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Article

Comparative analysis of half-cut monofacial monocrystalline solar panel and traditional full-cell monofacial monocrystalline solar panel

Akpovi Oyubu Oyubu*, Ufuoma Kazeem Okpeki, Anthony Onoharigho Okpare, Ikechukwu Emmanuel Onuigbo, Favour Emmanuel Egwuenu, Akpoghene Destiny Dibie

Electrical/Electronic Engineering Department, Delta State University, Abraka 330106, Nigeria; ukokpeki@delsu.edu.ng (UKO); okpareao@delsu.edu.ng (AOO); emmaneuelonuigbo71@gmail.com (IEO); egw.favour@gmail.com (FEE); destinydibie@gmail.com (ADD)

* **Corresponding author:** Akpovi Oyubu Oyubu, oaoyubu@delsu.edu.ng

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Abstract: Despite the theoretical benefits of the half-cut cells over the traditional full-cell monocrystalline panel, there is limited comparative analysis showing its power output by comparing voltage, current, efficiency and other parameters between both panels under varying sunlight conditions; thus this research aimed to evaluate and compare the performance of both panel technologies in terms of voltage, current, and power output at different times of the day, while also considering environmental factors such as temperature, humidity, and solar irradiance. An experimental research design was adopted using two 400 W solar panels with measurements taken simultaneously at 2.5 h intervals between 10:00 am and 3:00 pm for a period of three months under two scenarios—without shading and with shading. The findings revealed that while the traditional panels consistently produced higher voltage values, the half-cut panels generated significantly higher current outputs resulting in greater overall power generation. Statistical analysis including percentage variance, and standard deviation reveal that the energy yield of the half cut is slightly higher than that of the full cut; but the Analysis of Variance (ANOVA) carried out to deepen the result of the statistical analysis depict that there is no significant difference in the power generation of both technologies under the 'without shading' scenario. However, from the ANOVA, a significant difference under the 'with shading' scenario with the half-cut panels having a higher power generation thus confirming the superior energy yield and performance stability of the half-cut panels under all environmental conditions including shading when compared to their traditional full-cell counterpart.

Keywords: half-cut; full-cell; monofacial; monocrystalline; solar

1. Introduction

Solar energy has emerged as one of the most sustainable and rapidly growing sources of electrical energy (electricity) worldwide. The increasing demand for renewable energy solutions has driven advancements in PV (photovoltaic) technology, with the monocrystalline technology being the most efficient and widely used of all types [1–5]. Monocrystalline panels are known for their high efficiency, long lifespan, and superior performance compared to other PV technology types, making them preferred choice for residential, commercial and industrial applications [4–6].

Around 10 years ago the sizes of the solar panels were large and hence large lands were required for solar power generation. Advancement in solar technology has significantly reduced land footprint required for the same amount of generation.

Similarly, efficiency was the second parameter, the performance of a solar system using a PV system software was investigated by Omorogiuwa et al. [7, 8] wherein a 10 kW and a 650-kW grid-connected PV system were simulated. The effect of solar irradiation, and temperature on the energy output of the PV array, performance ratio and PV array loss were considered. Array output was directly proportional to irradiation. However, increase in temperature above 300 °C led to decrease in energy output.

As solar technology evolves, modifications such as the half-cut cell technology have been introduced to better improve efficiency and also reduce loss of energy during operations. Half-cut Mono-facial Monocrystalline panels are designed to enhance output by reducing resistive losses and increasing shade tolerance [9–12]. Previous studies suggest that half-cut cells minimize heat losses and improve module durability, leading to higher power output compared to the traditional mono-facial monocrystalline panels [13]. However, limited real-time studies exist comparing the performance of the two panel types under real life environmental conditions. There is need for a real time comparative analysis of their performance, understanding how these panels perform in terms of voltages, current, and power output at different times will help in optimizing their usage in various solar power applications.

Despite the theoretical benefits of the half-cut cells over the traditional full-cell monocrystalline panel, there is limited comparative analysis showing its power output by comparing voltage, current, efficiency and other parameters between both panels under varying sunlight conditions; thus, this study presents a comparative analysis of half-cut monofacial monocrystalline solar panels and traditional full-cell monofacial monocrystalline solar panels under real-time tropical conditions at Delta State University, Abraka, Oleh Campus, a city in the Niger Delta region of Nigeria. The research aimed to evaluate and compare the performance of both panel technologies in terms of voltage, current, and power output at different times of the day, while also considering environmental factors such as temperature, humidity, and solar irradiance. An experimental research design was adopted using two 400 W solar panels with measurements taken simultaneously at 2.5 h intervals between 10:00 am and 3:00 pm for a period of three months under two scenarios-without shading, and with shading. The findings revealed that while the the energy yield of the half cut is slightly higher than that of the full cut; traditional panels consistently produced higher voltage values, the half-cut panels generated significantly higher current outputs resulting in greater overall power generation. Statistical analysis including percentage variance, and standard deviation analysis established that the half-cut panels regularly outperformed the traditional panels in terms of power output. Though the standard deviation indicated higher variations in the output of the half-cut panels due to varying climatic conditions, their mean energy yield remained constantly higher than that of the conventional full-cell panels.

However, the ANOVA carried out to deepen the result of the statistical analysis depict that there is no significant difference in the power generation of both technologies under the 'without shading' scenario. But from the ANOVA, a significant difference in power generation of both technologies was observed under the 'with shading' scenario with the half-cut panels having a higher power generation thus confirming the superior energy yield and performance stability of the half-cut panels under all environmental conditions including shading when compared to their traditional full-cell counterpart. These can be adduced to their innovative cell design, which offers higher efficiency due to reduced resistive losses and improved electrical flow which lies in the split cells. Their ability to mitigate shading losses makes them more reliable in varying environmental conditions, ensuring a more consistent power output.

Overall, this study makes an invaluable contribution to both the academic literature and practical solar engineering by addressing the environmental, methodological, and comparative gaps identified in previous studies. The findings establish that half-cut monocrystalline panels are not only theoretically more efficient but also empirically superior under tropical climatic conditions. Accordingly, the study provides engineers, solar-power system installers, policymakers, and capitalists with reliable, evidence-based guidance for choosing photovoltaic technologies appropriate for deployment in Nigeria and other regions with similar environmental conditions.

Oyubu et al. [14] employ a methodology in assessing efficiency degradation and offers a framework that will be adopted to compare the resilience of half-cut and traditional panels under similar environmental stresses. Oyubu et al. [14, 15] concentrated on Niger Delta, providing a framework for this study since they all address the unique environmental challenges faced by solar installations in this area, providing insights that are directly applicable to local conditions. Oyubu et al. [14] do not comparatively analyze various solar panel technologies but was limited to the analysis of a neat panel and soot covered panel surface. However this study will specifically compare half-cut and traditional mono-facial monocrystalline panels, offering a more targeted analysis and improvements [14].

Okpeki et al. [16–20] provide insights into designing and implementing a solar power system, with details of the selection of components like solar panels, batteries, and inverters, offering a benchmark for assessing the efficiency and suitability of various panel technologies in comparable setups. However, the research does not present a comparative appraisal of different solar panel technologies; rather, this work articulates the shortcomings by investigating the performance dissimilarities between half-cut and conventional monocrystalline solar panels.

Jatoi et al. [21–25] identify current advancements in the efficiency of monocrystalline solar panels, which backs up the objective of this article to compare the performance of half-cut and conventional monofacial monocrystalline panels. They specify a functional framework for examining important performance pointers, including power output, temperature response, and degradation rates, which are important for the comparative analysis carried out in this research. Nonetheless, the studies do not investigate panel performance under Nigeria's climatic conditions, where elements such as high ambient temperatures, dust accumulation and environmental conditions can considerably influence solar panel efficiency.

Abdullahi et al. [3] examine the performance of monocrystalline photovoltaic solar panels in Kano, Nigeria, a region marked by high temperatures and substantial accumulation of dust. Their outcomes contribute important insight into the consequences of these environmental conditions on panel performance. This evidence acts as an important resource for the current study, which analyzes the efficiency of conventional monocrystalline and half-cut solar panels which are in operation under identical climatic conditions.

Dallaev et al. [9–12] present an exhaustive survey of half-cut solar cell technology, emphasizing design advancements that mitigate resistive losses, enhance power output, and amplify tolerance to partial shading. These findings offer a robust theoretical background for comprehending the functional advantages of half-cut solar panels and backs up their juxtaposition with conventional monocrystalline panel designs in this study.

Oyubu et al. [14] focused on the performances of installed solar street lights in Oleh the same environment where this study was carried out. Although a comparative study of both the full-cell and half cut technologies was not carried out in the work, it however provides an insight into the performance of photovoltaic panels in the study environment.

2. Materials and methods

A real-time comparative analysis of half-cut mono-facial monocrystalline panels and the traditional full cell mono-facial monocrystalline panels was carried out specifically focusing on measuring voltage, current, and power output under varying environmental conditions: temperature, humidity and solar irradiance. The study framework comprises diverse experimental arrangements, data collection procedures and analytical approaches.

The photovoltaic panels, a 400 W half-cut mono-facial monocrystalline panel and a 400 W traditional (full-cell) mono-facial monocrystalline panel, were operated and investigated under the same environmental conditions in Oleh, Delta State, Nigeria.

Both panels (One 400 W half-cut mono-facial monocrystalline and one 400 W traditional (full-cell) mono-facial monocrystalline) were exposed to the same environmental conditions in Oleh, Delta State, Nigeria, to guarantee an impartial and objective performance comparison. The main parameters computed were:

a) Voltage (V) output.
b) Current (A) output.
c) Power (W) output.
d) Environmental Temperature.
e) Humidity.
f) Solar irradiance.

The outcomes of the experiment were analyzed to decide on the solar panel technology with the best efficiency, the most optimal performance, and the utmost stability under variable climatic conditions. This design framework for the study was chosen because direct experimental assessment produces more reliable and authentic results than the ones obtained mainly from simulation-based studies or results gotten from secondary data examination.

Further materials employed in this study are:

1. Measuring Instruments.
    - Digital multimeter (to measure voltage and current).
    - Pyranometer (to measure solar irradiance).
    - Thermometer (to monitor environmental temperature).
    - Hygrometer (to obtain the humidity measurement).
2. Other Accessories.
    - Datasheet for recording values.
    - Large pieces of cut cartons to simulate shadings.
    - Tilt stand for mounting both panels at the same inclination.

The experiment was performed in an exposed outdoor environment wherein the two photovoltaic solar panels were exposed to unimpeded direct sunshine over the duration of the test. To guarantee maximal solar energy absorption under Nigerian climatic conditions, the panels were installed on the same ground surface and oriented southward at an optimum tilt angle of 15°. Both panels were positioned on same support base, with a very small distance of separation between them to ensure they were put through the same environmental conditions, like solar irradiance, ambient temperature, and shading effects. 25% of the total surface area of each panels were covered with large pieces of cut carton to mimic shading all through the experiments on the shading scenario spanning the period of the study in order to observe the shading effect on both panels. The four sides of each of the panels were covered one side per each experiment and measurement taken. These strategies assured an objective and reliable comparison of the two panel technologies' performance.

The electrical output parameters of the two photovoltaic panels investigated, particularly voltage and current, were evaluated concurrently for both panels at separate times of the day to observe variations in their operational performance.

2.1. Data collection procedure

The data collection process involves the following steps:

1. Initial Setup: This procedure includes:
    - Ensuring both panel are clean and properly mounted.
    - Connect the multi-meter and pyranometer.
2. Measurement of Voltage and Current: Measurements were taken at 2:30 h intervals between 10:00 am and 3:00 pm which is the average peak sunlight duration (5 h) in Delta State, for consecutive days.
    - Measured parameters are:
        1) Open circuit voltage (V_{oc}).
        2) Short-circuit current (I_{sc}).
        3) Maximum power output (P_{max}).
        4) Environmental temperature and humidity.
    - Record open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}) for both panels.

- Power output was calculated using the formula:

$$P = V \times I$$

Where: P = Power (W);
V =Voltage (V);
I = Current (A).
Solar Irradiance and Temperature Monitoring:

- Measure solar irradiance (W/m^2) at the time of each reading.
- Record the environmental temperature of the panels to analyze its effect on efficiency.

3. Data Logging:

- Store the recorded values in a spreadsheet for analysis.

2.2. Data analysis

The collected data were analyzed using the following techniques:

- Graphical Analysis:
  Voltage, Current and Power output were plotted against time of the day to compare performance trends using ANOVA.
- Comparison of Efficiency:
  Efficiency was calculated using the formula:

$$Efficiency = \frac{Power\ Output}{Solar\ Irradiance \times Panel\ Area} \times 100$$

- Effect of Temperature and Irradiance:
  The impact of high temperatures and varying irradiance on panel performance was analyzed.

The specifications as well as the pictorial view of the investigated panels are presented in **Table 1** and **Figure 1** respectively.

Table 1. Specifications of the solar panels investigated.

Specifications	Half-cut	Full-cell
Rated Maximum Power (P_{max})	400 W	400 W
Power Tolerance	0–±5 W	0–±3 W
Maximum Power Voltage – V_{mp} (V)	34.4 V	67.32 V
Maximum Power current – I_{mp} (A)	10.27 A	7.68 A
Open Circuit Voltage – V_{oc} (V)	40.6 V	57.22 V
Short Circuit Current – I_{sc} (A)	11.25 A	6.99 A
V_{oc} & I_{sc} Tolerance	±3%	±3%
Maximum System Voltage	1,000 V	1,000 V
Maximum Series Fuse Rating	20 A	15 A
Operating Temperature	(−40 °C)–+85 °C	(−40 °C)–+85 °C
Protection Class	Class II	Class II

Figure 1. Pictorial view of the investigated panels.

3. Results

Result obtained from the research over the period of study for both scenarios ('without shading' and 'with shading') are here presented.

3.1. Three months mean values of data for 'without shading scenario'

Three months mean values of data for 'without shading scenario' are presented in **Tables 2–4**.

Table 2. Month 1 mean value of data for 'without shading' scenario.

Time	Voltage (V)		Current (A)		Power (W)		Temperature (°C)	Humidity (%)	Solar irradiance (W/M^2)
	Half	Full	Half	Full	Half	Full			
10:00 am	37.11	64.83	4.91	2.32	182.21	150.41	26.6	73.7	134.6
12:30 pm	36.94	64.83	5.81	2.81	214.62	182.17	27.9	72.9	179.9
03:00 pm	37.27	65.29	6.34	3.16	236.29	206.32	28.4	71.9	196.8

Table 3. Month 2 mean value of data for 'without shading' scenario.

Time	Voltage (V)		Current (A)		Power (W)		Temperature (°C)	Humidity (%)	Solar irradiance (W/M^2)
	Half	Full	Half	Full	Half	Full			
10:00 am	37.14	64.77	4.31	2.03	160.07	131.48	26.3	77.4	124.6
12:30 pm	37.21	64.44	6.66	3.57	247.82	230.05	27.4	78.7	185.4
03:00 pm	36.76	62.93	4.20	2.07	154.39	130.27	26.7	78.1	121.3

Table 4. Month 3 mean value of data for 'without shading' scenario.

Time	Voltage (V)		Current (A)		Power (W)		Temperature (°C)	Humidity (%)	Solar irradiance (W/M^2)
	Half	Full	Half	Full	Half	Full			
10:00 am	37.14	65.60	3.22	1.56	119.60	102.34	25.4	78.7	112.7
12:30 pm	36.53	65.57	5.07	2.39	185.21	156.71	26.4	77	134.4
03:00 pm	36.59	64.23	3.90	1.80	142.70	115.61	26.4	76.3	125.8

3.2. Three months mean values of data for 'with shading scenario'

Three months mean values of data for 'with shading scenario' are presented in **Tables 5–7**.

Table 5. Month 1 mean value of data for 'with shading' scenario.

Time	Voltage (V)		Current (A)		Power (W)		Temperature (℃)	Humidity (%)	Solar irradiance (W/M^2)
	Half	Full	Half	Full	Half	Full			
10:00 am	36.41	64.00	2.46	0.81	89.57	51.84	26.6	73.7	134.6
12:30 pm	36.19	64.26	2.71	0.89	98.07	57.19	27.9	72.9	179.9
03:00 pm	36.29	64.77	2.86	1.20	103.79	77.72	28.4	71.9	196.8

Table 6. Month 2 mean value of data for 'with shading' scenario.

Time	Voltage (V)		Current (A)		Power (W)		Temperature (℃)	Humidity (%)	Solar irradiance (W/M^2)
	Half	Full	Half	Full	Half	Full			
10:00 am	37.21	64.39	1.79	0.63	66.61	40.57	26.3	77.4	124.6
12:30 pm	36.90	64.04	2.88	1.14	106.27	73.01	27.4	78.7	185.4
03:00 pm	36.90	62.67	1.67	0.51	61.62	31.96	26.7	78.1	121.3

Table 7. Month 3 mean value of data for 'with shading' scenario.

Time	Voltage (V)		Current (A)		Power (W)		Temperature (℃)	Humidity (%)	Solar irradiance (W/M^2)
	Half	Full	Half	Full	Half	Full			
10:00 am	36.67	64.94	1.33	0.16	48.77	10.39	25.4	78.7	112.7
12:30 pm	35.99	64.94	2.15	0.36	77.38	23.38	26.4	77	114.4
03:00 pm	36.06	63.73	1.57	0.27	56.61	17.21	26.4	76.3	125.8

3.3. Graphical representation of the results of the various scenarios studied

Three points on the graphs (**Figures 2–5**) illustrate voltage and current at three different time intervals of 2.5 h spanning from 10:00 am to 3:00 pm matching the 5 h peak sun time in Delta State. It has differences in line slope that suggest variation in the solar panels performance across months offering an insight into the solar panel behaviour that an increase in sun intensity will result to increase in power.

Each specific data point representing measured current and voltage value for each month, helps us understand how the different solar panel technologies behave when subjected to the same environmental conditions.

It can be seen from the plots (**Figures 2** and **4**) that the half-cut monofacial monocrystalline panel generated lower voltages but far higher current when juxtaposed with the full cell monofacial monocrystalline panel technology; hence higher power throughout the period of study.

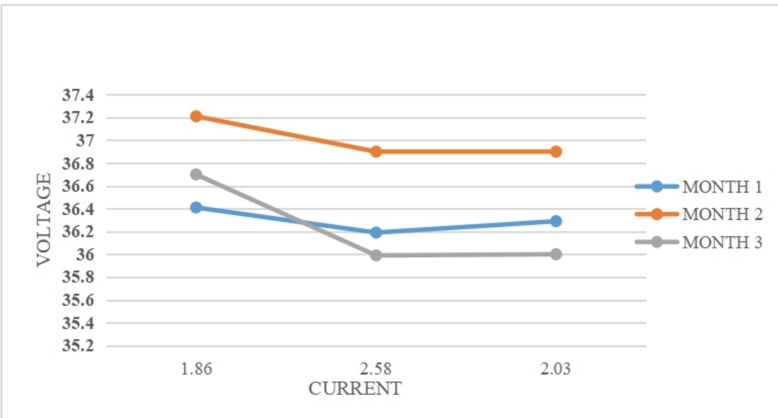

Figure 2. Graph of voltage against current of the half-cut monofacial monocrystalline panel under 'with shading scenario' for three months.

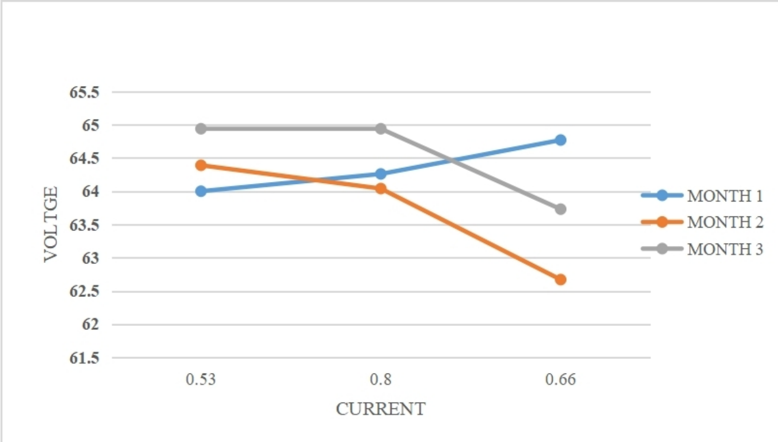

Figure 3. Graph of voltage against current of the full cell monofacial monocrystalline panel under 'with shading scenario' for three months.

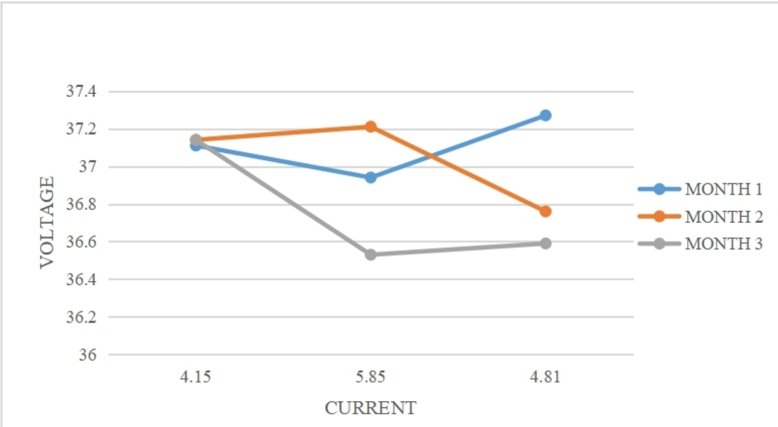

Figure 4. Graph of voltage against current of the half-cut monofacial monocrystalline panel under 'without shading scenario' for three months.

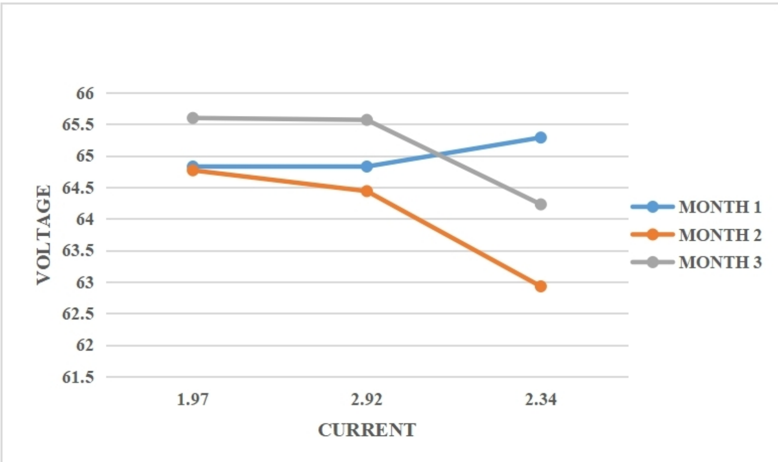

Figure 5. Graph of voltage against current of the full cell monofacial monocrystalline panel under 'without shading scenario' for three months.

3.4. Data analysis

3.4.1. Percentage variance

Percentage variance (**Tables 8–13**) in the current, voltage and power of the half-cut monofacial monocrystalline solar panel from the traditional full cell monofacial monocrystalline solar panel for both scenarios were obtained by applying the formula:

a) Percentage Variance in Voltage (V)

$$\frac{mean\ (V)\ half-cut - mean(V) traditional\ full\ cell}{mean(V)\ traditional\ full\ cell} \times 100$$

b) Percentage Variance in Current (A)

$$\frac{mean\ (A)\ half-cut - mean(A) traditional\ full\ cell}{mean(A)\ traditional\ full\ cell} \times 100$$

c) Percentage Variance in Power (W)

$$\frac{mean\ (W)\ half-cut - mean(W) traditional\ full\ cell}{mean(W)\ traditional\ full\ cell} \times 100$$

Table 8. Percentage variance in voltage (V) (without shading).

Months	Half cut (mean)	Full cell (mean)	Percentage variance
1	37.11	64.98	−42.89%
2	37.04	64.05	−42.17%
3	36.75	65.13	−44.34%

Table 9. Percentage variance in current (A) (without shading).

Months	Half cut (mean)	Full cell (mean)	Percentage variance
1	5.69	2.76	106.16%
2	5.06	2.58	96.12%
3	4.06	1.92	111.46%

Table 10. Percentage variance in power (W) (without shading).

Months	Half cut (mean)	Full cell (mean)	Percentage variance
1	211.04	179.63	17.49%
2	187.43	163.93	14.34%
3	149.17	124.89	19.44%

Table 11. Percentage variance in voltage (V) (under shading).

Months	Half cut (mean)	Full cell (mean)	Percentage variance
1	36.30	64.34	−44.27%
2	37.00	63.70	−41.92%
3	36.24	64.54	−43.85%

Table 12. Percentage variance in current (A) (under shading).

Months	Half cut (mean)	Full cell (mean)	Percentage variance
1	2.68	0.97	176.29%
2	2.11	0.76	177.63%
3	1.68	0.26	546.15%

Table 13. Percentage variance in power (W) (under shading).

Months	Half cut (mean)	Full cell (mean)	Percentage variance
1	97.14	62.25	56.04%
2	79.18	48.51	63.22%
3	60.92	17.00	258.35%

While charts representing the power generated by the half-cut monofacial monocrystalline and full cell monofacial monocrystalline solar panels for both scenarios within the period of the study are shown in **Figures 6** and **7**.

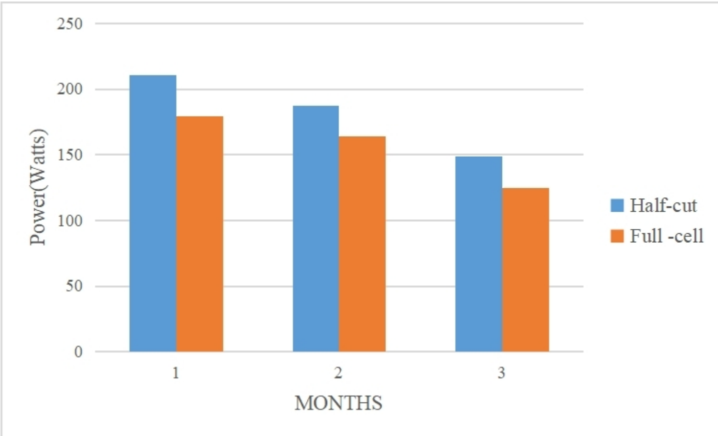

Figure 6. Chart of power of the half-cut solar panel versus power of the full cell solar panel for 3 months (under 'without shading' scenario).

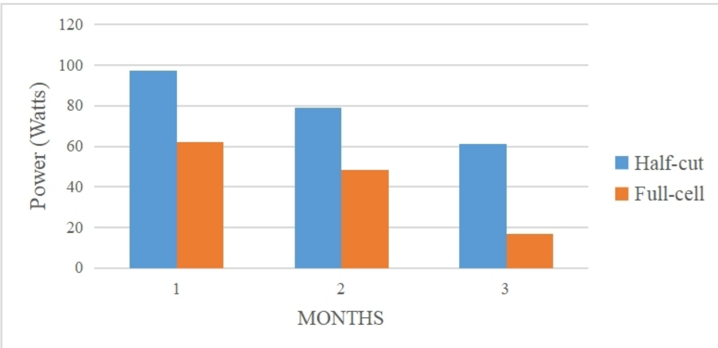

Figure 7. Graph of power of the half-cut solar panel versus power of the full cell solar panel for 3 months (under 'with shading' scenario).

3.4.2. Standard deviation in power generated

The standard deviation in the power generated by the half-cut and traditional full cell monofacial and monocrystalline solar panel during the duration of the study (3 months) under the same environmental condition for 'without shading' and 'with shading' scenarios were calculated using the Microsoft Excel spreadsheet, the result obtained are briefly presented as follows (**Tables 14–17**).

A. Half-Cut Monofacial Monocrystalline Solar Panel

Table 14. Standard deviation in the power of half-cut panels (without shading).

Total power generated	Mean of power generated	Standard deviation
9,901.10	176.81	79.31

Table 15. Standard deviation in the power of half-cut panels (with shading).

Total power generated	Mean of power generated	Standard deviation
4,055.95	83.19	65.78

B. Full cell Monofacial Monocrystalline Solar Panels

Table 16. Standard deviation in the power of full cell panels (without shading).

Total power generated	Mean of power generated	Standard deviation
7,872.18	151.39	74.12

Table 17. Standard deviation in the power of full cell panels (with shading).

Total power generated	Mean of power generated	Standard deviation
2,745.67	58.70	52.16

3.4.3. Analysis of Variance (ANOVA) test

To further analyze the obtained result from the comparison of the power generated by the half-cut monofacial monocrystalline solar panel and the traditional full cell monofacial monocrystalline solar panels throughout the study, an analysis of variance test was carried out for both scenarios in an Excel as presented in this subsection as follows (**Tables 18–21**):

A. Without shading scenario

Table 18. Summary (ANOVA) ('without shading').

ANOVA: Single factor				
Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
Half-Cut	9	1,642.91	182.545556	1,879.11218
Full cell	9	1,405.36	156.151111	1,813.24144

Table 19. Statistical analysis (ANOVA) ('without shading').

ANOVA						
Source of variation	**SS**	**Df**	**MS**	**F**	***p*-value**	**F crit**
Between Groups	3,135.00014	1	3,135.00014	1.69810396	0.21097826	4.49399848
Within Groups	29,538.8289	16	1,846.17681			
Total	32,673.8291	17				

B. With shading scenario

Table 20. Summary (ANOVA) (with shading).

ANOVA: Single factor				
Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
half cut	9	708.69	78.7433333	463.294975
full cell	9	381.25	42.3611111	563.554811

Table 21. Statistical analysis (ANOVA) (with shading).

ANOVA						
Source of variation	**SS**	**Df**	**MS**	**F**	***p*-value**	**F crit**
Between Groups	5,956.49742	1	5,956.49742	11.6014971	0.00361338	4.49399848
Within Groups	8,214.79829	16	513.424893			
Total	14,171.2957	17				

4. Discussion

The findings from this research are here discussed as follows:

1) Voltage Comparison
The results obtained from the analysis reveals that the half-cut monofacial monocrystalline solar panel produces lesser voltage values compared to the traditional full cell monofacial monocrystalline solar panel.
2) Current Comparison
Schneider et al. (2019) explained that the electrical advantages of half-cell modules arise partly from reduced resistive losses and current gains at the module level. The division of cells reduces the current flowing through individual interconnections, thereby reducing resistive losses and improving the electrical performance of the module. The half-cut monofacial monocrystalline solar panel produces higher current output compared to the traditional full cell monofacial monocrystalline solar panel. This arises partly from reduced resistive losses and current gains at the module level. The division of cells reduces the current flowing through individual interconnections, thereby reducing resistive losses and improving the electrical performance of the module [11].
3) Power Comparison
The half-cut panel consistently delivered higher power output throughout the day compared to the traditional panel an improvement as stated. This shows that half-cut cell technology promotes elevated energy production straightly. The half-cut panel also sustained upper level performance in comparison to the traditional panel during off-peak sunshine hours.
4) Daily Efficiency Comparison
Efficiency was calculated as:

$$Efficiency = \frac{Power\ Output}{Solar\ Irradiance\ \times Panel\ Area} \times 100$$

Where *Power Output* is the manufacturer's rated panel power output.
The results showed that the half-cut panel consistently achieved higher efficiency percentages compared to the traditional full cell.
5) Analysis of Variance (ANOVA)
The one-way ANOVA test conducted on the power outputs of the half-cut and full-cell monofacial monocrystalline solar panels for the result of the "without shading experiment"(**Tables 18** and **19**) produced the following results: the calculated F-value was (1.6981), while the F-critical value was (4.49399) at a

95% confidence level. Since the F-value is less than the F-critical value, the test indicates that the difference in mean power output between the two panel types is not statistically significant. Furthermore, the p-value obtained was (0.21097), which is greater than the alpha 0.05, reinforcing the decision to accept the null hypothesis (H_0) and reject the alternative hypothesis (H_1).

While for the shading experiment, from the statistical analysis table obtained from the ANOVA (**Tables 20** and **21**), it can be seen that the F-value (11.6014971) is higher than the F-critical (4.49399848). This indicates that the difference between the power generated by the half cut monofacial monocrystalline and full cell monofacial monocrystalline solar panels is significant. This signifies that the higher average of power generated by the Half cut solar panels (**Tables 10** and **13**) compared with the lower average of the power generated by the Traditional Full cell solar panels was not coincidental, thus indicating that the Half cut solar panels generated high power throughout the study under both scenarios. The *p*-value of (0.00361338) which is less than the alpha 0.05. *p*-value ≤0.05 further shows a significant difference between the power generated by the half-cut solar panels and the traditional full-cell solar panels within the study.

6) Performance Differences

Even though the difference in mean power output between the two panel types is not statistically significant for the “without shading experiment”, the difference between the power generated by the half cut monofacial monocrystalline and full cell monofacial monocrystalline solar panels is statistically significant for the shading experiment. Also, the half-cut monofacial monocrystalline solar panel outperformed the traditional panel in three key metrics—current, power and overall efficiency in both scenarios. This implies that the half-cut panel showed a descriptive advantage in average power output, while statistically significant superiority was demonstrated only under shading condition. The differences were more pronounced under peak sunlight conditions, showing that the half-cut panel is better optimized for environments with high irradiance. The principal benefit of this design remains in segmenting the cells into miniature segments, thus lowering the current carried by each cell, reducing resistive heating, and ultimately enhancing the panel’s overarching performance and reliableness.

7) Environmental Influences

Climatic conditions, which include ambient temperature, cloud cover, and shading, produced obvious consequences on the performance of both solar panels. In the cloudy periods, the output power of both panels diminished; nevertheless, the half-cut panel demonstrated superior performance stability. This enhanced stableness can be alluded to its half-cell design, which promotes tolerance to incomplete shading by permitting the unshaded half-cells to keep generating electricity not minding that a portion of the panel is blocked from receiving sunlight.

8) Implications of Findings

The findings show that half-cut solar panels are better alternatives for residential use as they give superior efficiency and higher reliability, especially in regions where the intensity of sunshine fluctuates or partial shading is prevalent. Their enhanced performance in the state of these conditions helps residents to realize a more regular energy generation.

For commercial and industrial solar setups, the merits are even more substantial. Even though the efficiency enhancement may seem moderate, an increment of 10–15% in energy output can result in significant gains in electricity generation, smaller operational costs, and enhanced returns on investment over the lifespan of extensive solar farms.

For policymakers and capitalists, inspiring the acceptance of half-cut solar panel technology provides the prospect to accelerate the transition to renewable energy. Since these panels provide enhanced performance with only meager extra cost, their expansive deployment can promote the comprehensive efficiency and economic profitability of solar power systems while augmenting sustainable energy advancement.

9) Limitations and Applicability

This study was conducted under the tropical conditions of Oleh, a city in the Niger Delta region of Nigeria having similar climatic conditions with other cities in the Niger Delta region and Nigeria. Therefore, the results from this study may not directly apply to other regions of Nigeria or other climes in the world but could provide engineers, solar-power system installers, policymakers, and capitalists with reliable, evidence-based guidance for choosing photovoltaic technologies appropriate for deployment in Nigeria and other climes with similar environmental conditions.

5. Conclusion

This comparative investigation of half-cut mono-facial monocrystalline panels and conventional full-cell mono-facial monocrystalline panels emphasizes clear disparities in efficiency, shading tolerance, and overall performance. The half-cut panels manifested superior efficiency, primarily because their segmented-cell structure reduces resistive losses and promotes current flow. Their enhanced ability to withstand partial shading also culminated in more stable energy generation under changing climatic conditions. Additionally, the lower operational temperatures of half-cut panels give rise to improved durability and a longer lifespan, thus cutting long-term maintenance needs.

The experimental results constantly depicted obvious performance peculiarities between the two panel technologies. While the conventional full-cell panels typically recorded higher voltage values, the half-cut panels generated considerably higher current outputs. This increment in current culminated in higher overall power generation, particularly during periods of peak solar irradiance, thus substantiating the expected efficiency benefits of half-cut technology. The split-cell structure lowers electrical resistance, contribute to current distribution, and aids tolerance to partial shading as depicted in the more stable performance of the half-cut panels under shaded scenarios.

Descriptive statistical analysis further backed these findings. The percentage variance analysis established that the half-cut panels regularly overmatched the traditional panels in terms of power output. Though the standard deviation indicated higher variations in the output of the half-cut panels due to varying climatic conditions, their mean energy yield stayed constantly higher than that of the conventional full-cell panels.

In general, this study makes an invaluable contribution to both the academic literature and practical solar engineering by addressing the environmental, methodological, and comparative gaps identified in previous studies. The findings establish that half-cut monocrystalline panels are not only theoretically more efficient but also empirically superior under tropical climatic conditions. Accordingly, the study provides engineers, solar-power system installers, policymakers, and capitalists with reliable, evidence-based guidance for choosing photovoltaic technologies appropriate for deployment in Nigeria and other regions with similar environmental conditions.

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