FULafia Journal of Science & Technology
ISSN (print) 2449-0954 \ ISSN (online) 2636-4972
https://lafiascijournals.org.ng/index.php/fjst
Sponsored By TERTIARY EDUCATION TRUST FUND
Manuscript => Received: Oct., 2025; Accepted: Dec., 2025; Published: Dec., 2025 https://doi.org/10.62050/fjst2025.v10n1.653

A SHORT-TERM PERFORMANCE MONITORING AND EVALUATION OF A PHOTOVOLTAIC SYSTEM AT YABA COLLEGE OF TECHNOLOGY USING A DATA LOGGER

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ABSTRACT
The increasing global demand for sustainable energy has amplified the relevance of solar photovoltaic (PV) systems. This study investigates the performance of a 40 W monocrystalline PV module monitored over a four-month period using a UX 120-006M data logger. The system was deployed on a rooftop in the Physical Science Department of Yaba College of technology Lagos, Nigeria, capturing real-time voltage and ambient temperature data at 60-second intervals. Additionally, electrical characterization was conducted using I-V measurements to derive key performance parameters including open-circuit voltage (Voc), short-circuit current (Isc), maximum power point (MPP), fill factor (FF), and overall efficiency. Results reveal a diurnal voltage pattern peaking at midday with values exceeding 22 V and a consistent average between 12–14 V. Ambient temperatures ranged from 26–34 °C, reflecting tropical climatic influence. An inverse correlation between voltage and temperature was observed, attributed to the negative temperature coefficient of silicon-based modules. Electrical testing yielded a maximum power output of 22.46 W at 11.51 V and 1.95 A, with a calculated efficiency of 9.71 %, significantly below the 15–22 % benchmark for monocrystalline modules. The low fill factor (0.48) suggests internal inefficiencies or environmental constraints. This underperformance underscores the importance of real-time monitoring for early fault detection and maintenance planning. Despite suboptimal efficiency, the system remains viable for educational or low-power off-grid applications. The integration of data logger technology presents a robust framework for enhancing PV system reliability and operational insight.

Keywords: Photovoltaic systems, Data logger monitoring, Temperature effects, Module efficiency

INTRODUCTION
Solar energy, a clean and renewable energy source, has emerged as a transformative force in the energy landscape, offering environmentally friendly power generation and reducing our reliance on fossil fuels (International Energy Agency [IEA], 2022). Recent global assessments indicate that solar photovoltaic (PV) technology continues to dominate renewable energy expansion due to declining costs and increasing deployment across both developed and developing regions (IEA, 2023). Optimization of such energy ensures that systems where it finds application operate at their peak efficiency, thereby maximizing the energy yield from the available sunlight (Silva *et al*., 2020; Fraunhofer ISE, 2024).
As the global shift towards sustainable energy sources intensifies, photovoltaic (PV) systems have become pivotal in the generation of clean and renewable electricity (Fraunhofer ISE, 2021). These systems are increasingly adopted for both residential and commercial applications due to their environmental benefits and potential cost savings (Soofar *et al*., 2022; Komp, 2022). Solar power, harnessed through PV modules, has become a pivotal component of the global shift toward renewable energy sources. However, recent studies emphasize that real-world PV performance often deviates significantly from laboratory-rated values due to environmental stressors, aging, and inadequate monitoring practices, particularly in tropical climates (Jordan *et al*., 2022; Bello *et al*., 2024). Consequently, optimal energy generation from PV systems is contingent upon efficient operation and maintenance, which, in turn, depends on accurate and comprehensive performance monitoring and evaluation (Akinyele & Rayudu, 2014).
To fully realize the potential of solar energy, it is imperative to ensure that PV systems operate optimally, delivering the highest energy yields while minimizing downtime and maintenance costs (Gholami *et al*., 2021). The achievement of these objectives relies on the ability to gather, analyze, and interpret real-time data from PV modules and their operational environment (Azzopardi *et al*., 2013). Recent advances in PV diagnostics further highlight the importance of data-driven monitoring frameworks for early fault detection, degradation assessment, and predictive maintenance (Ahmed *et al*., 2023; Sharma *et al*., 2022).
Traditionally, PV systems have been monitored primarily for electrical characteristics such as voltage and current. While this approach is valuable, it provides only a partial view of system performance (Liserre *et al*., 2010). The use of a data logger in the monitoring of the characteristics of a PV offers a holistic approach that simultaneously captures electrical data through IV

(current-voltage) curves, which are critical for identifying electrical faults and performance issues, and environmental parameters such as solar irradiance, temperature, and humidity (Zhou *et al*., 2011).
Recent studies confirm that low-cost, continuous data logging significantly improves fault visibility and operational reliability, especially in harsh climatic regions (Sharma *et al*., 2022; Bello *et al*., 2024).
The data logger technology allows for real-time performance analysis, early fault detection, predictive maintenance, and the optimization of energy production (Quaschning, 2016). By examining electrical data alongside environmental conditions, this approach provides a deeper understanding of how external factors, such as shading, temperature variations, or soiling, affect PV module performance (Spertino *et al*., 2015). Additionally, it opens the door to machine learning algorithms that can uncover subtle yet meaningful patterns within the data (Massi Pavan *et al*., 2019).
The integration of this tool offers a novel and advanced solution that addresses the challenges of maximizing the efficiency, reliability, and environmental impact of solar energy systems. The present research explores the capabilities and benefits of this integrated monitoring system and its potential to revolutionize the way we harness solar energy. As solar energy continues to play a pivotal role in the global transition to sustainable power sources, the innovative approach presented in this research holds the promise of advancing the industry's capabilities and impact (Chouder *et al*., 2013).
The need for monitoring photovoltaic (PV) module performance and weather parameters in solar energy systems has become increasingly evident as the solar industry continues to expand. While solar energy offers a sustainable and eco-friendly power source, several challenges such as performance optimization, early fault detection, weather-dependent energy generation, predictive maintenance, data-driven decision-making, energy grid integration, and environmental impact persist, hindering its optimal utilization (Skoplaki & Palyvos, 2009).
The lack of comprehensive and real-time monitoring solutions for PV modules and weather conditions significantly impacts the efficiency, reliability, and maintenance of solar power installations (Chakraborty *et al*., 2019). Accurate monitoring tools are needed for identifying issues like hotspots, cell degradation, and inverter failures (Nespoli *et al.*, 2018). Additionally, data-driven decision-making is essential for efficient energy production, grid integration, and energy storage (Petrone *et al.*, 2017). Addressing these challenges is essential for harnessing the full potential of solar energy and ensuring the efficient and sustainable operation of photovoltaic systems.
This study aims at comprehensively monitoring and evaluating the performance of a photovoltaic system using a data logger. The primary focus is to assess the system's efficiency, identify potential issues, and provide recommendations for optimization.

MATERIALS AND METHODS

A 40-watt monocrystalline photovoltaic modulewas mounted on the roof of a Physics laboratory situated at the School of Science, Yaba College of Technology, Lagos. The detailed specifications of the photovoltaic module are provided in Table 1. The module was connected toa fixed load and a 4 channel analog data logger, model UX 120-006M.
The data logger recorded the output voltage and ambient temperature throughout the monitoring period at an interval of 60 seconds between November 2024 and April 2025.The performance metrics of the photovoltaic module was determined from the set up shown in Figure 1. A 100 Ω variable resistor was connected to the panel and a multimeter. Current and voltage values for varying resistance from near zero ohms to the maximum value were recorded, from which the I-V curve was plotted.

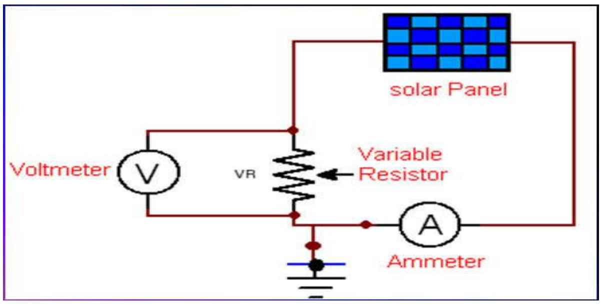

Figure 1: Photovoltaic system set up

Table 1: Module/panel specification

PARAMETER	VALUE
Maximum Power	40 W
Open Circuit Voltage Voc	43.2V
Short Circuit Current Isc	1.33A
Voltage at Maximum Power Vm	36.0V
Current at Maximum Power Im	1.11A 1000 Wm^{-2}
Irradiance under STC (@ AM1.5	1000 Wm^{-2}
Module dimensions	670 x 345 x 40 mm

The PV panel analysis was obtained by computing the following parameters:

- **Open circuit voltage (V_{oc}):** This refers to the maximum voltage obtainable from a solar cell. It is the voltage across its terminals when no external load is connected to it.
- **Short circuit current (I_{sc}):** This is the maximum current obtainable from a solar cell. It is the current flow at zero external resistance (and voltage equals zero).
- **Maximum power (P_{max}):** This is the maximum power delivered by a solar cell. It is the area of the largest rectangle under the IV curve of the cell.

$$P_{max} = V_{mp} * I_{mp} \quad (1)$$

Where: V_{mp} & I_{mp} are voltage and current at their maximum point respectively.

- **Fill factor (FF):** This is the ratio of the maximum power to the product of open circuit voltage and short circuit current.

$FF = V_{mp} * I_{mp} / (V_{oc} * I_{sc})$ (2) (Tariq *et al*., 2021)

- **Module efficiency:** This is the ratio of the electrical power output to the solar power incident on the solar cell.

$\eta = \frac{P_{max}}{G * A}$ x 100 % (3) (Chandel *et al*., 2021)

Where: G = Solar Irradiance at 1000 W/m^2, A = Area of the solar panel given as: Length x Width

RESULTS AND DISCUSSION

The measurements from the data logger for the output voltage and ambient temperature is depicted in Figures 2 and 3, respectively.

Diurnal Voltage Characteristics

A distinct and consistent diurnal voltage pattern is observed in Figure 2, characterized by a rapid increase in voltage during the early morning hours, a midday peak exceeding 22 V, and a sharp decline to near-zero values at nightfall. This behaviour is typical of photovoltaic (PV) modules operating under natural sunlight conditions and reflects the availability of solar irradiance throughout the day. The absence of voltage during nighttime hours (0 V) further confirms the passive nature of the module in the absence of solar input.

Across the monitoring period, the average operating voltage remained relatively stable, predominantly within the range of 12–14 V, indicating steady module operation under fluctuating irradiance conditions. This voltage profile is consistent with expected solar cycles and suggests that the panel received regular and adequate sunlight exposure. Similar diurnal voltage trends and operating voltage ranges have been reported for rooftop PV systems in tropical and subtropical environments, thereby corroborating the reliability of the observed results (Zhou *et al*., 2011; Chandel *et al*., 2021; Gholami *et al*., 2021).

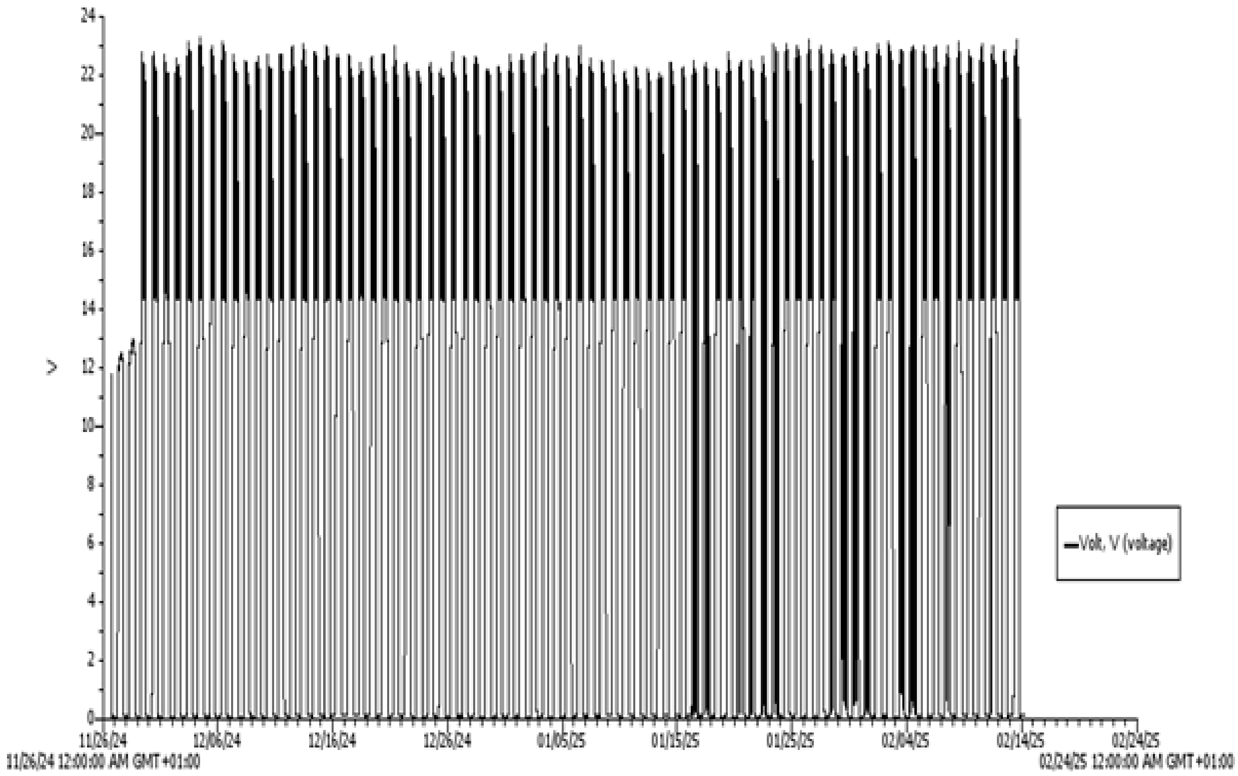

Figure 2: Measurement of voltage (volts) between November 2024 and February 2025

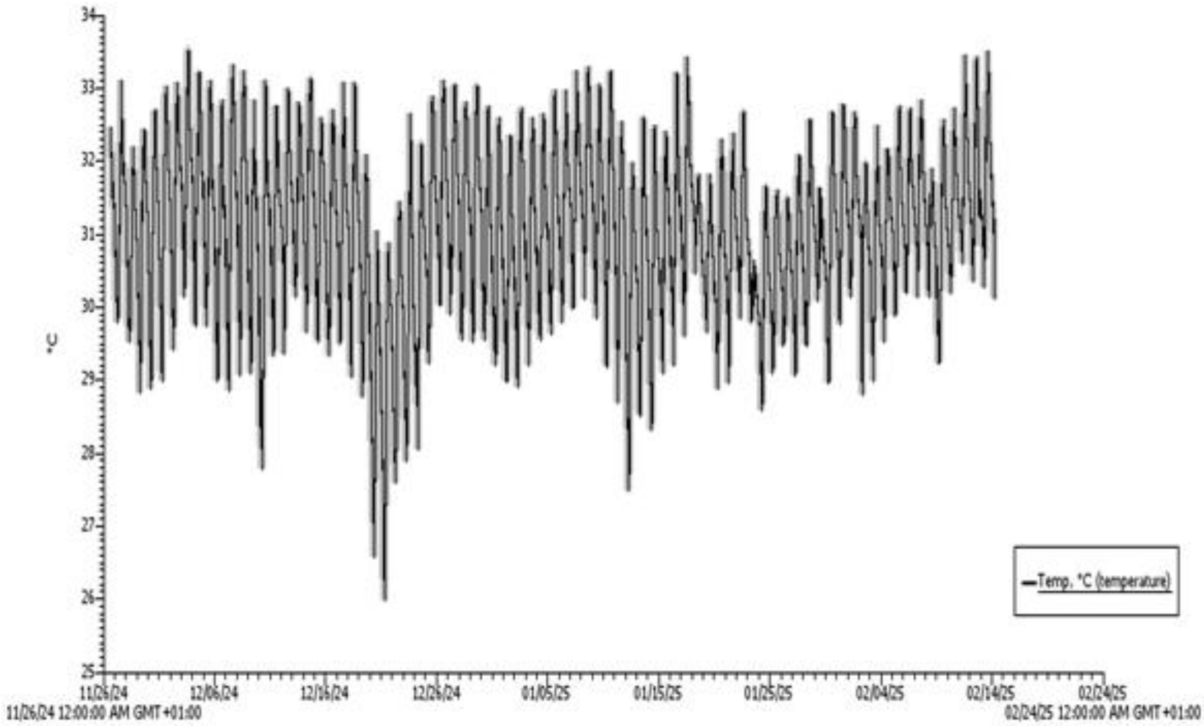

Figure 3: Temperature variations between November 2024 and February 2025

Temperature Behaviour and Trends

The observed ambient temperature range of 26–34 °C, with mean daily values between 29 and 32 °C, is consistent with temperature conditions reported for photovoltaic (PV) installations in tropical and subtropical regions. Similar operating temperature ranges have been documented in recent field studies conducted in India, the Middle East, and West Africa, where rooftop PV systems routinely experience ambient temperatures exceeding 30 °C for extended periods (Chandel *et al*., 2021; Tariq *et al*., 2023). These elevated temperatures impose significant thermal loads on silicon-based PV modules and are known to adversely influence electrical performance.

The persistent occurrence of maximum daily temperatures above 32 °C aligns with findings by Gholami *et al*. (2021) and Ahmed *et al*. (2023), who reported that sustained high ambient temperatures lead to increased cell operating temperatures, resulting in voltage reduction and efficiency losses due to the negative temperature coefficient of monocrystalline silicon modules. Comparable studies have shown that for every 1 °C rise above standard test conditions, module efficiency may decrease by approximately 0.4–0.5 % for crystalline silicon technologies (Chandel *et al*., 2021).

The temporary temperature reduction observed around mid-December is consistent with seasonal climatic variations such as increased cloud cover and rainfall typical of tropical environments. Similar short-term temperature depressions and their associated voltage fluctuations have been reported in outdoor PV monitoring studies, where transient weather conditions were shown to directly influence instantaneous energy yield (Tariq *et al*., 2021). While reduced temperatures may momentarily improve voltage output, concurrent reductions in solar irradiance often offset these gains.

Overall, the relatively narrow daily temperature variation suggests moderate thermal cycling, which is favorable for reducing mechanical fatigue and long-term material degradation, as noted in recent degradation-focused studies (Gholami *et al*., 2021). However, the consistently high ambient temperatures imply continuous thermal stress, which can accelerate performance degradation if adequate thermal management strategies are not employed. These findings corroborate existing literature and confirm that temperature remains a critical environmental factor influencing PV system performance in tropical climates.

Correlation between Temperature and Voltage

An inverse relationship between temperature and voltage is evident in the overlapping datasets (Figure 4). It is well-established that as the temperature of a monocrystalline panel increases, its open-circuit voltage (V_{oc}) decreases due to the narrowing of the semiconductor bandgap and increased charge carrier recombination (Skoplaki & Palyvos, 2009). Thus, while irradiance may remain consistent, voltage output is inversely affected by temperature.

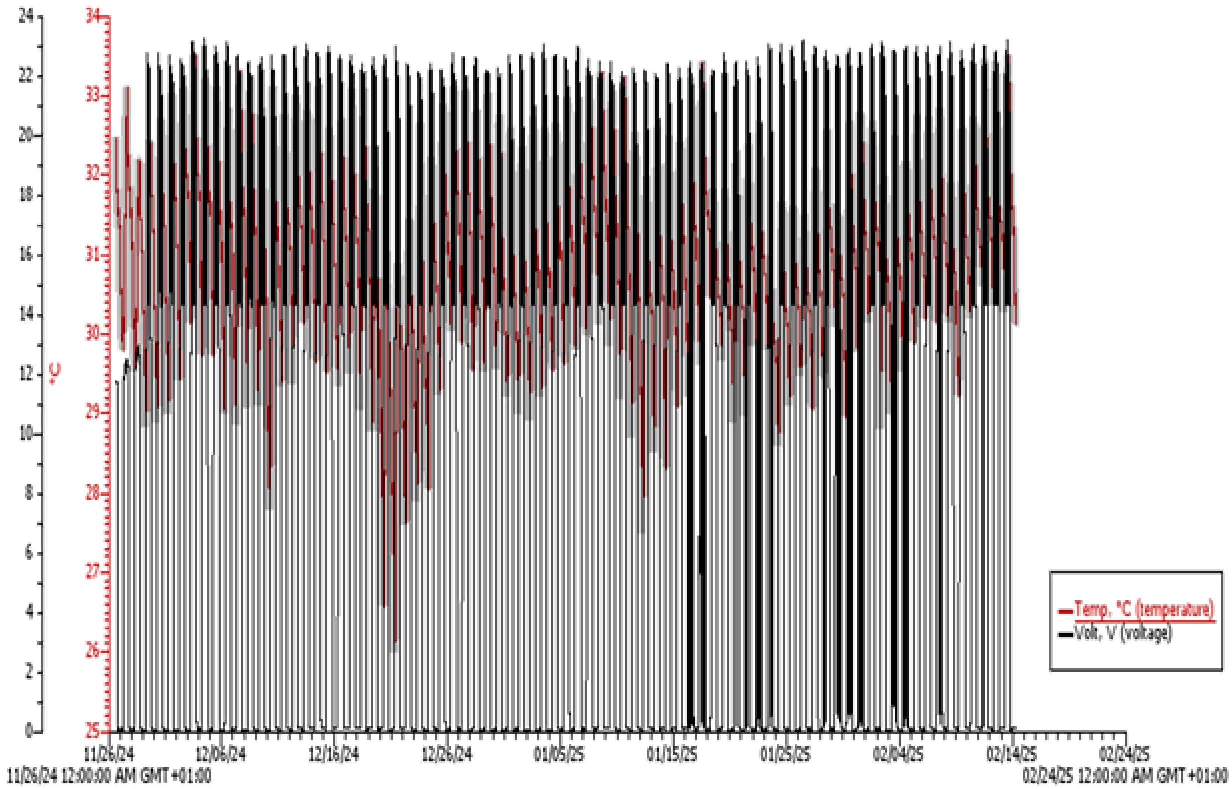

Figure 4: Correlation between temperature and voltage between November 2024 and February2025

As ambient temperatures increase during midday, a decline in voltage output is typically observed. This trend aligns with the known behavior of silicon-based photovoltaic materials, where elevated cell temperatures lead to a reduction in bandgap energy, resulting in lower output voltage (Radziemska, 2003; Huld *et al*., 2010). This phenomenon reflects the negative temperature coefficient characteristic of monocrystalline silicon panels; whereby higher temperatures diminish voltage even under strong irradiance. Notably, voltage dips consistently coincide with periods of elevated ambient temperature, confirming the thermal impact on the panel's electrical performance.

Performance Metrics of the Monocrystalline Module

The electrical characterization of the monocrystalline photovoltaic (PV) panel under test provides critical insights into its operational behavior and potential limitations. The current - voltage (I–V) curve (Figure 5), along with the extracted parameters - open-circuit voltage (Voc), short-circuit current (Isc), maximum power point (MPP), and fill factor (FF) form the basis for performance assessment under the given environmental and operational conditions.

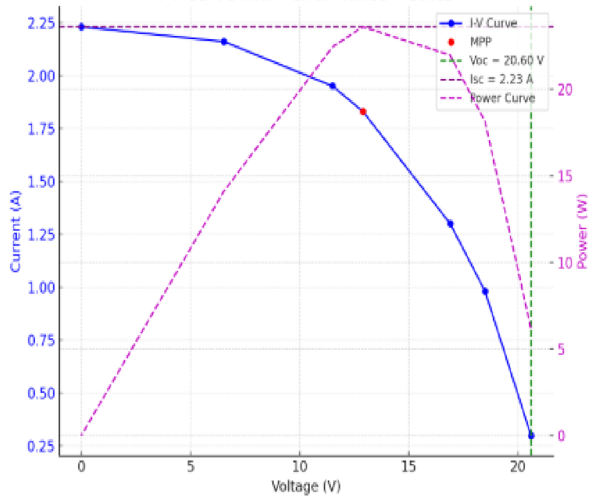

Figure 5: I-V curve with performance metrics

Open-Circuit Voltage

The open-circuit voltage was recorded at 20.6 V, which is within the expected range for monocrystalline silicon panels of similar specifications. This value indicates minimal recombination losses and confirms good cell integrity in the absence of a load. Such voltage levels suggest that the junction quality and internal electric field within the cells remain intact, with no significant degradation effects observed under open-circuit conditions.

Short-Circuit Current

The short-circuit current was measured at 2.23 A. While this reflects adequate photon absorption and charge carrier generation, the magnitude is slightly lower than typically expected for full-size monocrystalline modules. The reduced current may be attributed to a limited active cell area, partial shading, non-standard irradiance during testing, or elevated cell temperatures—all of which are known to suppress current output.

Maximum Power Point

The maximum power point was achieved at 11.51 V and 1.95 A, yielding a peak power output of approximately 22.46 W. This value, while modest, aligns with expectations for a small-format or demonstrator panel. The MPP represents the operational point at which the panel performs optimally under load, and the result confirms the panel's potential utility in low-demand or off-grid applications, especially where compact and portable solar solutions are desired.

Fill Factor and Efficiency Considerations

The fill factor was calculated to be approximately 0.48, significantly below the standard range of 0.70 to 0.80 for monocrystalline panels. A low fill factor generally indicates internal inefficiencies, which may arise due to high series resistancepotentially from degraded solder joints or interconnects - or low shunt resistance, suggesting the presence of leakage pathways. Other contributing factors may include cell mismatch, material degradation, or non-ideal testing conditions such as irradiance below 1000 W/m² or elevated ambient temperatures.

Module Efficiency

The efficiency of the photovoltaic (PV) module was computed based on its maximum power output and the corresponding incident solar power under standard irradiance conditions. Assuming a solar irradiance, G of 1000 W/m², which corresponds to standard test conditions (STC), the incident power on the surface of the panel is given by:

$$P_{in} = G \times A = 1000W/m^2 \times 0.2312\ m^2 = 231.2\ W$$

The measured electrical output at the maximum power point (MPP) of the panel was:

$$P_{max} = V_{mpp} \times Impp = 11.51V \times 1.95A = 22.46W$$

Consequently, the efficiency of the panel is calculated to be 9.71 %

The result is significantly lower than the typical range of 15–22 % for commercial monocrystalline PV modules (Skoplaki & Palyvos, 2009; Radziemska, 2003). This discrepancy indicates the presence of non-ideal operating conditions or degradation-related losses affecting panel performance, which in this instance is likely to be as a result of variations in irradiance and temperature (Huld *et al*., 2010).

Performance Implications

The electrical parameters collectively suggest below-optimal performance for the panel. Considering the high theoretical efficiency associated with monocrystalline silicon technology, the reduced fill factor, modest maximum power output and low efficiency point toward either external environmental constraints or internal panel degradation.

A comparative analysis of the panel's electrical parameters against its factory-specified STC baseline demonstrates pronounced underperformance (Table 2). While the manufacturer's data indicate a 72-cell monocrystalline module rated at 40 W under standard test conditions, the field measurements reveal a maximum power of only 22.46 W, corresponding to a 44 % loss in output. The decline is driven primarily by a sharp reduction in voltage, with Voc falling from 43.2 V to 20.6 V (a 52 % collapse) and Vmp from 36.0 V to 11.5 V (a 68 % drop). In contrast, current values exceed expectations: Isc rises from 1.33 A to 2.23 A and Imp from 1.11 A to 1.95 A. This imbalance between current enhancement and voltage suppression results in a markedly low fill factor of 0.48, compared with the expected ~0.70, and a module efficiency of only 9.71 %, well below the ~15 % reference.

Table 2: Comparative baseline of factory STC vs measured parameters

Parameter	Factory STC	Measured (Field)	Absolute Δ	% of STC
Open-circuit voltage, Voc	43.2 V	20.6 V	–22.6 V	47.7
Short-circuit current, Isc	1.33 A	2.23 A	+0.90 A	168
Voltage at Pmax, Vmp	36.0 V	11.5 V	–24.5 V	32.0
Current at Pmax, Imp	1.11 A	1.95 A	+0.84 A	176
Maximum power, Pmax	40 W	22.46 W	–17.5 W	56
Fill factor, FF	~0.70	0.48	–0.22	69
Module efficiency, η	~15 %	9.71 %	–5.3 %	65

Environmental effects alone are not likely to explain this magnitude of degradation. The simultaneous voltage collapse, depressed fill factor, and anomalously elevated short-circuit current point strongly to internal mismatch or fault conditions which could likely be due to malfunctioning bypass diodes, partial disconnection of substrings, or high series resistance arising from solder fatigue or interconnect failure. The net effect is a panel that falls considerably short of monocrystalline performance expectations and is therefore unsuitable for efficient or grid-integrated deployment.

The panel's performance under the tested conditions may limit its deployment in high-efficiency or grid-connected systems. Nonetheless, the device remains potentially suitable for use in small-scale, educational, or demonstration applications where high energy yield is not critical. Before integration into larger PV arrays or energy-sensitive applications, additional testing and diagnostics are warranted.

CONCLUSION

This study presented a short-term performance monitoring and evaluation of a rooftop-mounted monocrystalline photovoltaic (PV) module at Yaba College of Technology, Lagos, Nigeria, using a data logger–based monitoring framework. Continuous real-time measurements of voltage and ambient temperature, combined with electrical characterization through I–V analysis, provided valuable insights into the operational behaviour of the PV module under tropical climatic conditions.

The results revealed a clear and consistent diurnal voltage profile, with peak voltage values occurring around midday and near-zero output during nighttime hours, confirming normal photovoltaic response to natural solar irradiance. Ambient temperature values ranged between 26 and 34 °C, with mean daily temperatures largely above 30 °C. These elevated temperatures were shown to exert a pronounced influence on voltage output, as evidenced by the observed inverse temperature–voltage relationship, consistent with the negative temperature coefficient of monocrystalline silicon technology (Skoplaki & Palyvos, 2009; Radziemska, 2003; Huld *et al*., 2010).

Electrical characterization further revealed substantial deviation from the manufacturer's standard test condition (STC) specifications. Although current values exceeded nominal ratings, a severe collapse in voltage resulted in a low fill factor (0.48) and a reduced module efficiency of 9.71 %, significantly below the typical 15–22 % expected for commercial monocrystalline modules. Such performance degradation exceeds what would normally be attributed to environmental effects alone and strongly suggests the presence of internal electrical faults, mismatch losses, or degradation mechanisms, such as bypass diode malfunction, increased series resistance, or interconnect failure. Similar fault-induced performance deterioration has been reported in recent PV diagnostic studies employing field measurements and real-time monitoring (Chakraborty *et al*., 2019; Nespoli *et al*., 2018; Jordan *et al*., 2022).

Overall, the findings underscore the critical importance of continuous, data-driven monitoring in identifying underperformance, diagnosing hidden faults, and supporting informed maintenance decisions. While the investigated module is unsuitable for high-efficiency or grid-integrated applications in its present condition, it remains viable for low-power, educational, and demonstration purposes. The study further demonstrates that data logger–based monitoring provides a robust, scalable, and cost-effective approach for enhancing the reliability, operational insight, and long-term sustainability of photovoltaic systems, particularly in thermally stressed tropical environments.

Conflict of interest: The authors declare no conflict of interest reported in this work.

Acknowledgements: The researchers sincerely acknowledge the Tertiary Education Trust Fund (TETFund), Nigeria for the financial support provided through the Institution-Based Research Grant to carry out this work. They are equally thankful to the Centre for Research Support and Grants Management, Yaba College of Technology.

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