SINERGI Vol. 30, No. 2, June 2026: 647-656
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2026.2.026

Climate adaptive temperature correction for mitigating PV degradation in ASEAN climates

Arief Marwanto[1*], Gunawan Gunawan[1], Imam Much Ibnu Subroto[2], Mochammad Facta[3], Munawar Agus Riyadi[3], Tole Sutikno[4]
[1]Electrical Engineering Department, Universitas Islam Sultan Agung (UNISSULA), Indonesia
[2]Informatics Engineering Department, Universitas Islam Sultan Agung (UNISSULA), Indonesia
[3]Electrical Engineering Department, Diponegoro University (UNDIP), Indonesia
[4]Electrical Engineering Department, Ahmad Dahlan University (UAD), Indonesia

Abstract

The emphasis on the ASEAN area is appropriate due to its unique tropical environment, characterized by elevated temperatures, high humidity, and little seasonal fluctuations. These features affect PV operating temperatures and degradation patterns in ways that current temperature correction models designed for other tropical areas inadequately address. In tropical regions, photovoltaic modules frequently operate at temperatures exceeding 35 °C, which is above the Standard Test Conditions of 25 °C. The conventional linear temperature correction (γ ≈ –0.45%/°C) fails to account for nonlinear thermal effects, leading to an underestimation of losses, battery under sizing, and a reduction in system lifespan. This study presents a nonlinear temperature correction model that incorporates a severity factor (δ) for cell temperatures exceeding 35 °C. The model utilizes two regimes: linear (≤35 °C) and quadratic (>35 °C) to account for nonlinear degradation. Simulations conducted at 45 °C and 1000 W/m² for a 100 WP panel indicate that the proposed model predicts an output of 90.575 W, compared to 81.9 W from the conventional model, resulting in an approximate 9.5% improvement in accuracy. This method addresses a significant gap by incorporating high-temperature nonlinearities, thereby enhancing the reliability of photovoltaic output predictions and improving battery sizing in tropical climates. This contribution enhances the reliability of photovoltaic systems and extends battery lifespan for applications in Indonesia and ASEAN.

Keywords:
Heat Tropical;
Linear Model;
Power Correction;
PV Panels;
Quadratic Model;
Temperature Correction;

Article History:
Received: July 18, 2025
Revised: January 4, 2026
Accepted: February 4, 2026
Published: June 12, 2026

Corresponding Author:
Arief Marwanto
Electrical Engineering Department, Universitas Islam Sultan Agung (UNISSULA), Indonesia
Email: arief@unissula.ac.id

INTRODUCTION

The cell temperature (T_{cell}) is a significant factor in determining the output power of a solar panel. The voltage is reduced as a result of higher temperatures, which leads to a reduction in power. Photovoltaic (PV) panel performance is highly influenced by ambient temperature, especially in tropical regions where average cell temperatures can exceed 35°C [1]. The industry-standard model uses a linear temperature coefficient (γ), typically –0.45%/°C, to estimate output power reductions from the nominal STC (Standard Test Conditions) of 25°C with an irradiance of 1000 W/m² [1]. Consequently, the Nominal Operating Cell Temperature (NOCT) is employed to ascertain the actual operating temperature of the panel in the outdoor environment. However, this model assumes uniform linear behavior across all temperature ranges, which is not accurate in high-temperature environments [2]. Elevated temperatures accelerate performance degradation and increase battery load due to the energy deficit [3]. Therefore, more precise correction models are needed to optimize PV system sizing and reliability in tropical climates.

In tropical regions [4], the utilization of solar panels (PV) is confronted with significant obstacles, including diminished efficiency as a result of elevated operating temperatures. In tropical climates, an increase in panel temperature of up to 45°C can result in a 10–25% reduction in output power, according to a study conducted by [5, 6, 7, 8, 9]. The temperature coefficient (*kT*) of the cell material is the determining factor [1]. This phenomenon is further exacerbated by the presence of intense solar radiation (≥1000 W/m²), which elevates the panel temperature above the ambient temperature (Nominal Operating Cell Temperature/NOCT) 40–50°C [3, 10, 11].

According to [4][12], they conducted research that demonstrated that crystalline silicon panels experience a 0.4–0.5% loss of power as a result of negative *kT* for each 1°C increase above the standard temperature (25°C). In Indonesia, the operating temperature of the panel frequently exceeds 35–50°C [11, 13, 14, 15], resulting in a cumulative energy loss of up to 20% over the course of a year. A precise battery system is necessary to address this challenge, which necessitates mathematical correction and compensation.

The battery system is required to mitigate for the power loss caused by temperature [3, 7, 10, 16, 17, 18]. In conducted a study that demonstrated that battery design without temperature correction results in under sizing by 15–30%. This investigation suggests that the accurate calculation of battery capacity can be achieved by combining inverter efficiency with environmental parameters (NOCT, G) [19]. NOCT, radiation, and battery demand have not been incorporated in a single model for tropical climates in previous studies [5, 20, 21, 22, 23, 24, 25, 26]. A computational approach that has been verified is employed in this investigation to address this gap [27, 28, 29, 30, 31, 33, 35, 36].

METHOD

A solar-based power plant is the context in which this system models the energy conversion from thermal energy output to electrical energy output. The proposed model illustrates as stated in Figure 1 describes the correlation between thermal energy produced by solar irradiation and the consequent electrical output of photovoltaic systems. Temperature adjustment is implemented from normal test conditions to accommodating actual working situations.

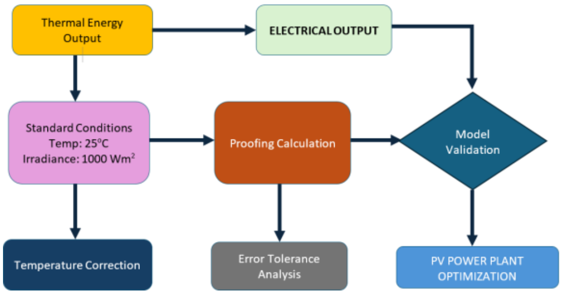

Figure 1. Proposed system model for temperature factor correction for temperature in tropical climate

The revised model undergoes validation calculations and error tolerance assessment to guarantee numerical consistency and robustness. Following validation with representative data, the model is used for optimizing solar power plants, facilitating more precise performance estimate under ASEAN climate circumstances. The accuracy of the model estimates was assessed by comparing the actual electrical power results with the back-calculations. Thereafter, an error tolerance analysis was implemented to quantify the discrepancy between the anticipated and actual outputs. Afterwards, model validation was implemented to guarantee that the temperature correction and power conversion corresponded to technical specifications. The final results were utilized to optimize power plants, with a particular emphasis on cost savings that were achieved through more precise temperature and irradiance modelling scenarios.

The NOCT Integration in the Temperature Correction Model at Nominal Operating Cell Temperature (NOCT) serves as a direct connection between the ambient temperature (T_{amb}) and the module cell temperature (T_{cell}) used in (2) and (3). NOCT denotes the photovoltaic module cell temperature under standard conditions: 800 W/m² irradiance, 20°C ambient temperature, 1 m/s wind velocity, and unobstructed installation. For modules functioning in the tropical ASEAN area, a plausible NOCT value ranges from 45 to 47°C, aligning with the attributes of elevated temperature settings and restricted natural ventilation.

The correlation between ambient temperature and cell temperature is determined using the conventional NOCT-based equation as shown:

$$T_{cell} = T_{amb} + \left(\frac{NOCT - 20}{800}\right) H$$

where *H* is solar irradiance (W/m²). This equation ensures that the T_{cell} used in the model is not assumed directly, but is physically calculated from

actual environmental conditions, thus being consistent with common PV modeling practices.
This T_{cell} value is then used directly in the temperature correction model. For the conventional model, the output power is calculated:

$$P_{conv} = P_{STC}[1 + \gamma(T_{cell} - 25)]$$

Regarding the suggested tropical linear model, further adjustments are implemented when $T_{cell} > 35°C$:

$$P_{lin} = P_{conv}[1 - \delta_{lin}(T_{cell} - 35)]$$

With a clear calculation flow from T_{amb} → T_{cell} → P_{output}.

The function of NOCT is clearly defined and consistently applied throughout the process. This integration enhances the transparency, physical clarity, and repeatability of the model, while guaranteeing that the suggested temperature changes accurately reflect the working conditions of PV modules in the tropical ASEAN environment.

The previous One-Way Linear formula [37][38]:

$$P = P_{STC} \, x \, [1 + \gamma \, x \, (T_{Cell} - 25)] \qquad (1)$$

has exhibits multiple deficiencies, including: The analysis does not account for the impacts of environmental temperatures exceeding 35°C [39]. The accuracy is insufficient for tropical climates characterized by high NOCT values ranging from 40 to 50°C. The increase in radiation on the temperature of the PV cell is not accounted for.

At a PV panel cell temperature of 35°C, the output power of the panel decreases to 91 W, which is approximately 9 W less than the nominal STC for temperature-related reasons. The threshold for the advent of additional thermal stress in tropical PV is frequently established at 35°C. A temperature correction factor is required to address this weakness. This factor should consider the following: (i) more realistic extreme hot tropical climate conditions [40], (ii) non-linear penalties when temperatures exceed 35°C, and (iii) the ability to be further calibrated with field data and actual NOCT, particularly in tropical countries like Indonesia [41].

A temperature correction is essential, particularly in tropical climates where the average temperature exceeds 35°C, as indicated by the aforementioned. Therefore, this investigation involves the deconstruction of the traditional formula into two novel equations: (1) a linear model and (2) a quadratic model. From the above explanation and background, this research aims to:

1. The objective is to create a nonlinear temperature correction model that effectively predicts photovoltaic output in high-temperature tropical environments by incorporating a severity factor (δ) for cell temperatures exceeding 35 °C.
2. The objective is to enhance battery sizing and photovoltaic system reliability in tropical climates by minimizing errors associated with traditional linear correction methods.

The initial novel equations that utilize the quadratic formula model are:

$$\begin{aligned} P_{quadratic} = P_{STC} \, x \, [1 + \gamma \, x \, (T_{cell} - 25)] \\ - \delta \, x \, (T_{cell} - 35)^2 \, x \, H] \end{aligned} \qquad (2)$$

Where:

P_{STC} = *Standar Power on STC* (25°C,100 *W/m*^{2}*), example* 100 *WP*

$P_{quadratic}$ = *actual output ppwer at High Temp. (Watt)*

γ = *Temp. Coefficient* – 0.0045 (*or* – 0.45%/°C)

T_{cell} = *PV Cell Temp.* (°C) *calculated from the ambient temperature* + *radiance effect*

H = *Solar irradiation in KW/m*^{2} (*normally* 0.8 – 1.0 *KW/m*$^{2)}$

δ = *Non – linear degradation coefficient* (*example* 0.0005 -*adjusted to the data*)

This quadratic model enhances the power reduction effect when temperatures surpass 35°C by incorporating the factor H, defined as the radiation ratio to 1000 W/m², which is suitable for tropical regions characterized by high solar exposure in both wet and dry conditions. Rendering it appropriate for Eastern Indonesia, Malaysia, and Thailand (arid and warm).

The comparison of conventional PV PV Power temperature correction models and quadratic models is illustrated in Figure 2. The conventional (old) model employs a linear approach that exclusively considers the temperature coefficient γ.

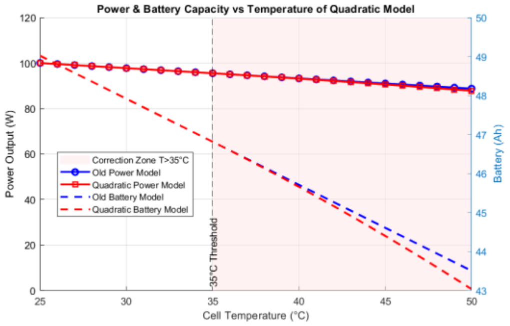

Figure 2. Comparison of Power and Battery Capacity vs. Temperature using Quadratic Equation Model

The quadratic model exhibits a more substantial decrease in power than the conventional model at temperatures exceeding 35°C (within the correction zone). This is indicative of an increase in PV inefficiency as a result of rising temperatures. Conversely, the battery requirements increase at elevated temperatures as a result of the PV panel's elevated temperature, albeit the disparity is not particularly large. This quadratic model predicts a decrease in performance; however, it is not yet entirely accurate in the extreme tropical climate. The quadratic model has accounted for the degradation of non-linear power as a result of elevated temperatures (via the Δ factor and the correction zone > 35 ° C).

The (3) is a linear model, namely:

$$P_{linear} = P_{STC}\ x\ [1 + \gamma\ x\ (T_{cell} - 25)]\ x\ [1 - \delta\ x\ (T_{cell} - 35)^2] \qquad (3)$$

This linear model provides moderate correction with high sensitivity to temperature extremes, making it suitable for humid tropical regions experiencing daily temperature fluctuations (Sumatra and Kalimantan).

As shown in Figure 3, the power loss difference is 9.1 Watts as a result of tropical correction (STC). For the purpose of comparison, the MATLAB simulation presents a linear model that compares the conventional formula and the novel temperature correction factor formula.

RESULTS AND DISCUSSION

To provide a clear picture of the graph above, the impact of power reduction is included in the PV panel lifespan reduction equation. The Impact of PV Panel Age has contributed to the power reduction, it's from 10% (from 100 W to 90 W) from standard condition. Moreover, high temperatures accelerate solar cell degradation. NREL study [42][43] shows that increasing operating temperature by 10°C above NOCT can accelerate degradation by 0.8%/year (from normal 0.5%/year).

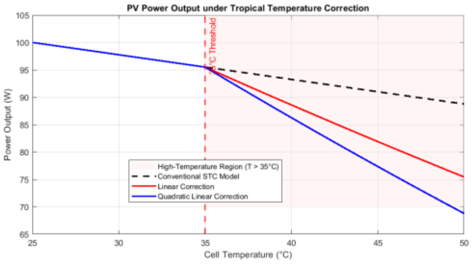

Figure 3. Comparison of PV Output Power and Temperatures Model

The results of the power degradation calculation simulation on PV panels with output power correction parameters are as follows: Normal degradation rate (25°C/NOCT), Around 0.5% per year. The degradation increases by 0.8% per year when the operating temperature exceeds NOCT by 10°C. Using the Long-term power degradation model over time (panel life) [19], where the annual degradation rate is, such as 0.005 (0.5%) or 0.008 (0.8%), the equation can be used to determine the reduction in panel life that results from an increase in temperature [44]:

$$P(t) = P_0 \times (1-r)^{t} \qquad (4)$$

$P(t)$ = panel power after t years
P_0 = initial power (e.g. 100 WP)
r = degradation rate per year (not temperature)
t = years of operation

Based on the (4), the following graph illustrates the consequences of the decrease in the lifetime of photovoltaic panels that occur as a result of high temperatures in tropical areas.

Figure 4 illustrates the power degradation of solar panels (PV) over a 25-year period of operation. The degradation rates are normal (0.5%/year) and high tropical (>35°C, 0.8%/year). The red line suggests that power degradation is accelerated by high temperatures, resulting in a reduction of approximately 18% compared to normal conditions. As a result, the system's capacity must be either increased or replaced at a faster pace to ensure that the necessary energy output is maintained. Consequently, thermal degradation models are indispensable for determining the long-term efficacy and lifespan of PV systems in heated regions.

In tropical regions, photovoltaic modules frequently surpass 35 °C, resulting in conventional linear temperature corrections (γ ≈ –0.45%/°C) underestimating losses and inaccurately calculating battery requirements.

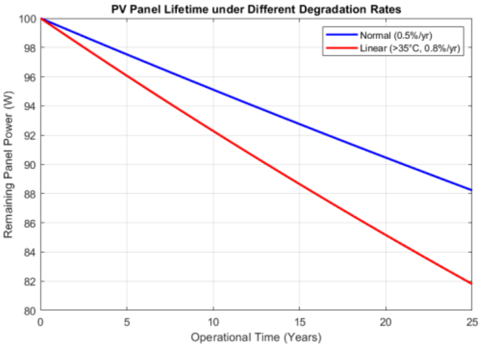

Figure 4. PV Panel Lifetime Degradation under Normal and High-Temperature Tropical Conditions

The proposed nonlinear model incorporating the severity factor δ addresses high-temperature nonlinearity, with simulations indicating approximately 9.5% increased accuracy at 45 °C and 1000 W/m². Thermal effects, irradiance, and humidity interact significantly; thus, precise photovoltaic modelling in hot climates necessitates the consideration of all three factors to guarantee reliable output and appropriate sizing.

Equation (4) indicates that the deterioration of the PV panel under normal circumstances is r=0.005 (0.5% per annum) and under higher temperature conditions is r=0.008 (0.8% per annum). Consequently, in the 25th year, the panel continues to exhibit around 88.22 W (88.2%) under standard settings, however at elevated temperature conditions, it preserves just approximately 81.81 W (81.8%).

The total power discrepancy attains around 6.4 W, which directly influences energy planning inaccuracies, battery over-sizing or under-sizing, and the assessment of system longevity. This chart substantiates the assertion that elevated non-thermal degradation rates in hot climates (ASEAN) must be explicitly included into long-term solar PV planning, rather than only using short-term temperature adjustments.

Table 1. The Calculation of Annual Power Output Comparison Results using (4)

Year	Normal (W)	High Temp. (W)
0	100.00	100.00
1	99.50	99.20
2	99.00	98.41
3	98.51	97.62
4	98.01	96.84
5	97.52	96.06
6	97.04	95.29
7	96.55	94.53
8	96.07	93.77
9	95.59	93.02
10	95.11	92.28
11	94.64	91.54
12	94.16	90.81
13	93.69	90.08
14	93.22	89.36
15	92.76	88.64
16	92.29	87.93
17	91.83	87.23
18	91.37	86.53
19	90.91	85.84
20	90.46	85.15
21	90.00	84.47
22	89.55	83.79
23	89.10	83.12
24	88.66	82.46
25	**88.21**	**81.80**

The degradation of the PV Power Output panel over a 25-years period is illustrated in Table 1. This suggests that the rate of degradation increases by 0.8% annually when the operating temperature exceeds NOCT by 10°C. Consequently, in order to ascertain the decrease in panel life that arises from an increase in temperature in Indonesia, temperature correction factors must be implemented. The measured values derived from the three PV Power Correction Models were validated using a reverse-proof approach to acquire a comprehensive picture in order to verify the two equations proposed in this study.

The Quadratic Power model is the equation that is being tested:

$$P_{quadratic} = P_{STC}\, x\, [1 + \gamma\, x\, (T_{cell} - 25)] - \delta\, x\, (T_{cell} - 35)^2\, x\, H]$$

It is known from the results:

P_{STC} = 100 WP

γ = – 0.0045

T_{cell} = 45 $°C$

δ = 0.00005

H = 0.85

$P_{quadratic}$ = 90.575 Watt

In summary, this quadratic formula effectively simulates the effects of tropical temperatures in a more realistic manner. The power differential in comparison to a straightforward linear model.

This indicates that traditional models are too optimistic for high heat scenarios; the quadratic model is more precise for tropical regions such as Indonesia as shown in Figure 5.

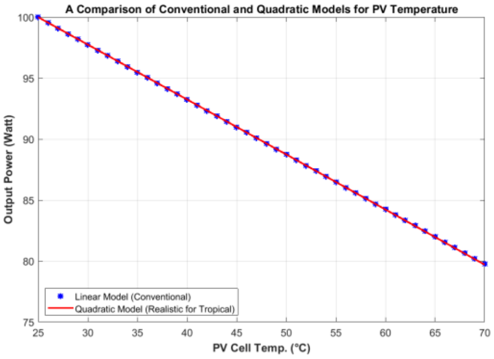

Figure 5 shows the outcomes of the conventional model's and the quadratic model's validation

The Linear Power Model is the equation that was evaluated:

$$P_{linear} = P_{STC}\ x\ [1 + \gamma\ x\ (T_{cell} - 25)]\ x\ [1 - \delta\ x\ (T_{cell} - 35)^2]$$

It is known from the results:

P_{STC} = 100 WP
γ = – 0.0045
T_{cell} = 45 $°C$
δ = 0.001
P_{linear} = 81.9 W

The equations have been demonstrated to be numerically valid and precise. This model is more plausible for tropical climates due to its incorporation of moderate non-linear degradation as shown in Figure 6.

The primary explanation is to the use of the correction factor, rather than the numerical value of δ alone.

(i) Linear model (paper example – multiplicative, cumulative loss)

The proposed linear tropical correction is applied multiplicatively to the already temperature-degraded power:

$$P_{\text{lin}} = P_{\text{conv}} \cdot (1 - \delta_{\text{lin}}(T - T_{\text{th}}))$$

This produces a 9.1 W loss, because: (i) The loss scales linearly with temperature, (ii) It is applied on top of STC degradation, and (iii) The reduction grows proportionally, not locally. This behavior is intentional, not a numerical artifact.

(ii) Quadratic model (localized, bounded loss)

The quadratic correction is applied as a small additive penalty:

$$P_{\text{quad}} = P_{\text{conv}} - \delta_{\text{quad}}(T - T_{\text{th}})^2$$

Despite a smaller δ, the quadratic model produces: (i) Only a localized correction, (ii) No compounding effect, (iii) A deliberately soft curvature near the threshold. The quadratic model is structurally less aggressive by design.

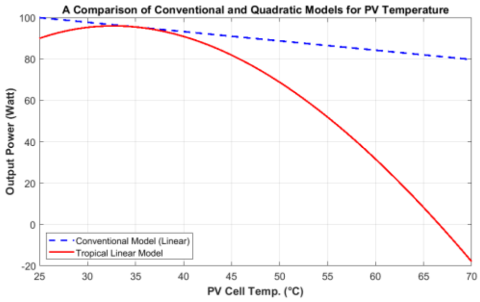

Figure 6. shows the outcomes of the conventional model's and the linear model's validation

The greater power drop anticipated by the linear model is not a mistake in computation but rather a result of its cautious multiplicative formulation, which accounts for accumulated thermal stress under tropical circumstances. At T = 45 °C, the conventional model produces P_conv = 91 W, and implementing the linear adjustment with δlin = 0.001. For a temperature surplus of 10°C, a value of 0.001 yields $Plin$ = 91 × (1 - 0.001 × 10) = 81.9 W, resulting in a 9.1 W loss. Conversely, the quadratic model employs an additive and constrained adjustment, where $\delta quad$ = 0.00005. results in a marginal decrease of 0.425 W, yielding a projected output of P_quad = 90.575 W. Analysis of actual photovoltaic operations in high-temperature areas demonstrates that the linear model more accurately represents long-term cumulative deterioration for system planning, but the quadratic model is preferable for short-term or localized thermal assessments.

Moreover, the temperature correction model must be incorporated into the battery capacity calculation to ensure that the PV system is not depleted of energy during periods of extreme heat. This will provide a more precise and accurate representation. Tropical regions are not adequately represented by conventional model calculations due to their failure to account for the combined effects of temperature and radiation [37][38]. The simulation results indicate that the temperature increases as *H* (radiation) increases, resulting in a decrease in power and a requirement for the battery to work harder. Due to this, it is imperative to investigate the battery capacity of each model that has been suggested. through the calculation of the panel operating temperature (T_{op}) with the radiation factor *H*, as well as the comparison of panel power, power loss, battery current, and battery capacity from three PV temperature correction models (conventional, quadratic, linear) based on clear parameters.

To convert ambient temperature to active cell temperature, one could apply the panel operating temperature formula:

$$T_{op} = T_{amb} + \left(\frac{NOTC - 20}{1000\frac{Watt}{m^2}}\right) x\ G \qquad (5)$$

The formula for battery capacity is used to determine the minimal battery size required to compensate for the power discrepancy:

$$C_{batt} = \frac{(P_{STC} - P_{actual})\ x\ t}{V_{system}\ x\ DOD} = \frac{P_{loss}\ x\ t}{V_{system}\ x\ DOD} \qquad (6)$$

Where:

$T_{op} = Operating\ Temperature$
$T_{amb} = Ambient\ Temperature$

DoD = Depth of Discharge

$V_{system} = Voltage\ Systems$

This document presents a computation of the panel operating temperature (T_{op}) and battery capacity (C_{batt}) in tropical circumstances (Indonesia/ASEAN) utilising three temperature correction methods.

As shown in Figure 7 and Table 2, the Quadratic model generates more conservative outcomes by considering non-linear degradation as a consequence of elevated temperatures. The conversion parameters are equivalent when the Conventional and Linear models are similar (e.g., −0.5%/°C = −0.5 W/°C for 100W). The Quadratic model is more plausible for estimating actual power and battery sizing in tropical climates such as Indonesia, where panel temperatures can rise significantly above 60°C

Recommended Application of Temperature Correction Models for PV Panels and Batteries in Indonesia & ASEAN:

Indonesian Region:

1. Hot & Dry Regions (NTT, Bali, Madura), use the Best Quadratic Model
2. Humid Tropical Regions (Riau, West Kalimantan) use the Linear Model

ASEAN Region:

1. Malaysia & Southern Thailand use a Linear Model, due to Similar Temperature & Radiation Patterns in Indonesia
2. Vietnam and Cambodia use a Quadratic Model, Very Suitable for Long Dry Seasons
3. Singapore, due to its Humidity, is recommended to use a Linear or Quadratic Model.

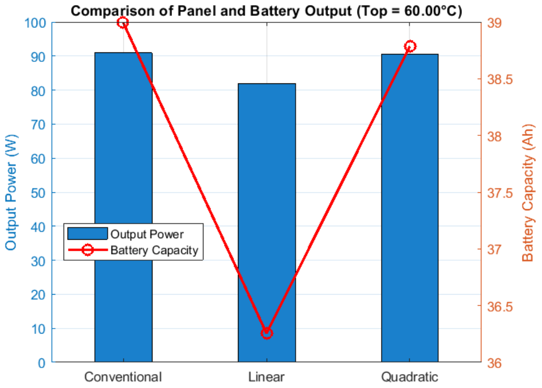

Figure 7. Illustrates the comparison of the calculation results of the three proposed models by using (5) and (6)

Table 2. Illustrates the comparison of the calculation results of the three proposed models

Equation Model	Power (W)	Current (A)	Battery Capacity (Ah)
Conventional	91	7.5833	37.9167
Linear	81.9	6.8250	34.1250
Quadratic	90.575	7.5479	37.7395

CONCLUSION

This research verifies that temperature correction factors particularly designed for ASEAN climatic conditions are essential for precise photovoltaic (PV) system development, implementation, and operation. The ASEAN area is marked by consistently elevated ambient temperatures, high humidity, and little seasonal variation, resulting in PV modules often functioning at cell temperatures over 35 °C, well beyond the 25 °C Standard Test Conditions (STC). The operating circumstances need temperature correction models that explicitly include nonlinear thermal behavior to prevent systematic misestimation of photovoltaic performance.

1. The comparative assessment of temperature correction methodologies reveals that the traditional linear model (γ = –0.45%/°C) fails to accurately depict high-temperature operating conditions. Under simulated circumstances of 45 °C and 1000 W/m² for a 100 WP module, the linear model forecasts an output of 81.9 W, revealing a negative estimate bias and heightened variance owing to its failure to account for nonlinear thermal losses. The suggested nonlinear temperature correction model utilizes a linear regime for cell temperatures ≤35 °C and a quadratic regime for temperatures >35 °C, including a severity factor (δ), and forecasts an output of 90.575 W. This indicates an estimated 9.5% increase in predictive accuracy, signifying less systematic bias and enhanced error tolerance at higher operating temperatures.
2. These results indicate that disregarding nonlinear temperature effects may result in battery under-sizing, erroneous energy production predictions, and decreased system longevity, especially in tropical photovoltaic installations. Therefore, implementing a region-specific nonlinear temperature correction framework is crucial for ensuring dependable system design, optimum energy output, and sustainable use of solar power in Indonesia and the wider ASEAN area. This work directly addresses high-temperature nonlinearities, offering a practical and theoretically sound basis for enhancing the dependability and long-term performance of photovoltaic systems in tropical regions.

3. This research examines crystalline photovoltaic modules in tropical environments, potentially restricting the applicability of findings to other module varieties. Future research should validate and adapt the nonlinear correction model for various technologies, including bifacial, thin-film (CdTe, CIGS), heterojunction, and perovskite photovoltaic systems across different climates, while incorporating long-term field data to improve its reliability.

ACKNOWLEDGMENT

This research was supported through personal financing by the authors. We also extend our sincere appreciation to our colleagues from Sultan Agung Islamic University (UNISSULA), Ahmad Dahlan University (UAD) and Diponegoro University (UNDIP), whose insights and expertise greatly assisted this study.

REFERENCES

[1] B. R. Paudyal and A. G. Imenes, "Investigation of temperature coefficients of PV modules through field measured data," *Solar Energy*, vol. 224, pp. 425–439, 2021, doi: 10.1016/j.solener.2021.06.013

[2] S. N. N. Ibrahim, H. Zainuddin, and S. I. Sulaiman, "Temperature-corrected Performance Ratio of Grid-Connected Photovoltaic System: Tropical versus Continental Climate.," *Pertanika J. Sci. Technol.*, vol. 33, no. 2, 2025, doi: 10.47836/pjst.33.2.10

[3] A. Sohail, M. S. Rusdi, M. Z. Abdullah, and S. M. Sultan, "Numerical investigation of the thermal performance of PV system under variable wind speeds and ambient temperatures in the tropical climate of Malaysia," *Green Technologies and Sustainability*, vol. 3, no. 3, p. 100210, 2025, doi: 10.1016/j.grets.2025.100210

[4] E. Iakovleva, D. Guerra, and A. Turysheva, "Increasing the Efficiency of Solar Power Plant in a Tropical Climate," in *2023 Seminar on Industrial Electronic Devices and Systems (IEDS)*, IEEE, 2023, pp. 109–112, doi: 10.1109/IEDS60447.2023.10426186

[5] A. Khan *et al.*, "Rooftop photovoltaic solar panels warm up and cool down cities," *Nature Cities*, vol. 1, no. 11, pp. 780–790, 2024, doi: 10.21203/rs.3.rs-3485787/v1

[6] M. I. Islam, M. S. Jadin, M. I. Bhuiyan, A. Al Mansur, and K. I. U. Ahmed, "Characterizing Fault Mechanisms and Performance Degradation of Decade-Old Nonoperational Rooftop Solar Panels: An Experimental Study in Tropics," in *2024 6th International Conference on Sustainable Technologies for Industry 5.0 (STI)*, IEEE, 2024, pp. 1–6, doi: 10.1109/STI64222.2024.10951132

[7] S. Vig and S. Kumar, "Analysis of temperature effect on PV panel," *Mater. Today Proc.*, 2023, doi: 10.1016/j.matpr.2023.07.069

[8] J. Sánchez-Balseca, J. L. Pineiros, and A. Pérez-Foguet, "Influence of environmental factors on the power produced by photovoltaic panels artificially weathered," *Renewable and Sustainable Energy Reviews*, vol. 188, p. 113831, 2023, doi: 10.1016/j.rser.2023.113831

[9] A. Durez, M. Ali, and S. Kumarasamy, "Investigation of Optimum Phase Change Material for PV Panels in Malaysian Climatic Conditions," in *2023 International Conference on Energy, Power, Environment, Control, and Computing (ICEPECC)*, IEEE, 2023, pp. 1–5, doi: 10.1109/ICEPECC57281.2023.10209533

[10] S. N. N. Ibrahim, H. Zainuddin, and S. I. Sulaiman, "Temperature-corrected Performance Ratio of Grid-Connected Photovoltaic System: Tropical versus Continental Climate.," *Pertanika J. Sci. Technol.*, vol. 33, no. 2, 2025, doi: 10.47836/pjst.33.2.10

[11] Y. He, D. J. C. Hii, and N. H. Wong, "Solar photovoltaics deployment impact on urban temperature: review and assessment recommendations," *Build. Environ.*, vol. 264, p. 111920, 2024, doi: 10.1016/j.buildenv.2024.111920

[12] Y. Ohnishi, Y. Takahashi, K. Fujiwara, K. Hidaka, and H. Morita, "Modeling of I-V characteristics for crystalline silicon photovoltaic modules based on a simplified equivalent circuit and a temperature correction," *Electrical Engineering in Japan*, vol. 215, no. 4, p. e23410, 2022, doi: 10.1002/eej.23410

[13] Y. A. Rahman, N. Amin, M. Masarrang, Y. Pirade, N. P. Yunfa, and R. Santoso, "Monitoring PV Output Power in Tropical Climates under Surface Temperature Distribution Area," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2023, p. 012037, doi: 10.1088/1755-1315/1157/1/012037

[14] J. F. B. de F Filho, W. L. A. Neves, and F. B. Costa, "Photovoltaic Module Temperature Prediction Model Incorporating Wind Direction and Precipitation Effects," *IEEE J. Photovolt.*, 2025, doi: 10.1109/JPHOTOV.2025.3574778

[15] V. Sun, A. Asanakham, T. Deethayat, and T. Kiatsiriroat, “Evaluation of nominal operating cell temperature (NOCT) of glazed photovoltaic thermal module,” *Case Studies in Thermal Engineering*, vol. 28, p. 101361, 2021, doi: 10.1016/j.csite.2021.101361

[16] Y. He, D. J. C. Hii, and N. H. Wong, “Solar photovoltaics deployment impact on urban temperature: review and assessment recommendations,” *Build. Environ.*, p. 111920, 2024, doi: 10.1016/j.buildenv.2024. 111920

[17] M. E. F. Octaviano, E. M. Loureiro, L. R. de Araujo, and D. R. R. P. de Araujo, “Battery Allocation and SOC in Distribution Systems Considering Temperature Constraints,” *IEEE Latin America Transactions*, vol. 22, no. 2, pp. 136–143, 2024, doi: 10.1109/TLA.2024. 10412030

[18] W. S. Ebhota and P. Y. Tabakov, “Influence of photovoltaic cell technologies and elevated temperature on photovoltaic system performance,” *Ain Shams Engineering Journal*, vol. 14, no. 7, p. 101984, 2023, doi: 10.1016/j.asej.2022.101984

[19] H. Hafdaoui, N. Belhaouas, N. Madjoudj, H. Assem, F. Hadjrioua, and F. Mehareb, “Measurement NOCT of PV Module Using Several Methods According to the IEC61215,” *AIJR Abstracts*, pp. 111–112, 2024, doi: 10.21467/169

[20] N. Kapilan, K. C. Nithin, and K. N. Chiranth, “Challenges and opportunities in solar photovoltaic system,” *Mater. Today Proc.*, vol. 62, pp. 3538–3543, 2022, doi: 10.1016/j.matpr.2022.04.390

[21] S. Vijayakumar, A. Mani, and S. Advaith, “Development and performance evaluation of solar absorption cold storage system for tropical climates,” *Solar Energy*, vol. 279, p. 112822, 2024, doi: 10.1016/j.solener.2024. 112822

[22] N. A. Ibrahim, S. R. W. Alwi, Z. Abd Manan, A. A. Mustaffa, and K. Kidam, “Climate change impact on solar system in Malaysia: Techno-economic analysis,” *Renewable and Sustainable Energy Reviews*, vol. 189, p. 113901, 2023, doi: 10.1016/j.rser.2023. 113901

[23] L. M. Shaker, A. A. Al-Amiery, M. M. Hanoon, W. K. Al-Azzawi, and A. A. H. Kadhum, “Examining the influence of thermal effects on solar cells: a comprehensive review,” *Sustainable Energy Research*, vol. 11, no. 1, p. 6, 2024, doi: 10.1186/s40807-024-00100-8

[24] Q. E. M. Hafizi, M. B. D. Zulkiffli, M. R. Omar, and A. R. M. Rais, “Solar energy potential on East Coast Peninsular Malaysia and Johor using Hargreaves–Samani model for PV generation,” *International Journal of Energy and Water Resources*, vol. 9, no. 3, pp. 1403–1415, 2025, doi: 10.1007/s42108-025-00343-1

[25] W. S. Ebhota and P. Y. Tabakov, “Assessment of solar photovoltaic potential of selected site locations in cities across sub-Saharan Africa,” *Energy Systems*, pp. 1–22, 2023, doi: 10.1007/s12667-023-00625-9

[26] O. A. Rozak, M. Z. Daud, S. Bakhri, and M. Z. Ibrahim, “Review of the impact of tropical climate on solar photovoltaic modules performances using the combination of cooling systems,” *J. Sustain. Sci. Manag.*, vol. 18, no. 1, pp. 228–236, 2023, doi: 10.46754/jssm.2023.01.014

[27] A. A. Akbar and M. Haddin, “Prediction of Electrical Energy Needs for Capital City of Central Java Based on Backpropagation and Linear Regression,” *Journal La Multiapp*, vol. 6, no. 2, pp. 370–390, 2025, doi: 10.37899/journallamultiapp.v6i2.2061

[28] L. Raji, A. A. Razak, and A. F. Sharol, “Comparative assessment of PV simulation tools for a megawatt-scale rooftop solar photovoltaic system in tropical climate,” *Next Energy*, vol. 9, p. 100452, 2025, doi: 10.1016/j.nxener.2025.100452

[29] A. Moshari, A. Aslani, A. Entezari, and K. Ghanbari, “Performance assessment of the integration of semitransparent solar cells with different geometry of greenhouses under different climate regions,” *Environmental Science and Pollution Research*, vol. 30, no. 22, pp. 62281–62294, 2023, doi: 10.1007/s11356-023-26244-6

[30] Y. Garcia Vera, A. Gallego, D. Camargo Cala, and F. Mesa, “Machine Learning Prediction of Thermal Losses in MonoPERC Solar Modules: A Novel Clustering Approach for Tropical Climate Applications,” *Energies (Basel).*, vol. 18, no. 22, p. 6029, 2025, doi: 10.3390/en18226029

[31] A. K. Pandey *et al.*, “Solar energy utilization techniques, policies, potentials, progresses, challenges and recommendations in ASEAN countries,” *Sustainability*, vol. 14, no. 18, p. 11193, 2022, doi: 10.3390/su141811193

[33] T. S. Bagavat Perumaal, P. Seshadri, B. Ashok Kumar, and S. Senthilrani, “A mathematical model to forecast solar PV performance,” *Journal of the Chinese Institute of Engineers*, vol. 46, no. 5, pp. 431–440, 2023, doi: 10.1080/02533839.2023. 2204896

[35] S. Chauhan, A. K. Sharma, and N. S. Singha, “On the performance and thermal stability of solar cell based on CIGS-Sb2S3 combination with> 35% power conversion efficiency,” *Solid State Commun.*, vol. 395, p. 115736, 2025, doi: 10.1016/j.ssc.2024.115736

[36] S. Kumar *et al.*, “Experimental performance investigation on a gold nanofluid laden spectral beam splitting photovoltaic/thermal system under tropical climate of India,” *Solar Energy Materials and Solar Cells*, vol. 293, p. 113834, 2025, doi: 10.1016/j.solmat.2025.113834

[37] S. Iqbal, S. N. Khan, M. Sajid, J. Khan, Y. Ayaz, and A. Waqas, “Impact and performance efficiency analysis of grid-tied solar photovoltaic system based on installation site environmental factors,” *Energy & Environment*, vol. 34, no. 7, pp. 2343–2363, 2023, doi: 10.1177/0958305X221106618

[38] K. R. Oyshei, K. M. S. Hasan, N. Sadat, and M. A. Hoque, “Comparative analysis of solar module configuration and tracking systems for enhanced energy generation in South Sakucia Union, Bhola, Bangladesh: A software based analysis,” *Heliyon*, vol. 10, no. 13, 2024, doi: 10.1016/j.heliyon.2024.e33884

[39] A. Aslam, N. Ahmed, S. A. Qureshi, M. Assadi, and N. Ahmed, “Advances in solar PV systems; A comprehensive review of PV performance, influencing factors, and mitigation techniques,” *Energies (Basel).*, vol. 15, no. 20, p. 7595, 2022, doi: 10.3390/en15207595

[40] F. M. Melo, F. S. Magnani, and M. Carvalho, “Optimization of an integrated combined cooling, heat, and power system with solar and wind contribution for buildings located in tropical areas,” *Int. J. Energy Res.*, vol. 46, no. 2, pp. 1263–1284, 2022, doi: 10.1002/er.7244

[41] S. Zhan, B. Dong, and A. Chong, “Improving energy flexibility and PV self-consumption for a tropical net zero energy office building,” *Energy Build.*, vol. 278, p. 112606, 2023, doi: 10.1016/j.enbuild.2022.112606

[42] D. Friedman, “Photovoltaics Research at NREL,” National Renewable Energy Laboratory (NREL), Golden, CO (United States), 2024, doi: 10.1117/12.367574

[43] C. Deline, D. Jordan, B. Sekulic, J. Parker, B. McDanold, and A. Anderberg, “PV Lifetime Project-2024 NREL Annual Report,” National Renewable Energy Laboratory (NREL), Golden, CO (United States), 2024, doi: 10.2172/2432497

[44] C. Deline *et al.*, “PV Fleet Performance Data Initiative Final Technical Report (FTR),” National Renewable Energy Laboratory (NREL), Golden, CO (United States), 2025, doi: 10.2172/2522744