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Towards Heat-Resilient Photovoltaics: Experimental Evidence of Performance Losses in the Far North Region of Cameroon

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Abstract. The Far North region of Cameroon, presents extreme thermal challenges for photovoltaics (PV), with ambient temperatures frequently exceeding 45°C. This study experimentally quantifies PV performance losses under real-world Sudano-Sahelian conditions in Maroua. Hourly monitoring over 12 months revealed critical thermal stress: PV modules operated 91% of the time above 25°C, peaking at 67°C. Despite high solar irradiance, close to 1000 W/m², this caused significant power degradation. Results show a power loss of approximately 9.5 W per module, 19% of rated power, corresponding to a thermal degradation rate of 0.46% per °C. These findings underscore the severe impact of heat on PV yield in Sudano-Sahelian climates and provide critical experimental evidence supporting the urgent need for advanced heat-resilient PV designs and cooling strategies to enhance energy production in such demanding environments.

INTRODUCTION

Amid a global energy transition, solar photovoltaics (PV) have emerged as a cornerstone technology, with capacity expanding consistently at over 25% annually[1]. While this growth is a testament to solar scalability, it masks a critical performance gap, particularly in extreme climates. Africa, despite its vast solar potential, has seen volatile growth rates, highlighting the challenges of deploying durable, high-yield systems. Cameroon exemplifies this paradox; with installed PV capacity projected to leap from 30.83 MW to 250 MW by 2030[2], there is an urgent need to understand how local environmental stressors impact system performance and longevity. This proliferation of PV installations signals not only a commitment to sustainable energy but also a pressing demand for empirical data to guide resilient system design in demanding environments.

The promise of solar energy is frequently challenged by the stark divergence between laboratory-rated specifications and field realities. PV module performance is benchmarked under Standard Test Conditions (STC): 25°C cell temperature and 1000 W/m² irradiance, yet these idealized settings are rarely met in practice. This discrepancy is most acute in the Sudano-Sahelian belt, a region characterized by extreme heat, high irradiance, and pervasive dust. In Maroua, Cameroon, a representative city in this zone, ambient temperatures regularly exceed 45°C, creating severe thermal stress that suppresses energy yield and accelerates material degradation[3]. Under such conditions, STC-based performance projections become unreliable, necessitating rigorous, site-specific experimental evaluations to inform engineering solutions.

Elevated temperature is the principal adversary to PV performance in these climates. As module temperatures rise, semiconductor efficiency declines due to increased carrier recombination, directly reducing the open-circuit voltage (V_{oc}) and maximum power output (P_{max})[4]. Field studies across arid regions have consistently documented significant power losses attributable to thermal stress, with efficiency declines ranging from 2.9% to over 9.0%[5]. This thermal challenge is often compounded by other environmental factors like dust soiling and humidity, which can further slash energy production. While various mitigation strategies, from active cooling to advanced materials, are being developed, their implementation is often hampered by a lack of localized performance data. The choice of PV technology is also critical; while monocrystalline silicon dominates the market for its efficiency and cost, its performance under sustained heat remains a key vulnerability.

To bridge the gap between theoretical solutions and field application, this study provides critical experimental evidence of performance losses under real-world Sudano-Sahelian conditions. Our research focuses on monocrystalline silicon modules, the most prevalent technology in the region, to ensure the findings are directly relevant to ongoing and planned deployments. By conducting a year-long, high-resolution monitoring campaign in Maroua, one of Cameroon's hottest localities, we aim to generate the precise data needed to advance heat-resilient photovoltaics.

The objectives of this study are threefold: (1) to experimentally quantify the deviation in key electrical parameters (I_{sc}, V_{oc}, P_{max}) from STC ratings; (2) to correlate these performance losses with measured ambient and module temperatures; and (3) to derive a clear, quantitative degradation rate specific to this extreme climate. This work provides the foundational evidence required to validate and inform the development of more effective cooling strategies, robust system designs, and ultimately, more resilient solar energy infrastructure for the hottest regions on Earth.

MATERIALS AND METHODS

Site Overview for Solar Energy Experiments

In Cameroon's Far North Region, where temperatures can soar up to 60°C ambient and 70°C module temperature in April, the efficiency of photovoltaic (PV) systems faces significant challenges. Maroua, characterized by its tropical Sudano-Sahelian climate, endures an intense four-month, March through June, of exceptionally high ambient temperatures, putting thermal stress on solar technologies. Experimental evidence highlights considerable performance losses in PV systems under these extreme temperatures, crucial for regions with high solar potential like Maroua. Despite abundant sunlight, the excessive heat diminishes energy conversion efficiency, undermining solar investment returns. The geographical diversity, from the flat Chad Plain to the elevated Mandara Mountains, further complicates installations, requiring heat-resilient solutions. Addressing these climatic impacts is essential to optimize solar energy output, emphasizing the need for adaptive technologies tailored to withstand the Far North's rigorous environmental conditions.

Experimental Setup

Figure 1 illustrates the experimental setup which evaluates photovoltaic (PV) panel performance under real climatic conditions. Panels are fixed at a 10° tilt facing true south, optimal for the Sudano-Sahelian climate in Maroua. Equipped with temperature sensors for both ambient and module surface readings, the setup captures critical data on heat impact. Multimeters track voltage, current, and power, while a battery stores generated energy, ensuring continuous operation. This configuration examines significant efficiency losses due to heat, crucial in regions with high temperatures and solar irradiance. By understanding these losses, we aim to develop strategies for enhancing PV reliability and output, offering solutions tailored to challenging climates like Maroua's.

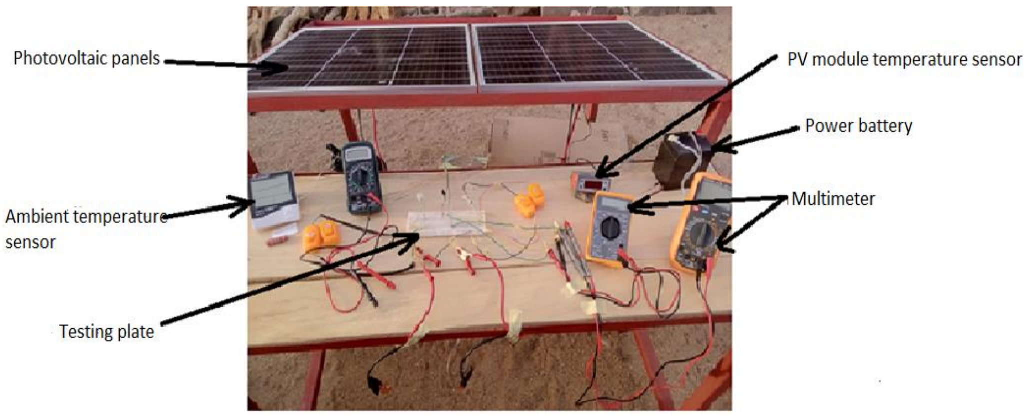


FIGURE 1. Experimental setup for the evaluation of the photovoltaic (PV) panel performance.

Figure 1 illustrates our experimental setup, meticulously crafted to assess the impact of heat on photovoltaic (PV) performance under the severe Sudano-Sahelian climate of Maroua. Central to this setup, a PV module converts sunlight into DC electrical power, functioning as the primary energy source amidst these harsh conditions. Environmental monitoring is facilitated by a Thermo-hygrometer (HTC-2), which continuously records ambient temperature and humidity. Precise temperature variations on the module's backsheet are captured by a thermocouple/module temperature probe (XH-W2060), enabling accurate adjustments to performance data against Standard Test Conditions (STC). Two digital multimeters are integral: the VC890D measures DC voltages, including open-circuit and operating voltages, while the DT-9205A measures DC currents, such as short-circuit and operating currents. Readings are organized through a testing plate with a shunt/resistor configuration, used for current sensing or as operational loads, with switches ensuring safe circuit management. This sophisticated configuration facilitates direct, real-time observation of temperature-related impacts on PV efficiency. The experimental setup was engineered to facilitate the concurrent collection of environmental and electrical data. It captures a range of parameters crucial for understanding PV performance under real conditions, with specific data types comprehensively outlined.

METHODOLOGY

Experimental Procedures

Between April 2024 and March 2025, a comprehensive set of environmental and photovoltaic (PV) performance parameters was collected at hourly intervals from 6:00 a.m. to 6:00 p.m., capturing daytime trends and seasonal variations. The measured parameters included global irradiance (E) in W/m², ambient temperature (T_{amb}) in °C, module temperature (T_{mod}) in °C, relative humidity (HR) in %, short-circuit current (I_{sc}) in A, open-circuit voltage (V_{oc}) in V, and maximum power (P_{max}) in W. Global irradiance represents the total solar radiation on a horizontal surface and offers insights into solar resource availability. T_{amb} and T_{mod} influence PV efficiency, where rising module temperatures typically reduce performance. HR affects atmospheric transmittance and component durability. Isc indicates the maximum current output under standard sunlight conditions, while V_{oc} provides the maximum voltage when the system is open-circuited, both essential for assessing module behavior. P_{max} reflects the real-time energy yield under operational conditions. All parameters were logged during daylight hours over the 12-month period, enabling comprehensive analysis of daily and seasonal PV system performance. This dataset serves as a reliable basis for evaluating system efficiency, environmental impact, and performance optimization under varying climatic and solar conditions. The process starts with assembling the experimental platform and installing sensors in a controlled workshop. Maroua is selected as the test site for its harsh conditions, followed by thorough PV module cleaning to eliminate contaminants. Baseline lab characterization measures key parameters like short-circuit current (I_{sc}, V_{oc}, P_{max}, and fill factor (FF). Modules are then deployed on-site for hourly field monitoring of environmental factors, solar irradiance (E), ambient temperature (T_{amb}), module temperature (T_{mod}), and relative humidity (HR), alongside real-time PV outputs (I_{sc}, V_{oc}, P_{max}). Post-collection, data normalization and analysis in the workshop reveal heat-induced degradation trends, informing strategies for resilient PV designs in arid regions like Cameroon's Far North. This evidence underscores the urgent need for thermal adaptations to sustain solar efficiency.

Critical Performance Parameters for Photovoltaic Modules

The critical performance parameters for photovoltaic (PV) modules include I_{sc}, V_{oc}, FF and P_{max}. To effectively compare module performance across varying operating conditions, field measurements taken under specific irradiance (G) and T_{mod} must be normalized to Standard Test Conditions (STC: G_{STC} = 1000 W/m², T_{STC} = 25°C).

The short-circuit current is the current delivered when the module terminals are shorted. It scales nearly linearly with irradiance and exhibits a weak positive temperature dependence. The normalized short-circuit current at STC is given by Equation (1)[6,7]:

$$I_{sc,STC} = I_{sc,meas} \times \left(\frac{G_{STC}}{G}\right) \times [1 + \alpha \times (T_{module} - T_{STC})] \quad (1)$$

Where:

- α is the temperature coefficient for I_{sc} (typically +0.05% to +0.1% per °C for crystalline silicon)
- The term $\left(\frac{G_{STC}}{G}\right)$ accounts for the linear dependence of current on irradiance
- The temperature correction term adjusts for the temperature difference from STC

The open-circuit voltage is the potential difference across the module terminals with no load connected. $V_{oc,STC}$ is strongly affected by temperature and to a lesser extent by irradiance and is provided by Equation (2)[6,8]:

$$V_{oc,STC} = V_{oc,meas} + \beta \times (T_{module} - T_{STC}) + \gamma \times ln\left(\frac{G_{STC}}{G}\right) \quad (2)$$

However, in many practical applications, especially when using absolute temperature coefficients, the irradiance dependence is approximated linearly or neglected due to its relatively small contribution. A simplified form (Equation (3)) often employed is:

$$V_{oc,STC} \approx V_{oc,meas} + \beta \times (T_{module} - T_{STC}) + \gamma \times \left(\frac{G_{STC}}{G} - 1\right) \quad (3)$$

Where:

- β is the temperature coefficient for V_{oc} (typically -0.3% to -0.4% per °C for crystalline silicon modules, or approximately -2.2 mV/°C for a 60-cell module)
- γ is the irradiance coefficient for V_{oc} (typically 0.02-0.05 V, and often omitted in simplified models)

The fill factor is a measure of PV module quality, representing how closely the I-V characteristic approaches the ideal rectangular shape. FF is calculated from measured parameters using Equation (4)[9,10]:

$$FF = \frac{P_{max,meas}}{V_{co,meas} \times I_{sc,meas}} \quad (4)$$

Where $P_{max,meas} = V_{mp,meas} \times I_{mp,meas}$ is the measured maximum power at the operating point.

Unlike I_{sc} and V_{oc}, FF cannot be reliably normalized to STC using simple linear corrections due to its nonlinear dependence on irradiance, temperature, series resistance (R_s), and shunt resistance (R_{sh}). Therefore, FF is typically reported under actual field conditions or estimated via detailed device modeling rather than direct normalization.

The maximum output power is the most critical performance indicator for energy yield assessment. To normalize field-measured power to STC, an empirical model accounts for both irradiance and temperature effects:

$$P_{max,STC} = P_{max,meas} \times \left(\frac{G_{STC}}{G}\right) \times [1 + \gamma_P \times (T_{module} - T_{STC})] \quad (5)$$

Where:

- γ_P is the temperature coefficient for maximum power (typically -0.35% to -0.5% per °C for crystalline silicon)
- The irradiance correction assumes linear scaling with irradiance

If the temperature coefficient is given in absolute terms (W/°C) rather than relative terms (%/°C), the equation becomes:

$$P_{max,STC} = P_{max,meas} \times \left(\frac{G_{STC}}{G}\right) \times [1 + \gamma_{ABS} \times (T_{module} - T_{STC})] \quad (6)$$

Under real operating conditions, PV panel output is significantly affected by environmental factors. The real-time electrical output power can be estimated using Equation (7):

$$P_{PV} = P_{stc}\left(\frac{G}{G_{STC}}\right) \times [1 + \beta(T_{module} - T_{STC})] \quad (7)$$

Where:

- P_{PV} is the actual output power under operating conditions
- P_{stc} is the rated power at STC
- β is the temperature coefficient for power (%/°C) (typically -0.3% to -0.5%/°C for crystalline silicon).
- G and G_{STC} are the actual and standard irradiance values
- T_{module} and T_{stc} are the actual and standard module temperatures

The temperature coefficient β can be determined experimentally using Equation (8):

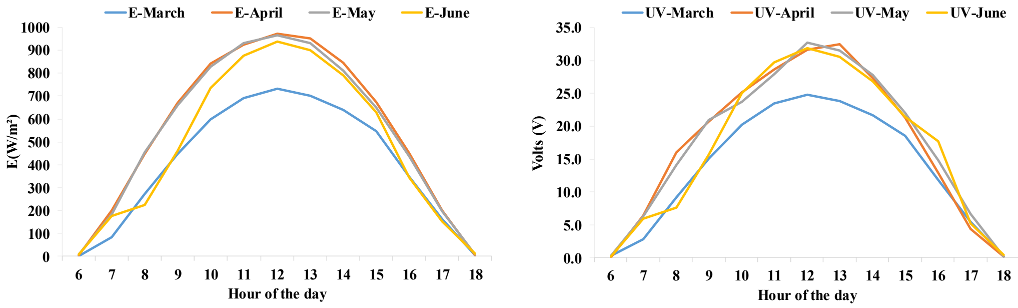
$$\beta = \frac{P_{STC} - P_{meas}}{P_{STC}(T_{module} - T_{STC})} \quad (8)$$

This coefficient quantifies the percentage power loss per degree Celsius rise in temperature above STC, providing essential information for accurate performance prediction under varying thermal conditions. The most critical performance parameters for a photovoltaic (PV) module include I_{sc}, V_{oc}, FF and P_{max}. These parameters to convert your field measurements (taken under varying irradiance G and temperature T_{mod} into equivalent values at STC $G_{STC} = 1000\ W/m^2$, $T_{mod,STC} = 25°C$. The electrical parameters $V_{oc}(t)$ and $I_{sc}(t)$ are measured using the experimental setup. These measurements provide the empirical data necessary for evaluating the real-world performance of PV panels and for validating theoretical models under varying environmental conditions.

RESULTS AND DISCUSSION

Variation of Solar Irradiance (E) and Ultraviolet Radiation (UV)

Figures 2(a-b) depict hourly solar irradiance (E) and ultraviolet (UV) radiation variations from 6 AM to 6 PM on representative days in March through June, Cameroon's hottest months. These data quantify solar energy availability for photovoltaic (PV) systems while revealing stressors like intense heat and UV that accelerate performance degradation in Maroua's Sudano-Sahelian climate. In March, irradiance starts low (83 W/m² at 7 AM), peaks midday (692-732 W/m² from 11 AM-2 PM), and declines, with UV mirroring this trend (peaking at 24.82 W/m² around noon). Though moderate compared to later months, this exposure still induces thermal stress, promoting encapsulant breakdown and coating discoloration, early signs of efficiency losses. Such patterns underscore the need for heat-resilient PV designs to mitigate long-term durability issues in arid regions.



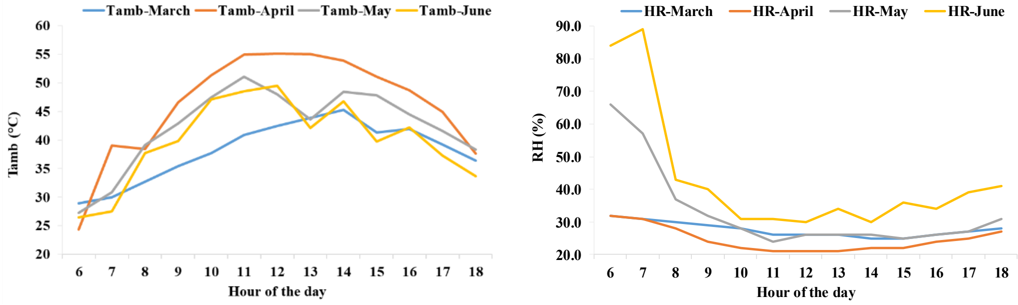
(a) (b)

FIGURE 2a, b. Monthly variation of solar irradiance and ultraviolet radiation as a function of time.

Cameroon's peak hot months, April through June, intensify challenges for photovoltaic (PV) systems in Maroua's Sudano-Sahelian climate. These patterns highlight abundant energy potential alongside severe thermal and degradative stressors, driving performance losses. In April, irradiance surges from 200 W/m² at 7 AM to an annual high of 923-971 W/m² (11 AM-2 PM), with UV peaking at 31.6-32.44 W/m² around noon. This amplifies PV output but heightens thermal stress, slashing efficiency and accelerating delamination and corrosion, far beyond March's milder effects. May mirrors April closely, starting at 183 W/m² and peaking at 932-967 W/m², with UV at 27.87-32.74 W/m². Identical diurnal trends sustain comparable output gains and degradation risks, as high temperatures exacerbate UV-induced material breakdown in encapsulants and backsheets. June maintains high levels, from 177 W/m² to 878-939 W/m² peaks, and UV up to 29.77-31.84 W/m². Though slightly cooler ambient temperatures offer marginal relief, the relentless exposure still promotes efficiency derating. Across these months, elevated irradiance boosts instantaneous PV power, yet it's undermined by thermal losses, efficiency drops precisely when output should peak. Synergistic heat and UV accelerate long-term degradation, underscoring the urgent need for resilient PV technologies to balance yield and durability in arid, high-heat regions like Cameroon's Far North.

Variation of T_{amb} and RH

Figures 3(a-b) illustrate diurnal variations in ambient temperature (T_{amb}) and relative humidity (RH) from 6 AM to 6 PM across March-June, Cameroon's hottest months, exposing photovoltaic (PV) systems in Maroua's Sudano-Sahelian climate to severe thermal stress. T_{amb} follows a classic solar-driven pattern: rising from early-morning lows, peaking midday (12-2 PM), and declining by evening. RH inversely trends high mornings, plummeting at peak heat, then rebounding, correlating with the dry season's aridity. In March, T_{amb} climbs from 28.9°C (6 AM) to 45.3°C (1 PM), with RH falling from 32% to 25%. April intensifies this, surging from 24.4°C to a blistering 55.1°C (11 AM-2 PM), RH dipping to 21%. May peaks at 51.1°C, starting with 66% RH that crashes to 24%. June reaches 49.5°C, but morning RH spikes to 89%, signaling rainy season onset, before dropping to 30% midday. These extreme T_{amb} levels devastate PV efficiency, rated at 25°C under Standard Test Conditions (STC). Each °C above causes 0.3-0.5% loss in crystalline silicon modules, with operating temperatures often 20-35°C hotter than ambient, potentially exceeding 70°C during 11 AM-2 PM peaks in April. This thermal derating slashes output precisely when irradiance is highest, amplifying performance losses in the Far North. RH plays a minor direct role, as PV cells convert light, not moisture. Though high morning humidity in May-June may indirectly foster soiling or long-term degradation (e.g., corrosion, delamination, PID), it pales against immediate heat-induced inefficiencies. These findings demand heat-resilient PV innovations to safeguard solar viability in arid, high-heat regions like Cameroon's Far North.



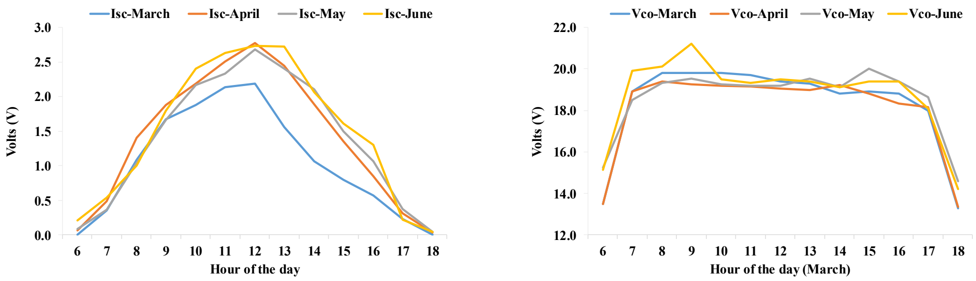
(a) (b)

FIGURE 3 a, b. Diurnal variations in ambient temperature and relative humidity from 6 AM to 6 PM across March-June.

The biggest challenge for solar panels in Maroua's hot months is extreme heat, not humidity. PV modules are rated at a cell temperature of 25°C, but in reality, they run 20-35°C hotter than the surrounding air. With ambient temperatures hitting 45-55°C from April to June, panel temperatures can soar to 80°C, slashing efficiency by 0.3-0.5% for every degree over 25°C. This thermal derating causes immediate, significant power losses during peak sunlight hours. While humidity may contribute to long-term wear, like corrosion or delamination, it has little effect on real-time performance, as PV cells generate electricity from light, not moisture. Ultimately, heat, not humidity, is the main culprit behind reduced solar output in this harsh climate.

Variation of Open-Circuit Voltage and Short-Circuit Current

Figures 4 (a–b) illustrate the diurnal profiles of I_{sc} and V_{oc} for the photovoltaic (PV) system, measured hourly from 6 AM to 6 PM during March–June, the peak hot season in Maroua, Cameroon. Both parameters exhibit a solar-driven pattern: rising post-sunrise, peaking midday, and declining toward sunset, in direct alignment with irradiance variations. V_{oc} initiates low near dawn (6 AM), rises sharply in the early morning, and attains maxima of 19-20 V between 8 and 10 AM. It remains relatively stable through midday, albeit with a subtle decline attributable to rising module temperatures, before gradually decreasing to early-morning levels by 6 PM. This consistent peak range across months, underscores voltage stability, tempered by thermal effects.



(a) (b)

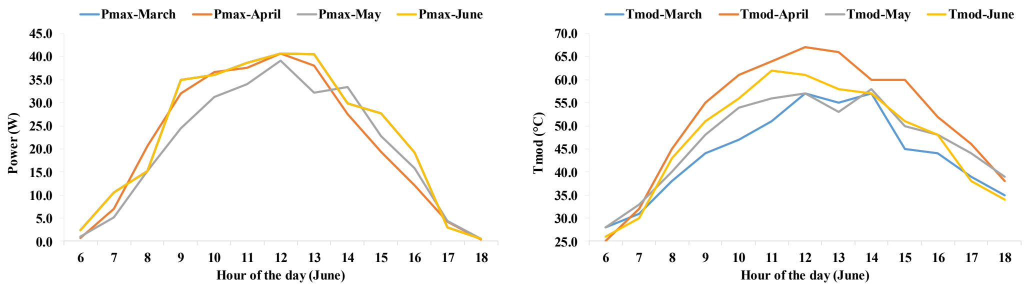
FIGURE 4. Diurnal variations of (a) I_{sc} and (b) V_{oc} from 6 AM to 6 PM across March-June.

In contrast, I_{sc} commences near zero at sunrise, escalates progressively with irradiance, and reaches maxima around 11 AM–noon (2.2 A in March, increasing to 2.8-3.0 A by June), reflecting enhanced solar intensity and daylight duration. Afternoon values taper symmetrically. Month-specific trends reveal nuances: In March, V_{oc} stabilizes at 20 V until 2 PM, with I_{sc} forming a symmetric bell curve peaking at 2.2 A. April maintains V_{oc} at 20 V while elevating I_{sc} to 2.8 A under intensified irradiance. May shows V_{oc} slightly below 20 V with a broadened I_{sc} profile, indicating prolonged high-output periods. June features an early V_{oc} peak of 22 V followed by a minor midday dip (temperature-induced), alongside the highest I_{sc} of 3.0 A. These observations conform to established PV behavior: V_{oc} exhibits a modest midday reduction due to the negative temperature coefficient of silicon cells, while I_{sc} faithfully tracks irradiance. The progressive monthly escalation in I_{sc} highlights seasonal solar gains; however, thermal stress attenuates

V_{oc}, thereby constraining maximum power output during peak irradiance. In Maroua's extreme climate, this interplay exemplifies heat-induced performance losses, emphasizing the imperative for temperature-resilient PV technologies to optimize yield in the Far North Region of Cameroon.

Variation of of P_{max} and T_{mod}

Figures 5 (a–b) delineate the diurnal profiles of P_{max} and T_{mod} for the photovoltaic (PV) system, recorded hourly from 6 AM to 6 PM during March–June, the zenith of thermal extremes in Maroua, Cameroon. T_{mod} exhibits a pronounced solar-correlated ascent, initiating at 30-40°C near dawn, escalating to peaks of 55-67°C between 12 and 2 PM, and subsiding toward evening. April records the apex at 67°C, contrasting March's nadir of 57°C, underscoring escalating seasonal heat. P_{max} traces a canonical bell-shaped trajectory: near-zero at 6 AM, culminating midday, and reverting to baseline by 6 PM. Peak values ascend from 32 W in March to 40-41 W in April-June, though June displays volatility, including a transient dip around 9-10 AM before recovering. A pivotal inverse correlation emerges: while T_{mod} surges or sustains elevations into early afternoon, P_{max} plateaus or attenuates post-noon, exemplifying thermal derating. This attenuation, evident in April and June's fluctuating outputs amid extreme T_{mod}, aligns with the negative temperature coefficient of silicon PV cells, where efficiency erodes around 0.3-0.5% per °C above 25°C STC. Consequently, peak irradiance coincides with maximal thermal penalties, curtailing energy yield in Maroua's Sudano-Sahelian furnace. These findings compel advancements in heat-mitigating PV architectures to bolster resilience and efficacy in the Far North Region.



(a) (b)

FIGURE 5 a, b. Diurnal variations of P_{max} and T_{mod} from 6 AM to 6 PM across March-June.

Comparison of Results on PV Module Efficiency Loss

This comparative analysis of temperature-induced PV efficiency losses across global climates reveals stark regional disparities, emphasizing the critical role of environmental conditions in energy yield. Prior studies report power loss rates ranging from 0.22%/°C in Malaysia's tropical climate[11] to 0.9%/°C in Biskra, Algeria's arid Saharan environment[12], with intermediate values in Djibouti (0.7%/°C;[13]), Europe (0.45%/°C;[14]), and Baghdad (0.45%/°C;[10]). These findings underscore a consistent trend: hotter climates amplify thermal derating, primarily due to elevated module temperatures (T_{mod}) reducing silicon PV efficiency via its negative temperature coefficient of around 0.3 to 0.5%/°C. The present study in Maroua, Cameroon (0.46%/°C), aligns with temperate and Sahelian zones, reflecting its Sudano-Sahelian climate marked by high irradiance but moderated temperatures compared to extreme arid regions. Diurnal analysis during March–June reveals synchronized T_{mod} and power output (P_{max}) peaks (55-67°C; 11:00 a.m.-1:00 p.m.), followed by midday efficiency attenuation as heat stress outweighs solar gains. Notably, Maroua's performance contrasts with Algeria's Saharan extremes but mirrors Senegal's Sahelian trends, highlighting climatic gradients' influence. These results reinforce the urgency of adaptive thermal management strategies such as advanced cooling systems or temperature-resilient materials to mitigate losses in hot climates. Site-specific data on irradiance, temperature, and humidity emerge as indispensable tools for pre-deployment optimization, ensuring PV systems balance high irradiance absorption with thermal stability. Ultimately, Maroua's intermediate loss rate underscores its potential for sustainable solar energy in Cameroon's Far North Region, advocating for context-driven designs to harness solar resources while countering environmental stressors. This synthesis bridges global research gaps, offering actionable insights for resilient, climate-adapted PV deployment.

CONCLUSION

This study experimentally quantifies temperature-induced performance losses in photovoltaic generators within the hot Sudano-Sahelian climate of Maroua, Far North Cameroon. Hourly measurements of ambient temperature (T_{amb}), module temperature (T_{mod}), solar irradiance (E), open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), and maximum power (P_{max}) spanned 12 months, with diurnal analyses emphasizing March-June, the region's thermal zenith. Diurnal trends elucidate a solar-driven synergy: post-sunrise escalations in E, V_{oc}, I_{sc}, and P_{max} culminate midday (11 AM–1 PM), where T_{mod} peaks at 67°C (April) and P_{max} at 41 W. However, sustained irradiance belies subtle V_{oc} and P_{max} declines, attributable to the silicon PV negative temperature coefficient, manifesting an inverse thermal-performance relationship. Annually, T_{amb} exceeded 25°C for 67% of daylight hours and T_{mod} for 91%; April's extremes (T_{amb} 55.9°C, T_{mod} 67°C) induced 19% power reduction (9.5 W loss), yielding a site-specific derating of 0.46%/°C, consistent with analogous Sahelian contexts. Maroua's irradiance bounty positions it as a solar hotspot, yet thermal stressors erode efficiency, underscoring the imperative for site-specific environmental profiling and pre-deployment trials. Mitigation strategies, enhanced ventilation, optimized tilts, and heat-resilient modules, can preserve yields and reliability. These insights inform manufacturers on hot-climate material innovations and designers on adaptive architectures. Future investigations should integrate aerosols, dust, and humidity effects to holistically address degradation in arid-semi-arid PV deployments, advancing resilient solar infrastructure in the Far North.

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