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Performance analysis of monocrystalline and polycrystalline photovoltaic cells under different solar irradiance conditions

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Abstract

This study presents a performance analysis of monocrystalline and polycrystalline photovoltaic (PV) cells under varying solar irradiance conditions. Two 250 W PV panels one of each type were evaluated using a controlled experimental setup exposed to natural sunlight. Solar irradiance was measured with a lux meter, while output voltage and current were recorded using digital meters to determine power output and efficiency. The results demonstrate a strong positive correlation between solar irradiance and electrical output for both panel types. However, the monocrystalline panel consistently outperformed the polycrystalline panel, achieving a maximum power output of 247.25 W and peak efficiency of 20.35% at an irradiance of 632 W/m^2, compared to 214.20 W and 17.80% for the polycrystalline panel under the same conditions. A slight drop in efficiency at the highest irradiance levels suggests the influence of thermal effects. Overall, the findings confirm that monocrystalline PV cells offer superior performance across a range of irradiance levels, particularly in both low and high light environments, making them more suitable for applications requiring high energy efficiency.

Keywords: Solar Irradiance; Photovoltaic; Monocrystalline; Polycrystalline

1. Introduction

Solar energy has emerged as a cornerstone of sustainable energy development, offering an inexhaustible and environmentally friendly alternative to fossil fuels. The rapid global growth in energy demand, alongside concerns about climate change and greenhouse gas emissions, has intensified interest in photovoltaic (PV) technologies. These systems convert solar irradiance the power of solar radiation per unit area into electrical energy through the photovoltaic effect. However, the efficiency of PV systems is highly dependent on several environmental factors, among which solar irradiance plays a pivotal role (Echendu and Amadi, 2018). Photovoltaic cells are broadly categorized based on their material composition and manufacturing techniques. The two most common types are monocrystalline and polycrystalline silicon solar cells. Monocrystalline cells are fabricated from a single continuous crystal structure, giving them a uniform appearance and higher efficiency, typically ranging between 18–22%. In contrast, polycrystalline cells are composed of multiple silicon crystals, making them less expensive to produce but generally less efficient, with average efficiencies of around 15–17% (Green et al., 2020).

1.1. Importance of Solar Irradiance in PV Performance

Solar irradiance significantly influences the electrical output parameters of a solar panel, including open-circuit voltage (Voc), short-circuit current (Isc), and maximum power output (Pmax). Studies have consistently shown that an increase in irradiance leads to a proportional increase in current output, while voltage sees a marginal rise (Duffie et al., 2020). As a result, the overall power output of PV systems increases with irradiance, up to the limits of the panel's rated capacity. Given these dynamics, several researchers have sought to characterize the performance of PV modules under

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varying irradiance levels. For instance, (Ishaque et al., 2011) conducted a simulation-based study to model PV behavior under partial shading and irradiance variations. Their findings highlighted the non-linear relationship between irradiance and PV output and the importance of real-time monitoring and control systems. Similarly, (Mekhilef et al., 2012) evaluated different PV technologies under fluctuating environmental conditions and emphasized the superior performance of monocrystalline modules in low-light environments.

1.2. Comparative Studies on Monocrystalline and Polycrystalline PV Modules

There has been considerable interest in comparing the behavior of monocrystalline and polycrystalline PV modules under varying solar conditions. (Kymakis et al., 2009) compared the outdoor performance of both technologies in Crete and reported that monocrystalline panels maintained higher efficiency and power output across a wide range of irradiance and temperature conditions. Polycrystalline modules, while economically advantageous, exhibited greater susceptibility to performance drops under low irradiance and high-temperature scenarios. Additionally, a study by (Chatta et al., 2018) investigated the daily and seasonal performance variations of both panel types in tropical environments. Their results showed that while the initial cost of monocrystalline modules was higher, the superior energy yield over time could justify the investment in regions with inconsistent irradiance. The study also noted that polycrystalline modules performed adequately under stable high-irradiance conditions, making them suitable for areas with consistent sunlight.

2. Motivation for the Present Study

Despite these comparative studies, the need for localized and experimentally validated data remains strong, particularly in regions where solar irradiance varies significantly throughout the day and across seasons. This is especially relevant in tropical and subtropical climates, where cloud cover, atmospheric humidity, and dust can substantially affect solar panel performance (Ajayi et al., 2010) . Furthermore, as more decentralized solar systems are deployed in rural and urban environments, understanding the real-world performance of different PV technologies under specific irradiance profiles becomes crucial. This study seeks to address these gaps by conducting an experimental investigation into the impact of solar irradiance on the electrical output of monocrystalline and polycrystalline photovoltaic cells. By measuring output parameters such as voltage, current, and power under varying light intensities, the research aims to provide comparative insights into the performance of these two PV technologies. This work is particularly significant for engineers, energy planners, and policymakers seeking to optimize solar installations for maximum efficiency and cost-effectiveness in diverse climatic zones.

Table 1 current and Voltage Readings from Monocrystalline and Polycrystalline PV

Irradiance (lux)	Irradiance (W/m^2)	Mono Voltage (V)	Mono Current (A)	Mono Power (W)	Poly Voltage (V)	Poly Current (A)	Poly Power (W)
20,000	158.0	18.0	2.5	45.00	17.5	2.3	40.25
40,000	316.0	19.5	5.0	97.50	18.8	4.6	86.48
60,000	474.0	20.2	7.4	149.48	19.4	6.8	131.92
80,000	632.0	21.0	9.8	205.80	20.0	9.0	180.00
100,000	790.0	21.5	11.5	247.25	20.4	10.5	214.20

3. Methodology

This study aims to investigate the impact of solar irradiance on the electrical output of monocrystalline and polycrystalline photovoltaic (PV) cells. A comparative experimental approach was employed using two 250 W PV panels one monocrystalline and the other polycrystalline under varying solar irradiance levels. Key electrical parameters such as voltage, current, and power output were measured and correlated with solar irradiance levels recorded in real time.

3.1. Experimental Setup

The experiment was conducted in an open outdoor environment with minimal shading to ensure maximum exposure to natural sunlight. The setup comprised the following components

- **Two 250 W solar panels**: One monocrystalline and one polycrystalline, each with similar physical dimensions and ratings for fair comparison.
- **Lux meter**: Used to measure the incident solar illuminance in lux (lx), providing a proxy for solar irradiance.
- **Digital voltmeter**: Connected across the output terminals of each panel to measure the open-circuit voltage (Voc) and operating voltage under load.
- **Clamp Meter**: use to clamp the panel wires under short circuit test and short circuit current is measured S_{ic}.

3.2. Procedure

- **Panel Positioning**: Both panels were mounted at a fixed tilt angle approximating the local latitude to maximize solar exposure. Panels were aligned southward (in the northern hemisphere) for optimal solar tracking.
- **Instrument Calibration**: Prior to data collection, the lux meter, ammeter, and voltmeter were calibrated according to the manufacturers' specifications to ensure accurate readings.
- **Data Collection**: The experiment was conducted across different times of the day (morning, noon, and afternoon) under clear sky conditions. The following steps were taken at each measurement interval
- The **lux meter** was positioned on the surface of each panel to record the solar illuminance in lux.
- The **voltage** across the terminals of each panel was recorded using the voltmeter.
- The **current** was measured by the ammeter under a known resistive load.
- **Power output** was calculated using the formula:

$$P = V \times I$$

- Measurements were repeated multiple times at each irradiance level to ensure reliability and averaged for consistency.
- **Replicability and Validation**: The procedure was repeated on different days to account for natural variation in irradiance and weather conditions. Data were averaged and analyzed to identify trends in PV performance relative to solar intensity.

3.3. Data Analysis

The collected data were tabulated, and graphs were plotted showing the relationship between solar irradiance (in lux) and the following electrical parameters for both types of PV panels

- Output Voltage (V)
- Output Current (I)
- Output Power (P)
- Efficiency (if calculated using

$$Efficiency = \frac{Pout}{Pin} \times 100$$

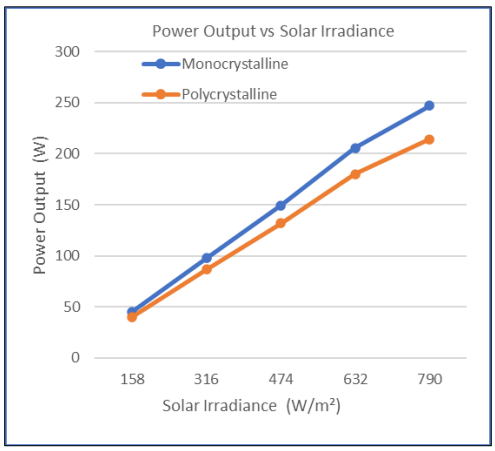


Figure 1 Graph Analysis: Power Output vs. Solar Irradiance

From the plotted graph

- **Power output increases linearly with irradiance** for both panel types, which is expected due to the direct relationship between sunlight intensity and photon-induced current generation.
- The **monocrystalline panel consistently outperforms** the polycrystalline panel across all irradiance levels. At peak irradiance (790 W/m^2), the monocrystalline panel reaches ~247 W compared to the polycrystal line's ~214 W.
- **Efficiency difference widens at higher irradiance levels**, indicating that monocrystalline panels are better suited for high-irradiance conditions.

At low irradiance (158 W/m^2), both panels show a similar drop-off in performance, though monocrystalline still leads slightly, demonstrating better low-light sensitivity.

Table 2 Comparison of Monocrystalline and Polycrystalline Efficiency under the same Irradiance

Irradiance (W/m^2)	Monocrystalline Efficiency (%)	Polycrystalline Efficiency (%)
158.0	17.80	15.92
316.0	19.28	17.10
474.0	19.71	17.39
632.0	20.35	17.80
790.0	19.56	16.95

3.4. Graph Analysis: Efficiency vs. Solar Irradiance

- **Monocrystalline panel shows higher efficiency** than polycrystalline across all irradiance levels.
- Peak efficiency for monocrystalline (~20.35%) occurs at around **632 W/m^2**, suggesting it performs best under moderately high irradiance.
- Polycrystalline efficiency peaks slightly earlier but stays consistently lower, reaching a maximum of ~17.8%.
- At very high irradiance (790 W/m^2), both panels show a slight **decline in efficiency**, which may be attributed to temperature effects or saturation of photoactive material

4. Results and Discussion

The experimental results demonstrate a clear and consistent relationship between solar irradiance and the electrical performance of both monocrystalline and polycrystalline photovoltaic (PV) panels. As expected, output power increased proportionally with rising irradiance levels for both types of PV panels. However, the monocrystalline panel consistently outperformed the polycrystalline panel in terms of voltage, current, power output, and efficiency under all irradiance conditions.

4.1. Power Output Comparison

The monocrystalline panel generated a maximum output of 247.25 W at an irradiance level of 790 W/m^2, while the polycrystalline panel produced 214.20 W under the same conditions. This corresponds to a performance difference of approximately 15.4%, affirming the superior photon-to-electron conversion capability of monocrystalline silicon cells. Additionally, the voltage output of the monocrystalline panel was marginally higher across the entire irradiance range, contributing to its greater power output.

4.2. Efficiency Trends

Efficiency was calculated by comparing output power to the estimated solar power input, assuming a panel area of 1.6 m^2. The monocrystalline panel achieved peak efficiency of 20.35% at 632 W/m^2, while the polycrystalline panel reached a maximum of 17.80% at the same irradiance level. Notably, the monocrystalline panel-maintained efficiency above 19% across most irradiance levels, while the polycrystalline panel hovered between 15.9% and 17.8%. Interestingly, both panels exhibited a slight drop in efficiency at the highest irradiance level (790 W/m^2). This may be due to thermal effects, as higher irradiance often results in increased panel temperature, which negatively affects performance particularly voltage output due to reduced bandgap efficiency in semiconductors. This observation aligns

with findings from prior studies (e.g., Abdelhady et al., 2020, Solanki, 2015) that highlight the temperature dependence of PV panel performance.

4.3. Low-Irradiance Performance

At the lowest irradiance level (158 W/m^2), both panels experienced significant drops in power output, with the monocrystalline panel producing 45 W and the polycrystalline generating 40.25 W. Despite the lower absolute values, the monocrystalline panel again showed superior efficiency (17.8% vs. 15.9%). This suggests better low-light sensitivity, which is advantageous for applications in cloudy regions or during early morning/late afternoon hours.

5. Conclusion

This study investigated the effect of solar irradiance on the output performance of monocrystalline and polycrystalline photovoltaic panels using experimental measurements of voltage, current, power, and efficiency. The results reveal the following key findings

- Monocrystalline panels outperform polycrystalline panels in terms of power output and efficiency across all tested irradiance levels.
- Efficiency of monocrystalline panels peaks at around 20.35%, compared to 17.80% for polycrystalline, indicating better conversion efficiency.
- Both panel types show reduced performance at very high irradiance, likely due to thermal effects.
- Monocrystalline panels are better suited for low-light and high-efficiency applications, offering a broader operating range.

These findings support the preferential use of monocrystalline panels in applications where space efficiency, performance under variable lighting, and long-term energy yield are critical. However, polycrystalline panels may still be viable in budget-sensitive scenarios where marginally lower efficiency is acceptable.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Ajayi, O. O., Fagbenle, R. O., Katende, J., Okeniyi, J. O., and Omotosho, O. A. (2010). Wind energy potential for power generation of a local site in Gusau, Nigeria. International Journal of Energy for a Clean Environment, 11(1–4), 99–116. https://doi.org/10.1615/InterJEnerCleanEnv.2011003309

[2] Chatta, M. B., Ali, H. M., Ali, M., and Anser Bashir, M. (2018). EXPERIMENTAL INVESTIGATION OF MONOCRYSTALLINE AND POLYCRYSTALLINE SOLAR MODULES AT DIFFERENT INCLINATION ANGLES. In Journal of Thermal Engineering (Vol. 4, Issue 4). Yildiz Technical University Press.

[3] Duffie, J. A. ., Beckman, W. A. ., and Blair, Nate. (2020). Solar engineering of thermal processes, photovoltaics and wind. Wiley.

[4] Echendu, R. E., and Amadi, H. N. (2018). Performance Evaluation of a Standalone Solar PV System for Electricity Generation in an Estate. European Journal of Electrical Engineering and Computer Science, 2(4). https://doi.org/10.24018/ejece.2018.2.4.24

[5] Green, M. A., Dunlop, E. D., Hohl-Ebinger, J., Yoshita, M., Kopidakis, N., and Hao, X. (2020). Solar cell efficiency tables (version 56). Progress in Photovoltaics: Research and Applications, 28(7), 629–638. https://doi.org/10.1002/pip.3303

[6] Ishaque, K., Salam, Z., and Syafaruddin. (2011). A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two-diode model. Solar Energy, 85(9), 2217–2227. https://doi.org/10.1016/j.solener.2011.06.008

[7] Kymakis, E., Kalykakis, S., and Papazoglou, T. M. (2009). Performance analysis of a grid connected photovoltaic park on the island of Crete. Energy Conversion and Management, 50(3), 433–438. https://doi.org/10.1016/j.enconman.2008.12.009

[8] Mekhilef, S., Saidur, R., and Kamalisarvestani, M. (2012). Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. In Renewable and Sustainable Energy Reviews (Vol. 16, Issue 5, pp. 2920–2925). https://doi.org/10.1016/j.rser.2012.02.0