A New Approach to Temperature Coefficient Comparative Analysis of PV Modules Power

S. SEMAOUI, N. BELHAOUAS, H. HAFDAOUI, I. BENDAAS, F. MEHAREB, B. TAGHEZOUIT, N. MADJOUDJ, H. ASSEM, A. HADJ ARAB
Centre de Développement des Energies Renouvelables,
CDER, B.P. 62, Route de l'observatoire,
Bouzareah, 16340 Algiers,
ALGERIA

Abstract: - Accurate determination of the temperature coefficient of maximum power (TC_{Pmax}) is essential for evaluating photovoltaic (PV) module performance. This work compares two techniques for TC_{Pmax} determination: a conventional outdoor method and a novel approach based on long-term monitoring. The research was conducted on grid-connected PV installation located at Algiers. Three representative PV modules exhibiting different failure severity levels were selected for analysis. Results show good agreement between two methods, with deviations not exceeding ± 5% in most cases. However, TC_{Pmax} values were found to decrease as the severity of module degradation increased, indicating a strong correlation between failure severity and temperature sensitivity. The proposed method, while requiring a longer data collection period, offers a cost-effective, non-intrusive alternative suitable for in-field applications. The comparative analysis highlights the advantages and limitations of each technique and demonstrates the potential of the proposed method for real-time performance diagnostics and degradation assessment in PV systems.

Key-Words: - PV module degradation, TC of maximum power, TC_{Pmax} determination, Sun-Tracking method, Data-Driven monitoring, Temperature effect.

Received: June 27, 2025. Revised: September 29, 2025. Accepted: November 9, 2025. Published: May 21, 2026.

1 Introduction

PV systems are increasingly deployed worldwide as a sustainable and environmentally friendly energy solution, [1], [2]. However, their performance and energy yield are highly sensitive to environmental conditions, particularly temperature, [3], [4], [5]. The TC_{Pmax} is a critical parameter that quantifies the impact of temperature variations on PV module output and is therefore essential for accurate performance prediction, modelling, and degradation analysis, [6], [7], [8], [9].

The International Electrotechnical Commission (IEC) standard 61215 outlines standardized procedures for determining this coefficient under outdoor conditions as well as under controlled conditions, [7]. Mostly, the TC_{Pmax} is determined through outdoor testing using a sun-tracking structure to ensure consistent irradiance and temperature variation, [10].

While this method provides high accuracy, it requires specialized equipment and the temporary disconnection of the PV module from the installation, which can be costly and impractical, particularly for large-scale or remote PV systems, [10]. To address these limitations, this work proposes and validates an alternative method based on the analysis of long-term monitoring data from operating PV systems, [11]. This novel technique utilizes electrical and meteorological data collected during normal operation, eliminating the need for additional infrastructure or system shutdown. The method offers a practical, low-cost, and continuous approach to TC_{Pmax} determination under real working conditions, [12], [13], [14].

In this work, both the conventional sun-tracking method and the proposed monitoring-based technique have been applied to a 9.6 kW grid-connected PV installation located on the rooftop of the CDER in Bouzareah, Algeria.

Three representative PV modules with varying levels of degradation severity (low, high, and very high) were selected to assess the sensitivity of temperature coefficient determination to failure severity.

The obtained TC_{Pmax} values were compared across methods and with manufacturer datasheet values to evaluate accuracy and highlight possible correlation between this TC_{Pmax} and the PV module degradation in terms of failure exhibition and its severity. This paper presents a comparative analysis of both methods, discusses their respective advantages and limitations, and demonstrates the feasibility of monitoring-based approaches for in-field performance diagnostics and degradation assessment in PV systems.

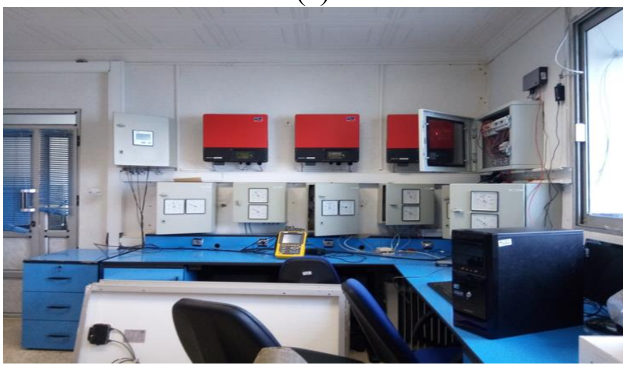
Other standardized performance and reliability tests classification of degradation severity and the visual inspection results have been addressed in our previous research, we clarified the criteria used to classify degradation levels by relating them to measured power loss percentages and observed electrical performance deviations, which are directly relevant to the objective of the TC_{Pmax} analysis and are applied to the same PV modules.

2 Methodology

2.1. PV installation description

The PV installation analyzed in this study has been located on the rooftop of the CDER in Bouzareah, a city in northern Algeria, [15]. An overview of grid-connected PV system has been presented in Figure 1.

(a)



(b)

Fig. 1 Overview of grid-connected PV installation: (a) PV arrays; (b) inverters and grid connection components

Source: Created by the authors.

The site of CDER is positioned at geographical coordinates 36° 47′24″N and 3°01′04″E, at an altitude of 345 meters above sea level.

The system has been subjected to a Mediterranean climate, characterized by mild, wet winters and hot, dry summers, [16]. This grid-connected PV system comprises an array of 90 monocrystalline PV modules, each with a rated peak power output of 106 W. The main electrical and thermal parameters of the photovoltaic modules have been summarized in Table 1 and Table 2.

The array has been configured into three identical sub-arrays, each with a nominal capacity of 3.2 kW_P, consisting of 30 modules. Each sub-array includes two parallel strings, with 15 modules connected in series per string.

Power conversion has been handled by three single-phase inverters from SMA of type SB 3000 TL ST-21, each rated at 3 kW, with their outputs directly fed into the utility grid, [15].

Table 1. Electrical characteristics of the PV module

Parameter	Value
Maximum Power of the Module (P_{max})	106 W
Short-Circuit Current of the Module (I_{sc})	6.54 A
Open-Circuit Voltage of the Module (V_{oc})	21.6 V
Voltage at Maximum Power Point (V_{mpp})	17.4 V
Current at Maximum Power Point (I_{mpp})	6.10 A
Number of Series-Connected Cells	36

Source: [15].

Table 2. Thermal characteristics of the PV module

Temperature Coefficient of I_{sc} ($TC_{Isc} \approx \alpha$)	+0.042 %/°C
Temperature Coefficient of V_{oc} ($TC_{Voc} \approx \beta$)	–0.328 %/°C
Temperature Coefficient of P_{max} ($TC_{Pmpp} \approx \gamma$)	–0.40 %/°C

Source: Created by the authors.

2.2 Temperature coefficients determination

The temperature coefficients of current, voltage, and power for the selected PV module have been determined in accordance with the IEC 61215-2 standard, [10]. However, in this work, only the temperature coefficient of maximum power (TC_{Pmax}) has been considered. Two distinct approaches have been employed for its determination. The first is a conventional and widely adopted method conducted under outdoor conditions using a sun-tracking structure to ensure optimal alignment with solar irradiance. The second is a novel technique proposed in this work, based on the analysis of continuously monitored meteorological and electrical data from the operating PV system, [17], [18], [19]. This method offers a practical, non-intrusive, and cost-effective alternative for estimating TC_{Pmax} under real operating conditions, without requiring physical relocation or operational interruption of the PV module, [20].

2.2.1 TC_{Pmax} based on the Sun-tracking method

A test has been conducted to record the current–voltage (I–V) and power–voltage (P–V) characteristic curves of the selected photovoltaic (PV) module under a constant irradiance of 1000 W/m², while systematically varying the module temperature. To achieve the desired temperature range, the PV module has been precooled, enabling a temperature rise of at least 30 °C upon outdoor exposure. Characteristic curves have been measured at approximately 2 °C intervals in module temperature, ensuring a sufficiently broad range for the accurate determination of temperature coefficients. To facilitate these measurements, a mobile sun-tracking structure has been developed to maintain optimal alignment with solar irradiance throughout the testing period.

The experimental setup has incorporated an electronic load for I–V curve acquisition, a data logger for real-time monitoring, a calibrated reference PV cell for irradiance measurement, and multiple sensors to monitor both module and ambient temperatures, among other relevant environmental and electrical parameters (see Figure 2). The acquired data have been used to generate the I–V and P–V curves corresponding to each temperature increment.

Subsequently, linear regression analysis has been applied to extract the temperature coefficients by examining the relationship between the electrical output parameters and the module temperature.

Fig. 2 Sun-tracking structure for the tested PV module

Source: Created by the authors.

2.2.2 TC_{Pmax} based on data-driven monitoring method

This method for determining the temperature coefficients has been based on long-term monitoring data collected over a sufficient temperature range, specifically, a minimum span of 30 °C in PV module temperature. Achieving this range has typically required a data acquisition period of three to six months, depending on seasonal variations and the local climatic zone.

To ensure accurate temperature measurements, sensors have been affixed to selected representative PV modules within the installation. The collected dataset, including both electrical parameters and meteorological variables, has been used to establish linear relationships between each electrical parameter and the corresponding module temperature. In this context, the grid-connected PV system under investigation has been divided into three sub-arrays (see Figure 1). For each sub-array, one representative PV module has been selected and instrumented with multiple temperature sensors to accurately record its surface temperature. The configuration of the sub-arrays and the placement of sensors on the rear side of the modules are illustrated in Figure 3.

The data-driven monitoring method is based on a linear regression model that relates the measured maximum power output $P_{\max}$ to the corresponding module operating temperature T. For each PV module, is expressed eq 1.

$$P_{\max}(T) = a + bT \quad (1)$$

where $a$is the intercept representing the extrapolated power at zero temperature, and $b$is the temperature sensitivity coefficient. The regression parameters are estimated using the ordinary least squares method under the assumptions of linearity, independence of residuals, homoscedasticity, and normally distributed errors.

The quality of the regression is evaluated using the coefficient of determination R^2, indicating a strong linear relationship. The uncertainty of the estimated temperature coefficient is quantified through the standard error of the slope, providing a measure of confidence in the derived TC_{Pmax} values. This formulation ensures transparency and allows direct comparison with the sun-tracking-based approach.

(a)

(b)

Fig. 3 The PV array showing selected modules with varying levels of failure severity: (a) PV modules exhibiting different degrees of degradation, (b) temperature sensor fixed behind the module.
Source: Created by the authors.

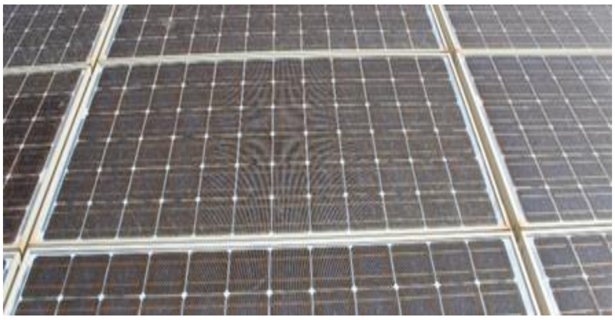
3 Results and Discussion

It should be noted that the temperature coefficient of maximum power (TCP_{max}) provided in manufacturer datasheets corresponds to initial, non-degraded modules and is typically obtained under controlled laboratory conditions close to standard test conditions. As such, these coefficients represent baseline values before the onset of field-induced aging mechanisms. The relatively larger deviations observed between datasheet and measured TC_{Pmax} values for heavily degraded modules are therefore expected and should not be interpreted as methodological inconsistencies. Instead, they highlight the impact of long-term degradation on the thermal and electrical behavior of PV modules. The use of outdated datasheet temperature coefficients in energy yield simulations of aging PV plants may lead to systematic inaccuracies, particularly under high-temperature operating conditions, potentially resulting in overestimation of power output. These findings emphasize the importance of periodically updating temperature coefficients using field-based measurements to improve the accuracy of performance assessment and long-term yield predictions.

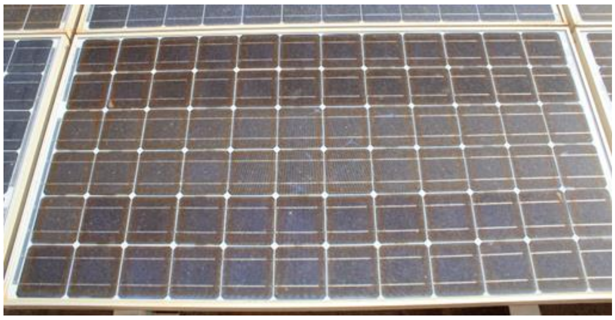
In this work, three PV modules exhibiting varying levels of failure severity, categorized as low (a), high (b), and very high (c), have been selected from the PV array for detailed analysis (see Figure 4).

The temperature coefficients for each module have been determined using both the conventional sun-tracking method and the proposed monitoring-based technique, and the results have been evaluated and compared as follows:

(a)



(b)



(c)

Fig. 4 Representative PV modules selected from the installation, each exhibiting a different level of failure severity: (a) low, (b) high, and (c) very high.
Source: Created by the authors.

3.1 TC_{Pmax} based on the Sun-tracking method

The selected and representative PV module sample has been deployed and tested using the proposed technique. The results obtained from the analysis are presented in Table 3. The measured temperature coefficients have been compared with the corresponding values provided in the manufacturer's datasheet, as shown in Table 1, in which the variation has been calculated using the datasheet value of TC_{Pmax} (- 0.4 %/°C) as the reference.

This comparison reveals that TC_{Pmax} is significantly influenced by the severity of the observed failures. Specifically, the values of TC_{Pmax} decrease as the severity of the exhibited degradation increases, indicating a clear correlation between module degradation and temperature coefficient behavior in terms of TC_{Pmax}.

Table 3. TC_{Pmax} values determined using the sun-tracking method

Temperature coefficients	Sun-tracking method	Variations
TC_{Pmax} _M1	- 0.408 %/°C	2.125%
TC_{Pmax} _M2	- 0.441 %/°C	10.25%
TC_{Pmax} _M3	- 0.467 %/°C	16.75%

Source: Created by the authors.

3.2 TC_{Pmax} based on data-driven monitoring method

The data have been processed based primarily on wind speed and solar irradiance stability, in accordance with the guidelines specified in IEC 61215. Specifically, only measurements collected under wind speeds below 2 m/s and solar irradiance levels close to 1000 W/m², with fluctuations not exceeding ± 2 %, have been considered to ensure measurement consistency and reliability.

Based on this filtered dataset, the TC_{Pmax} for the three representative PV module samples has been computed and is summarized in Table 4.

Table 4. TC_{Pmax} values determined using the proposed data-driven monitoring method

Temperature coefficients	Proposed technique	Variations
TC_{Pmax} M1	- 0,417	4.25 %
TC_{Pmax} M2	- 0,460	15 %
TC_{Pmax} M3	- 0,487	21.75 %

Source: Created by the authors.

The obtained results have shown that the TC_{Pmax} values exhibit notable deviations from the reference value (-0.4 %/°C) provided in the manufacturer’s datasheet. Specifically, the calculated TC_{Pmax} values have ranged from - 0.417 %/°C to -0.487 %/°C, corresponding to a maximum deviation of 0.07 %/°C. This variation represents an approximate relative difference of 17.05 % compared to the nominal reference. Furthermore, the severity and inhomogeneity distribution of observed failures in the tested PV modules have increased. This degradation has contributed to a further decline in TC_{Pmax} values, indicating a strong correlation between failure severity and the reduction in the temperature coefficient of maximum power.

3.3 Comparison of Results Obtained by the Two Methods

This section presents a detailed comparison of the results obtained using the two methods for determining the TC_{Pmax}. The comparison addresses both the accuracy of each approach and its respective practical advantages and limitations. The TC_{Pmax} values have been determined for three representative PV module samples using both the conventional sun-tracking method and the proposed data-driven monitoring technique.

The results have demonstrated a high level of consistency between the two methods, with deviations not exceeding ± 5 %, see Table 5. These findings confirm the viability of the proposed method for accurately estimating TC_{Pmax} under real operating conditions.

Beyond the quantitative agreement between the two approaches, the observed decrease in TC_{Pmax} with increasing degradation severity can be explained by the underlying physical degradation mechanisms affecting PV modules.

Degradation modes such as increased series resistance due to solder bond fatigue or corrosion lead to enhanced ohmic losses, which become more pronounced at elevated operating temperatures.

Cell mismatch caused by localized defects, microcracks, or non-uniform aging results in uneven current distribution and increased thermal sensitivity of the weakest cells, thereby amplifying power losses as temperature rises. Encapsulant discoloration and material aging further reduce optical transmittance and heat dissipation capability, increasing module operating temperature and exacerbating temperature-induced power degradation. These mechanisms alter the internal electrical and thermal behavior of degraded modules, resulting in a stronger negative temperature dependence of the maximum power output.

The consistent observation of this trend using both the sun-tracking and monitoring-based methods reinforces the physical validity of the proposed approach for assessing degradation-induced temperature sensitivity in PV modules.

Table 5. Comparison of TC_{Pmax} values obtained using the proposed data-driven monitoring method and the conventional sun-tracking method

Temperature coefficients	Sun-tracking method	Proposed technique	Variations between the two methods
TC_{Pmax} 1	- 0.408	- 0,417	2.25%
TC_{Pmax} 2	- 0.441	- 0,460	4.75%
TC_{Pmax} 3	- 0.467	- 0,487	5%

Source: Created by the authors.

However, the analysis has also revealed the influence of module degradation and failure severity on the accuracy of TC_{Pmax} determination. Notably, PV modules M2 and M3 have exhibited significant discrepancies between the measured values and the reference TC_{Pmax}, which are attributed to the presence of high-severity degradation. Such failures have been shown to alter the modules' electrical behavior, thereby affecting the accuracy of coefficient estimation.

In contrast, module M1, which has shown only minor degradation, has demonstrated excellent agreement between the TC_{Pmax} values obtained by both methods. In summary, while the sun-tracking method offers slightly higher accuracy and faster coefficient determination, it requires substantial investment in equipment and may necessitate temporary system shutdowns. Conversely, the proposed monitoring-based method provides a cost-effective, continuous, and non-intrusive alternative that performs reliably once sufficient operational data have been collected, typically after a monitoring period of approximately three months under local environmental conditions.

The advantages and disadvantages of the two methods are summarized in Table 6. The proposed technique, based on the analysis of monitoring data from a functioning PV module, has demonstrated a low-cost and sufficiently accurate means of determining the TC_{Pmax}. This method requires only one or a few temperature sensors installed on a selected module and leverages power output data typically available from the inverter. A major advantage of this approach is its ability to operate continuously throughout the system's lifetime, without requiring any interruption or partial shutdown of the PV installation. However, a key limitation lies in its reduced accuracy during the initial implementation phase. Accurate TC_{Pmax} estimation depends on the availability of a sufficiently large dataset, which typically requires more than three months of continuous monitoring under local climatic conditions (in this work: Mediterranean climate).

Table 6. Advantages and disadvantages of the two techniques used for determining the TC_{Pmax}

Aspect	Sun-tracking method	Proposed technique
Accuracy	High	High (after sufficient data collection)
Speed of TC_{Pmax} Determination	Fast	Slower at the beginning (requires at least 3 months of data)
Impact on PV Installation	Requires partial or complete shutdown during test	No interruption; continuous and real-time operation
Cost	Expensive (requires dedicated equipment)	Low-cost (uses sensors and existing inverter data)
Operational Feasibility	One-time TC_{Pmax} determination, or as needed	Real-time monitoring can operate continuously throughout the system's life
Complexity	Requires a sun-tracking system and specific equipment	Simple setup using on-site monitoring data and temperature sensors

Source: Created by the authors.

In contrast, the sun-tracking-based technique for determining TC_{Pmax} offers high measurement accuracy, attributed to the precision of the specialized instrumentation used. It also enables faster determination of the temperature coefficient.

Nonetheless, this method is considerably more expensive due to the cost of equipment and logistical requirements. Additionally, its deployment typically necessitates partial or complete shutdown of the PV system to isolate and test the target module.

4 Conclusion

This paper has presented a comprehensive evaluation of two different techniques for determining the TC_{Pmax} in PV modules, in accordance with the IEC 61215 standard. A conventional sun-tracking-based method and a novel data-driven monitoring technique have both been applied and compared using three representative PV modules selected from a grid-connected installation in northern Algeria, each exhibiting different levels of failure severity. The results confirm that the proposed monitoring-based technique, which relies on real operational data, offers a reliable, cost-effective, and non-intrusive alternative to the traditional sun-tracking approach. Despite requiring a longer data accumulation period (typically over three months), the method has shown a high degree of accuracy, with deviations from the sun-tracking method remaining within ±5%.

This validates its potential for continuous performance assessment without disrupting PV system operation. Furthermore, the work has demonstrated a clear correlation between the severity of module degradation and the decrease in TC_{Pmax} values. Modules exhibiting more severe failures displayed significantly lower TC_{Pmax} values, diverging notably from both the datasheet references and values obtained via the sun-tracking method. This highlights the importance of incorporating real-time monitoring approaches for accurate, in-situ performance evaluation over a PV module's operational life. While the sun-tracking technique remains the benchmark for precision, the proposed monitoring-based method emerges as a promising alternative for long-term performance diagnostics, particularly in large-scale or remote installations where cost and accessibility are critical considerations.

References:

[1] Zheng, S., Bai, J., Akram, MW. (2025). An enhanced method for design and simulation of building integrated PV plants incorporating photovoltaic resource assessment. *Building Simulation*, vol. 18, pp. 1087-1101. https://doi.org/10.1007/s12273-025-1252-8

[2] Ding, C., Ren, X. (2025). Evolution and vulnerability analysis of global photovoltaic industry chain trade pattern. *Scientific Reports*, vol. 15, Article No. 6275. https://doi.org/10.1038/s41598-025-90234-6

[3] Saka, K. (2024). Evaluation of a grid-connected PV power plant: performance and agrivoltaic aspects. *Environ Dev Sustain*, vol. 26, pp. 32319-32336. https://doi.org/10.1007/s10668-024-05098-z

[4] Venkatesh, R., Logesh, K., Vinayagam, M., Prabagaran, S., Chaturvedi, R., Hossain, I., Soudagar, M., Salmen, S., Al Obaid, S. (2025). Hybrid PV solar system performance enriched by adaptation of silicon carbide made porous medium. *Electr Eng*, vol. 107, pp. 3271-3283. https://doi.org/10.1007/s00202-024-02694-0

[5] Madjoudj, N., Belhaouas, N., Nemsi, S., Hafdaoui, H., Mehareb, F., Bakria, K., Assem, H., Hadjrioua, F., Semaoui, S. (2023). Thermal Behavior of PV Modules for Building Integration. *Second International Conference on Energy Transition and Security (ICETS), Adrar, Algeria*, pp. 1-6. https://doi.org/10.1109/ICETS60996.2023.10410829

[6] Mussard, M., Riise, H.N., Wiig, M.S., Rønneberg, S., Foss, S.E. (2023). Influence of Temperature Coefficient and Sensor Choice on PV System Performance. *in IEEE Journal of Photovoltaics*, vol. 13, no. 6, pp. 920-928. https://doi.org/10.1109/JPHOTOV.2023.3311896

[7] Cotfas, D.T., Cotfas, P.A., & Machidon, O.M. (2018). Study of Temperature Coefficients for Parameters of PV Cells. International *Journal of Photoenergy*, vol. 2018, Article No. 5945602. https://doi.org/10.1155/2018/5945602

[8] Khala, M., El Yanboiy, N., Elabbassi, I., Eloutassi, O., Halimi, M., El Hassouani Y., Messaoudi C. (2025). Enhancing machine learning model for early warning in PV plants: air temperature prediction informed by power temperature coefficient. *The Journal of Supercomputing*, vol. 81, Article No. 394. https://doi.org/10.1007/s11227-024-06909-w

[9] Onaolapo, A. K., Sarma, R., Akindeji, K. T., Mtukushe, N. F., Aluko, A. O., Adefarati, T. (2025). Effect of Temperature Coefficient Evaluation on Optimal Analysis of Hybrid Energy Systems for a Mall in KwaZulu-Natal, South Africa. *NIPES - Journal of Science and Technology Research*, vol. 7, no. 3, pp.185–194. https://doi.org/10.37933/nipes/7.3.2025.1629

[10] Sohani, A., & Sayyaadi, H. (2020). Providing an accurate method for obtaining the efficiency of a photovoltaic solar module. *Renewable Energy*, vol. 156, pp. 395-406. https://doi.org/10.1016/j.renene.2020.04.072

[11] Al Mahdi, H., Leahy, P. G., Alghoul, M., & Morrison, A.P. (2024). A Review of Photovoltaic Module Failure and Degradation Mechanisms: Causes and Detection Techniques. *Solar*, vol. 4, no. 1, pp. 43-82. https://doi.org/10.3390/solar4010003

[12] Zulu, C.L., Dzobo, O. (2023). Real-time power theft monitoring and detection system with double connected data capture system. *Electr Eng*, vol. 105, pp. 3065-3083. https://doi.org/10.1007/s00202-023-01825-3

[13] Sakhria, B., Hamaidi, B., Djemana, M., & Benhassine, N. (2025). Harnessing neural networks for precise damage localization in photovoltaic solar via impedance-based structural health monitoring. *Electr Eng*, vol. 107, pp. 3229-3245. https://doi.org/10.1007/s00202-024-02700-5

[14] Mellit, A., Tina, G.M., Kalogirou, S.A. (2018). Fault detection and diagnosis methods for photovoltaic systems: A review. *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 1-17.

https://doi.org/10.1016/j.rser.2018.03.062

[15] Semaoui, S., Abdeladim, K., Taghezouit, B., Hadj Arab, A., Razagui, A., Bacha, S., Boulahchiche, S., Bouacha, S., Gherbi, A. (2020). Experimental investigation of soiling impact on grid connected PV power. *Energy Reports*, vol. 6, pp. 302-308. https://doi.org/10.1016/j.egyr.2019.08.060

[16] Hu, W., Li, X., Wang, J., Tian, Z., Zhou, B., Wu, J., Li, R., Li, W., Ma, N., Kang, J., Wang, Y., Tian, J., Dai, J. (2022). Experimental research on the convective heat transfer coefficient of PV panel. *Renew. Energy*, vol. 185, pp. 820-826. https://doi.org/10.1016/j.renene.2021.12.090

[17] Drews, A., Keizer, A.C., Beyer, H.G., Lorenz, E., Betcke, J., Sark, W.G.J.H.M., Heydenreich, W., Wiemken, E., Stettler, S., Toggweiler, P., Bofinger, S., Schneider, M., Heilscher, G., Heinemann D. (2007). Monitoring and remote failure detection of grid-connected PV systems based on satellite observations. *Solar Energy*, vol. 81, no. 4, pp. 548-564. https://doi.org/10.1016/j.solener.2006.06.019

[18] Hua, Z., Zhao, L., Xie, Z., Zeng, C., Xu, Z., Chen, Y. (2026). Research on the rear surface temperature monitoring method of PV panels based on BOTDR. *Sol. Energy*, vol. 307, no. 15, Article No. 114383. https://doi.org/10.1016/j.solener.2026.114383

[19] Triki-Lahiani, A., Bennani-Ben Abdelghani, A., Slama-Belkhodja, I. (2018). Fault detection and monitoring systems for PV installations: A review. *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 2680-2692. https://doi.org/10.1016/j.rser.2017.09.101

[20] Golive, Y.R., Kottantharayil, A., Shiradkar, N. (2022). Improving the accuracy of temperature coefficient measurement of a PV module by accounting for the transient temperature difference between cell and backsheet. *Sol. Energy*, vol. 237, pp. 203-212. https://doi.org/10.1016/j.solener.2022.03.049

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.