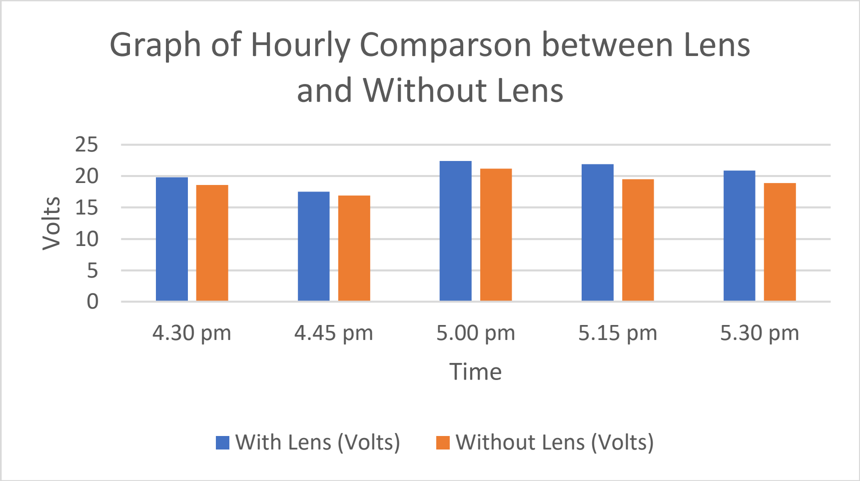

Figure 5: Timely Comparison between Lens and without Lens in Volts

Results of Timely Comparison between Lens and Without Lens Measured in Ampere

Table 2 and Figures 6-9 show the results of timely comparison between lens and without lens measured in ampere. From the results, it could be observed that without lens recorded increasing results at various hours while with lens experienced decreasing results. At 4.30 pm, the result for lens was 38 ampere while without lens had 60 ampere, at 4.45 pm, lens had 40 while without lens had 64 ampere, at 5.00 pm, with lens had 36 ampere while without lens had 58 ampere; at 5.15 pm, lens recorded 37 while without lens recorded 61 ampere while at 5.30 pm, lens had 34 ampere, without lens recorded 55 ampere. From the results, it could be observed that at 5.30 pm, the least ampere was recorded for both while at 4.45 pm, there was greater result indicating fluctuation of solar.

Table 2: Timely Comparison between Lens and without Lens Measured in Ampere

Time	With Lens (Ampere)	Without Lens (Ampere)
4.30 pm	38	60
4.45 pm	40	64
5.00 pm	36	58
5.15 pm	37	61
5.30 pm	34	55

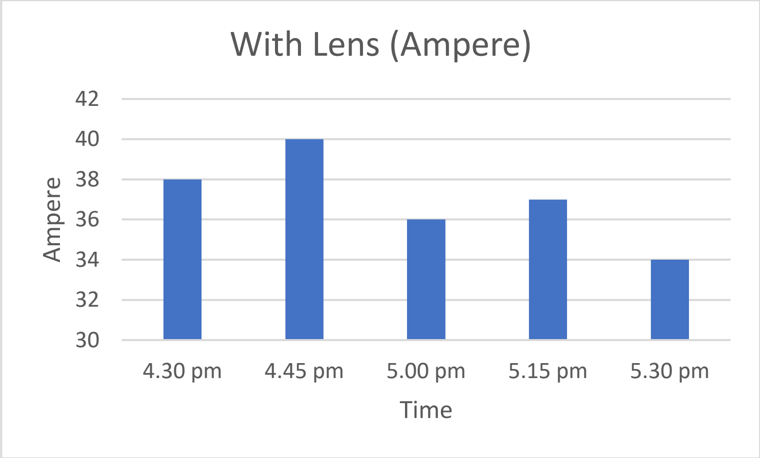

Figure 6: Lens Timely Result in Ampere

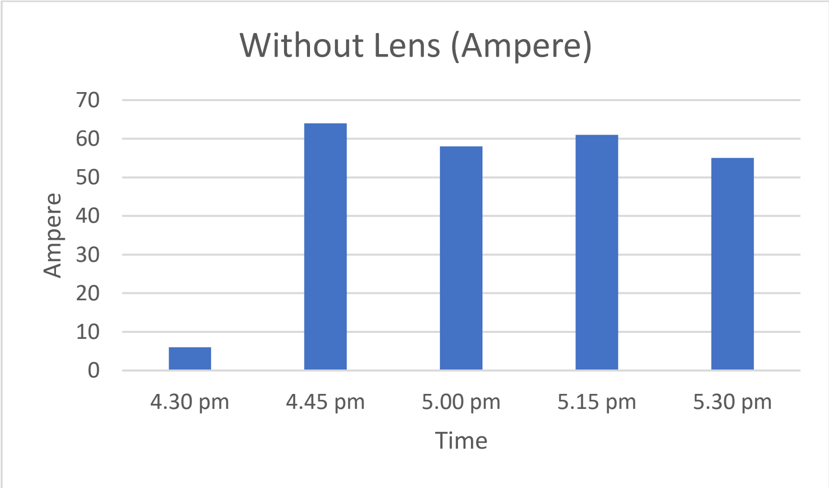

Figure 7: Timely Result for Without Lens in Ampere

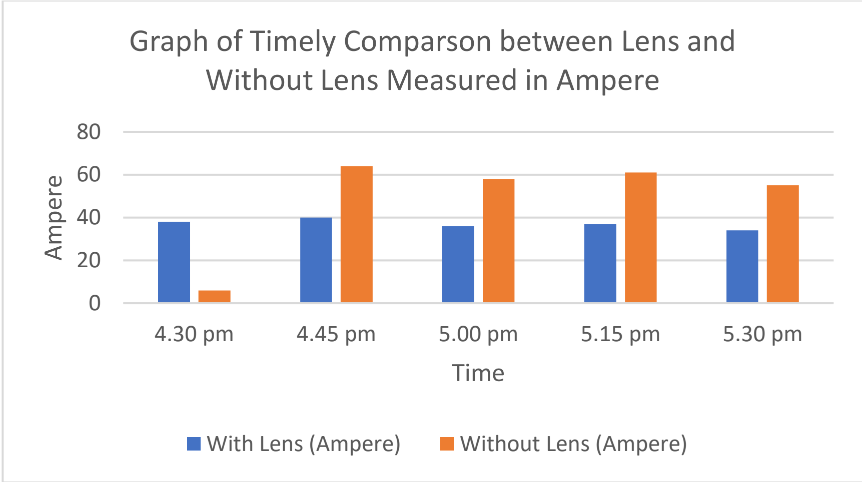

Figure 8: Timely Comparison between Lens and without Lens in Ampere

Figure 9: Generated Power after Installation

Discussion of Findings

The findings of this study has revealed that a diverging lens influences the efficiency of a solar module by dispersing the incoming light rays out from the focal point, resulting in a reduced intensity of light reaching the solar cells, affecting the solar module efficiency and especially at low solar intensity (Eshan & Maziyar, 2020). The above findings of this study corresponds with the findings of Slamet and Gatot (2018), who demonstrated that using a Fresnel lens concentrator increased the power output of a solar panel by approximately 119.2%.

The experiment revealed that a diverging lens causes light beams to diverge, resulting in less concentrated light striking the solar cells. For a solar panel that relies on direct, focused light, this can lead to lower power efficiency. This is more pronounced at low solar intensity, because there is already a limited amount of light available for conversion (Meng et al., 2025). This findings is in agreement with the findings of Slamet and Gatot (2018), who observed an increased and overall test power in solar panel using Fresnel lens optimization of 29.7 watts.

It was discovered that when the diverging lens spreads out light, some of it falls straight onto the panel's active area, especially since the panel was intended for a particular incident angle. This dispersion generated an increase in reflection losses, leading to increased inefficiency. This findings might be due to the fact that the solar panels were installed on static structures at varying time of the day as a well as the fact that the panel is not sun-oriented in east-west direct. This is in agreement with the findings of Katrandzhiev and Karnobatev (2019), who cited the factors responsible for diverging lens spreading out light.

The solar cells transformed light into electricity dependent on the intensity of the light that struck their surface. Divergence reduced the voltage and current generated, resulting in lesser efficiency (Proctor & Nguyen, 2015).

Solar modules were generally optimized for direct sunlight. Diverged light led to the solar cells not operating at their maximum efficiency, as they were likely designed to work best with focused or at least collimated light (Kolkowska, 2023). In essence, the utilization of a diverging lens on a solar panel at low solar intensity decreased the panel's efficiency by reducing light concentration, which limited the power conversion efficiency of the solar cells (Bunea et al., 2006).

CONCLUSION

The study's findings suggest that diverging lenses are indispensable tools in optical systems for controlling light paths and creating specific types of images owing to their ability to spread light outward. Conclusively, the relationship can be described as inversely proportion; in order words, as the diverging effect grows, the solar module's power output decreases. This impact in particularly pronounced when solar intensity is already low, as the additional light spreading reduces the effectiveness of the already limited solar energy. The study therefore recommended need for development of PV panels and cells, patenting of new solar PV products and emergence of PV technology clusters and hubs to stimulate industrial growth.

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