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Article

The impact of Aerosols on the performance of Photovoltaic module: A case study in Ajayi Crowther University, Oyo

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Abstract

The increasing global demand for renewable energy has highlighted the importance of optimizing photovoltaic (PV) system performance. However, environmental factors such as dust accumulation significantly impair PV efficiency by reducing solar radiation transmittance. This study investigates the impact of dust on PV modules at Ajayi Crowther University, Nigeria, using three cleaning scenarios: uncleaned (Dusty Panels A), shaded (Shaded Panels B), and regularly cleaned (Clean Panels C). Electrical performance was evaluated using I-V and P-V curves, maximum power output (P_{max}), and temperature measurements via an I-V Tracer (FTV200). Results revealed that dust accumulation reduced efficiency by up to 60% compared to clean panels, with power losses intensifying during peak irradiance hours (10:00 AM–2:00 PM). Temperature trends showed optimal performance at ~32°C, with efficiency declining above 40°C due to thermal effects. The study underscores the critical need for regular cleaning and maintenance to mitigate dust-induced losses and enhance PV system reliability. These findings provide actionable insights for improving solar energy output in dusty environments, particularly in regions like south western Nigeria.

Keywords: Photovoltaic (PV) modules, Dust accumulation, Solar efficiency, I-V curve analysis, Cleaning maintenance.

1. Introduction

During the 1980s, the increasing scarcity of conventional energy sources led to a growing demand for alternative, non-conventional energy options. Among these, renewable energy emerged as the most viable solution for producing clean, sustainable power. Solar energy, in particular, stands out as a reliable and abundant source. It has proven effective not only for generating electricity and heating water in residential settings but also for use in concentrated solar power plants [1]. The use of photovoltaic (PV) systems to convert sunlight directly into electricity has become widespread globally. The efficiency of a PV module is influenced by its geographical location (latitude, longitude, solar radiation intensity) as well as environmental conditions like temperature, humidity, wind, rain, and the specific PV technology employed.

Bashir [2] evaluated the performance of three commercially available PV modules under winter conditions in Taxila, Pakistan, and found monocrystalline modules to be the most efficient. Their study showed that solar irradiance significantly affects module output, with monocrystalline and polycrystalline modules producing 19.8% and 18.7% less energy, respectively, in summer compared to winter. Other studies [3] also confirm that environmental factors such as dust, air temperature, humidity, and pollution degrade PV module performance and efficiency.

Dust deposition, in particular, poses a significant challenge by reducing the amount of sunlight reaching the PV surface, thereby lowering energy output [4], [5]. The extent of performance loss depends on the dust's characteristics, such as particle size and density [6]. Previous research [7] indicates that in arid regions, dust can lead to energy losses of up to 15% in large-scale PV installations. Similarly, [8] found that air pollution can reduce solar panel performance by up to 18%, with slightly less impact during peak sunlight hours, although still non-negligible [3]. Any factor that obstructs sunlight—whether dust or pollutants—can impair a photovoltaic system's efficiency.

Numerous studies have highlighted the detrimental effects of dust. [9] observed a 0.4% efficiency drop at a dust density of 0.09 mg/cm². [10] found that dust accumulation could reduce power and efficiency by as much as 92% and 89%, respectively. [11] demonstrated the effects of dust in a controlled environment, applying dust evenly to panel surfaces, and noted a significant performance reduction. [12] reported power drops of 6% and 13% for crystalline and amorphous silicon panels, respectively, after 20 days of dust accumulation at 2.326 mg/cm². [13] showed efficiency reductions of 18.1% and 16.5% with mud and talcum dust, respectively. [14] and [15] also confirmed a correlation between increased dust density and reduced output power. Collectively, these findings emphasize that dust accumulation significantly hampers PV module performance and must be accounted for in performance assessments. The build-up of dust on photovoltaic (PV) cells adversely affects the glass surface, leading to reduced spectral transmittance and a decline in the efficiency of power generation [16]. Prolonged dust accumulation can also degrade the panel's protective layer, which not only lowers energy output but also shortens the overall lifespan of the PV system [17], [18].

Over the past few decades, the photovoltaic industry has experienced rapid growth. What began as experimental prototypes in laboratories has evolved into large-scale commercial production, with millions of PV modules deployed worldwide. In Nigeria, the adoption of photovoltaic systems has surged dramatically over the past ten years. Consequently, assessing the effects of environmental factors such as aerosols and temperature on PV performance has become increasingly crucial. This study aims to examine the impact of dust on the performance of photovoltaic (PV) modules. The electrical characteristics analysed include current-voltage (I-V) and power-voltage (P-V) curves, along with the maximum power output (Pmax) and the temperature of the solar panels. Measurements were carried out using the I-V Tracer FTV200 device under three different maintenance conditions: panels cleaned prior to each reading (Clean Panels C), panels subjected to controlled shading (Clean Panels B), and panels left uncleaned (Dusty Panels A).

1.1 Study Area

The experimental set-up was installed within the campus of Ajayi Crowther University, located in Atiba Local Government Area of Oyo State, in the south western region of Nigeria. The site is situated at approximately 7°50′N latitude and 3°56′N longitude, with an elevation of around 300 meters above sea level, as shown in Figure 1. This region experiences two primary seasons: the rainy season, which typically runs from April to October with average annual rainfall ranging between 1000 mm and 1500 mm, and the dry season, lasting from November to March [19]. The average daily temperature in the area is approximately 27°C. The study site is well-connected by a network of small roads and footpaths that link various parts of the university.

2. Methodology

The extent of power loss caused by dust accumulation was assessed using different cleaning scenarios on the test systems:

String A (Dusty Panels A): Comprised two PV panels that were never cleaned throughout the study, Figure 2.

String B (Shaded Panels B): Included two PV panels subjected to consistent shading, Figure 3.

String C (Clean Panels C): Consisted of two PV panels that were thoroughly cleaned before each measurement and served as the reference set, Figure 4.

2.1 Cleaning Procedures

Two manual cleaning methods were employed, depending on the type of debris:

(a) Dry cleaning was used for loose materials like dust, sand, or leaves.
(b) Wet cleaning with water was applied for more stubborn deposits such as bird droppings, plant residues, or compacted dust that couldn't be removed by dry cleaning alone.

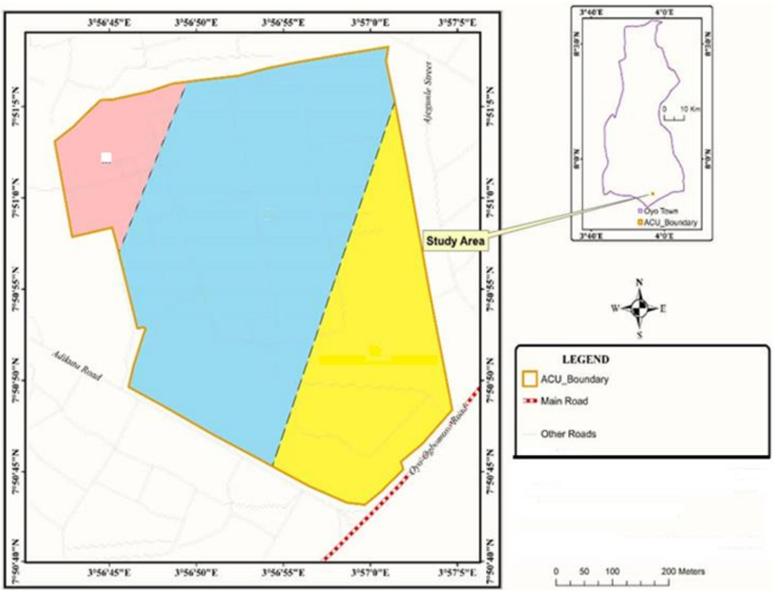

Figure 1: Location of the site, Ajayi Crowther University Oyo, Oyo State, Nigeria.

Figure 2: Dusty Panels A

Figure 3. Shaded Panels B

Figure 4. Clean Panels C

2.2 Test Equipment

The test system utilized a monocrystalline, JKM550PP PV panels, along with an I-V curve plotter and a PT-100 probe thermometer with four-wire configuration to measure ambient temperature.

2.3 Experimental Methodology

The output performance of the PV modules was evaluated using an I-V curve tracer (FTV200), Figure 5. Module temperatures were recorded using a thermometer. The cleaning schedule included:

(a) Two reference modules cleaned after every measurement.

(b) One module cleaned every 10 days as part of routine plant maintenance.

(c) Three modules that were left completely uncleaned.

Measurements were conducted on a weekly basis.

Figure 5. Tracer I-V FTV200 [20].

3. Results and Discussion

Six monocrystalline PV modules of the same voltage-current characteristic are set up at same inclination angles of 8 degrees which is the optimum angle for the location around the equator. The site located around the equator receives the maximum solar radiation at 8 degrees' inclination angle. Data was taken and recorded below for 7 days at 1hour interval 7 am to 4pm temperature is also measured.

Table 1: Data Presentation of panel A, day 1

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	19.00	18.40	20.00	368.00
8:00M	20.00	19.40	20.00	382.00
9:00AM	30.50	18.90	20.00	378.00
10:00 AM	30.90	18.60	21.00	390.60
11:00AM	31.80	18.90	21.00	396.90
12:00PM	34.40	17.90	21.00	375.90
1:00PM	37.40	17.70	19.00	336.30
2:00PM	34.10	18.10	20.00	362.00
3:00PM	35.40	18.10	19.00	343.90
4:00PM	34.50	18.10	20.00	362.0

Table 2: Data Presentation of panel B day 1

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	19.30	18.20	20.00	364.00
8:00M	20.20	19.30	22.00	424.60
9:00AM	30.50	19.10	22.00	420.20
10:00 AM	30.90	18.70	21.00	392.70
11:00AM	31.80	19.00	23.00	437.00
12:00PM	34.40	17.90	20.00	358.00
1:00PM	37.40	18.20	19.00	345.80
2:00PM	34.10	18.20	19.00	348.80
3:00PM	34.40	18.00	19.00	342.00
4:00PM	34.50	18.10	20.00	362.00

Table 3: Data Presentation of panel C day 1

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	19.00	18.00	17.00	306.00
8:00M	20.20	19.20	20.00	384.00
9:00AM	30.50	19.10	20.00	382.00
10:00 AM	30.90	18.70	20.00	374.00
11:00AM	31.80	19.50	21.00	409.50
12:00PM	34.40	17.90	20.00	358.00
1:00PM	39.40	18.20	20.00	364.00
2:00PM	34.30	18.20	19.00	345.80
3:00PM	37.20	17.90	19.00	340.10
4:00PM	34.50	17.80	19.00	338.20

Table 4: Data Presentation of panel A day 2

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	23.70	17.30	17.00	294.10
8:00M	29.20	19.20	15.00	288.00
9:00AM	33.40	19.30	15.00	289.50
10:00 AM	46.00	18.50	19.00	351.50
11:00AM	56.60	20.20	20.00	404.00
12:00PM	57.00	20.00	20.00	400.00
1:00PM	42.10	19.80	19.00	376.20
2:00PM	34.60	19.30	19.00	366.70
3:00PM	32.10	19.90	20.00	398.00
4:00PM	31.60	19.80	19.00	376.20

Table 5: Data Presentation of panel B day 2

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	23.70	18.00	12.00	216.00
8:00M	29.70	19.10	14.00	267.40
9:00AM	28.40	18.80	13.00	244.40
10:00 AM	49.10	16.70	17.00	317.90
11:00AM	57.10	19.30	21.00	405.30
12:00PM	58.50	19.80	21.00	415.80
1:00PM	48.90	20.10	20.00	402.00
2:00PM	35.00	19.40	19.00	368.60
3:00PM	32.20	19.90	19.00	378.10
4:00PM	32.20	19.70	19.00	374.30

Table 6: Data presentation of Panel C day 2

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	23.70	17.50	18.00	315.00
8:00M	29.80	18.90	14.00	264.60
9:00AM	38.40	18.90	12.00	226.80
10:00 AM	50.00	19.80	19.00	376.20
11:00AM	55.10	19.50	22.00	429.00
12:00PM	51.80	19.40	21.00	407.40
1:00PM	44.10	21.40	23.00	492.20
2:00PM	34.70	20.30	21.00	436.80
3:00PM	32.50	20.80	21.00	410.00
4:00PM	32.10	20.50	20.00	346.80

Table 7: Data Presentation of panel A day 3

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	24.10	17.00	19.00	334.40
8:00M	24.10	18.00	20.00	360.00
9:00AM	45.80	18.90	22.00	415.80
10:00 AM	47.30	19.20	21.00	403.20
11:00AM	450.00	18.60	18.00	334.80
12:00PM	47.30	18.50	19.00	351.50
1:00PM	50.30	18.50	20.00	370.00
2:00PM	35.80	17.60	20.00	352.00
3:00PM	33.30	17.60	19.00	332.50
4:00PM	24.00	14.50	19.00	246.50

Table 8: Data Presentation of panel B day 3

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	24.10	18.00	20.00	360.00
8:00M	32.20	18.90	20.00	378.00
9:00AM	46.80	19.00	22.00	418.00
10:00 AM	47.20	19.00	20.00	380.00
11:00AM	47.70	18.70	18.00	336.60
12:00PM	48.40	18.40	18.00	331.20
1:00PM	50.50	18.40	19.00	349.60
2:00PM	35.40	17.80	19.00	338.20
3:00PM	32.80	17.70	18.00	318.60
4:00PM	23.60	15.50	18.00	279.00

Table 9: Data presentation of Panel C day 3

Time (s)	Temp (⁰C)	Volt (V)	Current (A)	Power (P)
7:00AM	18.20	20.00	24.00	346.00
8:00M	19.10	21.00	31.10	401.10
9:00AM	19.80	23.00	49.30	455.40
10:00 AM	19.70	22.00	50.10	433.40
11:00AM	19.60	21.00	45.00	411.60
12:00PM	19.50	20.00	48.60	390.00
1:00PM	18.30	19.00	45.80	347.70
2:00PM	18.70	20.00	34.80	374.00
3:00PM	18.40	18.00	32.80	331.20
4:00PM	16.80	18.00	23..90	302.40

Table 10: Data presentation Panel A day 4

Time (s)	Temp (⁰C)	Volt (V)	Current (A)	Power (P)
7:00AM	24.30	15.00	17.00	255.00
8:00M	23.60	15.50	17.00	260.10
9:00AM	23.30	16.10	18.00	289.80
10:00 AM	25.60	19.00	18.00	342.00
11:00AM	21.20	20.00	20.00	400.00
12:00PM	32.60	19.00	19.00	361.00
1:00PM	34.40	18.90	19.00	359.10
2:00PM	33.00	17.90	19.00	340.10
3:00PM	26.60	19.50	20.00	390.00
4:00PM	27.00	19.10	18.00	343.80

Table 11: Data presentation of Panel B day 4

Time (s)	Temp (⁰C)	Volt (V)	Current (A)	Power (P)
7:00AM	15.70	17.00	23.70	266.90
8:00M	15.60	17.00	23.50	205.20
9:00AM	17.10	18.00	23.10	307.80
10:00 AM	18.90	18.00	25.50	340.20
11:00AM	19.80	20.00	29.00	396.00
12:00PM	19.10	18.00	33.90	343.80
1:00PM	19.30	18.00	35.10	347.40
2:00PM	18.40	18.00	32.40	331.20
3:00PM	19.30	21.00	26.40	405.30
4:00PM	19.00	18.00	26.80	342.00

Table 12: Data presentation Panel C day 4

Time (s)	Temp (⁰C)	Volt (V)	Current (A)	Power (P)
7:00AM	16.00	18.00	23.80	288.00
8:00M	16.70	18.00	23.50	300.60
9:00AM	17.90	17.00	23.20	304.30
10:00 AM	19.80	19.00	25.90	376.20
11:00AM	20.10	21.00	30.90	422.10
12:00PM	19.30	18.00	32.60	347.40
1:00PM	20.20	19.00	33.90	383.80
2:00PM	18.90	18.00	30.80	340.20
3:00PM	20.00	22.00	26.80	440.00
4:00PM	19.50	18.00	20.16	351.00

Table 13: Data Presentation of panel A day 5

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	23.30	17.50	15.00	259.50
8:00M	25.20	17.50	21.00	367.50
9:00AM	32.50	20.00	20.00	400.00
10:00 AM	39.40	19.20	19.00	364.80
11:00AM	48.10	18.00	19.00	342.00
12:00PM	51.70	18.00	19.00	342.00
1:00PM	55.80	18.00	18.00	342.00
2:00PM	50.80	19.00	19.00	361.00
3:00PM	33.30	18.50	20.00	370.00
4:00PM	32.50	18.00	18.00	324.00

Table 14: Data Presentation of panel B day 5

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	18.00	17.00	23.00	306.00
8:00M	19.00	18.00	25.00	342.00
9:00AM	19.10	23.00	33.90	439.30
10:00 AM	18.50	19.00	38.70	351.50
11:00AM	18.50	19.00	47.30	351.10
12:00PM	18.00	19.00	51.50	342.00
1:00PM	17.30	19.00	51.60	328.70
2:00PM	18.90	19.00	44.50	359.10
3:00PM	18.50	19.00	42.80	351.10
4:00PM	18.00	19.00	32.50	342.00

Table 15: Data Presentation of panel C day 5

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	18.00	18.00	23.30	324.00
8:00M	19.00	21.00	24.50	399.00
9:00AM	20.50	22.00	35.00	471.50
10:00 AM	19.50	20.00	38.40	390.00
11:00AM	19.00	20.00	49.60	380.00
12:00PM	19.20	20.00	46.10	384.00
1:00PM	19.80	21.00	47.60	415.80
2:00PM	18.90	20.00	46.40	378.00
3:00PM	19.50	21.00	42.40	409.50
4:00PM	19.00	19.00	32.60	361.00

Table 16: Data Presentation of panel A day 6

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	25.00	17.40	17.00	295.80
8:00M	27.40	18.00	18.00	324.00
9:00AM	41.30	19.80	18.00	356.40
10:00 AM	35.20	18.20	19.00	345.80
11:00AM	38.70	18.50	20.00	370.00
12:00PM	53.30	18.80	19.00	357.20
1:00PM	50.90	18.50	18.00	333.00
2:00PM	45.50	17.10	18.00	307.80
3:00PM	42.00	19.20	19.00	364.80
4:00PM	35.10	17.90	17.00	304.30

Table 17: Data Presentation of panel B day 6

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	18.50	17.00	24.70	314.50
8:00M	18.90	18.00	27.10	340.20
9:00AM	19.20	19.00	38.20	364.80
10:00 AM	18.20	19.00	35.60	345.80
11:00AM	18.50	21.00	39.00	388.50
12:00PM	19.10	19.00	34.50	362.90
1:00PM	18.00	18.00	49.40	324.00
2:00PM	18.90	18.00	48.50	336.60
3:00PM	19.20	18.00	43.80	345.60
4:00PM	17.90	18.00	35.30	322.20

Table 18: Data Presentation of panel C day 6

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	18.70	18.00	24.90	336.60
8:00M	19.60	20.00	27.10	392.00
9:00AM	20.40	21.00	38.60	428.40
10:00 AM	19.30	20.00	35.10	386.00
11:00AM	19.80	21.00	38.50	415.80
12:00PM	18.80	20.00	57.50	376.00
1:00PM	18.50	20.00	44.80	370.00
2:00PM	19.00	20.00	45.50	380.00
3:00PM	19.50	19.00	40.30	370.50
4:00PM	18.30	19.00	35.70	347.70

Table 19: Data Presentation of panel A day 7

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	25.70	18.30	20.00	366.00
8:00M	29.40	18.40	20.00	368.00
9:00AM	39.60	18.30	20.00	366.00
10:00 AM	51.20	18.30	20.00	366.00
11:00AM	53.80	18.00	19.00	342.00
12:00PM	48.90	18.10	19.00	343.90
1:00PM	52.30	17.80	19.00	338.20
2:00PM	42.90	19.50	19.00	307.50
3:00PM	48.70	18.10	19.00	343.90
4:00PM	43.20	17.20	18.00	309.60

Table 20: Data Presentation of panel B day 7

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	18.40	19.00	21.20	349.60
8:00M	18.40	19.00	24.90	349.60
9:00AM	18.50	20.00	39.80	370.00
10:00 AM	18.00	19.00	53.40	342.00
11:00AM	18.20	18.00	53.50	327.60
12:00PM	18.00	18.00	51.50	324.00
1:00PM	18.00	19.00	50.90	342.00
2:00PM	19.20	19.00	44.60	364.80
3:00PM	18.00	20.00	44.60	360.00
4:00PM	17.00	18.00	41.50	306.00

Table 21: Data Presentation of panel C day 7

Time (s)	Temp (^{0}C)	Volt (V)	Current (A)	Power (P)
7:00AM	19.00	20.00	25.40	380.00
8:00M	19.00	20.00	26.50	380.00
9:00AM	20.50	21.00	45.40	430.50
10:00 AM	19.30	20.00	54.00	386.00
11:00AM	19.20	20.00	56.00	384.00
12:00PM	19.10	19.00	50.20	362.90
1:00PM	19.20	20.00	51.70	384.00
2:00PM	20.00	21.00	56.80	420.00
3:00PM	18.80	20.00	42.80	376.00
4:00PM	8.00	20.00	40.80	360.00

3.1.1 Temperature Trends

Temperature ranged from as low as 15.6°C to a peak of 57°C, Figure 6, depending on the day and time. The hottest periods were typically from 10:00 AM to 1:00 PM. Days 2 and 5 showed the highest temperature readings, particularly for Panel A. All three panels followed a similar temperature pattern, peaking around midday. Panel C reached slightly higher temperatures, especially at 1:00 PM.

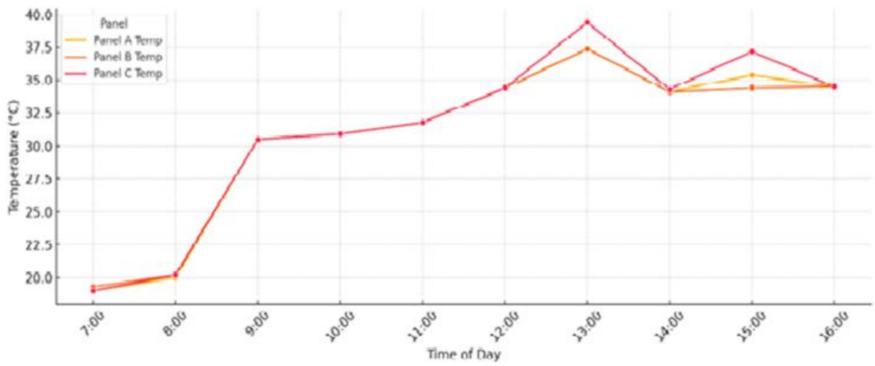

Figure 6: Temperature Trend (Day 1).

3.1.2 Power Output

Power (P = V × I) was computed for each time point. Across all panels and days, maximum power output exceeded 470 W (notably in Panel C Day 5). Morning hours (7–9 AM) generally produced lower power, as expected due to lower irradiance. Peak power output was typically observed between 10:00 AM and 2:00 PM, aligning with maximum solar irradiance [17], [18]. Power output follows a bell curve pattern, Figure 7: low in early morning, peaks mid-day, and declines late afternoon.

Consistent peak period: 10 AM to 1 PM.

3.1.2.1 Panel Performance Comparison

Panel A

Shows consistent output but generally lower max power compared to others. Days 3 and 5 showed slightly reduced performance, likely due to fluctuating temperature and lower irradiance.

Panel B

Exhibits variable performance with power ranging from 216 W to 439 W. Particularly high current values suggest either a higher irradiance exposure or panel-specific sensitivity.

Panel C

Tended to generate the highest power values across multiple days. Notably: Day 5 at 9:00 AM, 471.5W, day 7 at 2:00 PM ~420W. Strong indication of better efficiency or fewer environmental obstructions.

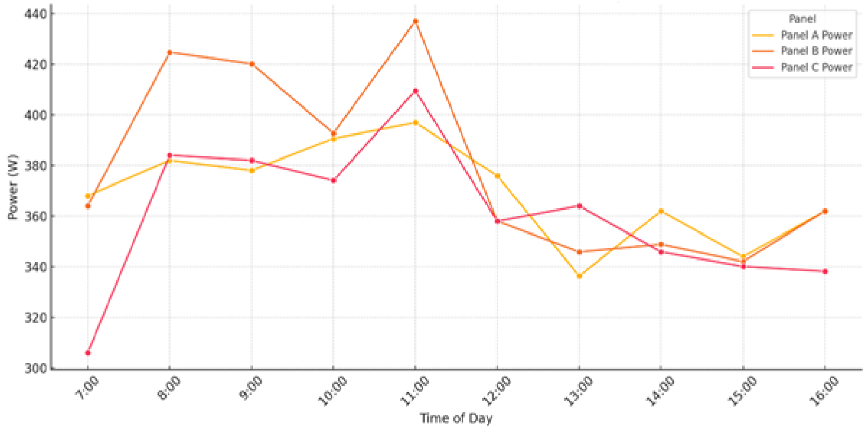

Figure 7: Comparison of the power output for Panels A, B, and C on Day 1.

3.1.3 Correlations and Trends

Temperature vs. Power

The plot, Figure 8, shows a general increase in power with rising temperature up to a point (~32°C). Beyond that, power output begins to decline, reflecting how excessive heat can reduce panel efficiency. PV panels tend to be less efficient at very high temperatures (>40°C), aligning with theoretical expectations Darwish et al. (2013).

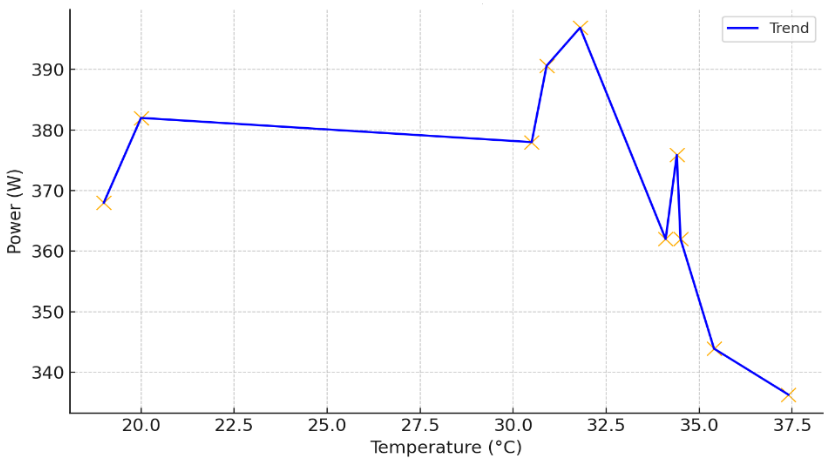

Figure 8: The graph of Temperature vs. Power Output for Panel A on Day 1

4. Conclusion

The primary cause of reduced performance in PV modules is the accumulation of dust on their surfaces. Dust blocks incoming solar radiation, reducing light transmittance and overall power generation efficiency, which ultimately diminishes the reliability of the solar panels. Regular cleaning can help prevent these power losses. This study examines how dust affects PV module performance under hazy weather conditions, using three different cleaning scenarios. Measurements were taken with an I-V tracer (FTV 200) alongside temperature recordings. The analysis revealed disruptions in the I-V and P-V curves for dusty panels, confirming the negative impact of dust. The findings indicate that dust accumulation can reduce solar panel efficiency by up to 60% compared to clean panels, significantly decreasing power output and reliability. This research provides valuable insights into the effects of dust on PV performance at Ajayi Crowther University, demonstrating that regular cleaning is essential for maintaining optimal solar panel efficiency. The results highlight the critical role of maintenance in maximizing energy output and system reliability.

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The author(s) hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

Author Contributions
All the authors (EJO and PCA) conceptualized and designed the study. EJO was involved in data collection/acquisition. EJO and PCA were involved in the analysis. All the authors were involved in the writing and revising the manuscript for intellectual content.

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