SiliconPV 2025, 15th International Conference on Crystalline Silicon Photovoltaics

Module Technologies and PV Systems

https://doi.org/10.52825/siliconpv.v3i.2685

Published: 20 Jan. 2026

Modelling of Solar Cell Junction Temperature for Crystalline Silicon Photovoltaic Module

Zewen Chen[1], Yuehua Yang[1], Haibo Niu[2], Youzhang Zhu[3], Xixiang Xu[4], Mingzhe Yu[4], and Hong Yang[1,*]

[1]School of Physics, Xi'an Jiaotong University, China

[2]Department of Physics, Xi'an Jiaotong University City College, China

[3]Engineering Research Center of Photovoltaic Technologies and Systems Universities of Shaanxi Province, China

[4]LONGi Green Energy Technology Co.,Ltd, China

*Correspondence: Hong Yang, solargroup@126.com

Abstract. Determination of the junction temperature of solar cells is critical for accurately evaluating on-site performance of solar modules. It is difficult to acquire the junction temperature of cells because solar cells are laminated and encapsulated in modules. In this paper, a fine steady-state thermal model is established to directly obtain the junction temperature of cells in the field. The model only needs plane of array (POA) irradiance, backsheet temperature, ambient temperature and wind speed. The junction temperature of the cells obtained from the model is validated by the equivalent cell temperature method in IEC 60904:2021. The results indicate that the model works well in the POA irradiance range of 400-800 W/m^2. In addition, the effect of POA irradiance, ambient temperature on temperature difference between junction temperature and backsheet temperature were investigated. It is found that the temperature difference between junction temperature and backsheet temperature is increased with increasing POA irradiance. The required time of modules to reach the thermoequilibrium state is affected by the ambient temperature. The obtained results in this paper provide useful insights into performance evaluation and power generation forecasting of solar modules.

Keywords: Junction Temperature, Mismatch, Thermal Model

1. Introduction

Photovoltaic power generation is getting increasingly attention due to the development of clean energy. Thus, the power generation of photovoltaic power stations and the aging and attenuation of photovoltaic modules have gained attention [1, 2]. Determination of module parameters is indispensable for accurately evaluating on-site performance of solar modules, thus the module temperature is a very important parameter [3, 4]. In reality, many people are using it incorrectly, thinking of backsheet temperature as module temperature. In fact, strictly speaking it should be the junction temperature. However, due to the fact that solar cells are laminated and encapsulated in modules, the junction temperature is hard to measure, the value is always replaced by backsheet temperature, which via thermal sensors attached to the module. The difference between T_j and T_{back} could lead to huge errors in follow-up calculations. Depending on different climate conditions, which include ambient temperature, wind speed and POA irradiance, the junction temperature is 1 to 3 degrees higher than the backsheet temperature, but the exact relationship between the two, temperature difference (ΔT) and environmental conditions, has not been studied.

$$\Delta T = T_j - T_b \tag{1}$$

Depending on the different purposes, many scholars have done a lot of work on the determination of junction temperature: some mathematical models were developed to evaluate the electrical efficiency of PV module [5]. Zhang et.al.[6] investigated the steady-state operating temperature of bifacial photovoltaic modules by ANSYS software, considering three different installation conditions. Jiang et.al.[7] developed a method based on the p-n junction semiconductor theory to the determine junction temperature.

In order to perform IEC 60891 procedures, a standard method for measuring the module temperature is IEC 60904:2021—the equivalent cell temperature (ECT), which is need to be determined in solar laboratory. So, it is very difficult to determine junction temperature. Thus, it is very necessary to develop a fast and accurate way to determine junction temperature during field operation.

In this study, a thermal steady-state model for IEC 60891 and IEC 61853 to measure junction temperatures is developed. This model only requires four environment factors: irradiance, wind speed, ambient temperature and backsheet temperature. The IEC 60904:2021 procedure is used to validate that the thermal model displays a satisfied consistence with the equivalent cell temperature. In addition, the relationship between ΔT and environmental conditions have also been analyzed by this steady state thermal model, and found that ΔT changes with irradiance during the whole day, and the thermal states of the module are affected by different ambient temperature [8].

2. Experimental details

A steady-state model of photovoltaic module that has been developed, which relates T_j to T_a, v_{wind} and G. The PV module is generally divided into 5 layers and thermal energy transfer processes are applied. Due to the high transparency of the front encapsulation materials (glass and EVA layer), most of the energy from the exposed light is absorbed by solar cell, which results in solar cell being the hottest layer of the module (i.e. T_j). After being absorbed, energy from the middle layer (the cell) is transferred to the both sides by thermal conduction. Thermal energy is also lost through convection and radiation. These processes are repeated and eventually a homeostatic equilibrium is established between the module and the environment.

3. Results and discussion

A steady-state model of photovoltaic module that has been developed, which relates T_j to T_a, v_{wind} and G. The PV module is generally divided into 5 layers and thermal energy transfer processes are applied. Due to the high transparency of the front encapsulation materials (glass and EVA layer), most of the energy from the exposed light is absorbed by solar cell, which results in solar cell being the hottest layer of the module (i.e. T_j). After being absorbed, energy from the middle layer (the cell) is transferred to the both sides by thermal conduction. Thermal energy is also lost through convection and radiation. These processes are repeated and eventually a homeostatic equilibrium is established between the module and the environment.

3.1 Theoretical model of determination of the junction temperature for PV modules

According to the structure of crystalline silicon photovoltaic modules, the energy transfer processes follow the law of conservation of energy:

$$A \cdot \tau \cdot G = Q_{radiation} + Q_{convection} \tag{2}$$

where

$$Q_{radiation} = A \cdot \varepsilon \cdot \sigma \cdot (T_{surface}^4 - T_a^4) \tag{3}$$

$$Q_{convection} = A \cdot h_{wind} \cdot (T_{surface} - T_a) \tag{4}$$

A is PV module surface area; τ is the heat conversion rate of PV module for sun light (i.e. how much energy is there for heat transfer); ε is emissivity of radiation; σ is Stefan-Boltzmann constant; h_{wind} is the convective heat transfer coefficient.

Inside the PV module, the thermal energy is fluxed from middle layer (the cell) to both sides, which for the rear side can be calculated as:

$$Q_{conduction} = A \cdot \frac{T_j - T_{back}}{R} \tag{5}$$

R is the effective heat transfer coefficient from cell to rear side. Four T-type thermocouples were attached to the backsheet to measure T_{back}, and via Eq. (4) to obtain T_j.

3.2 Experiment and Validation

The temperature difference between junction and backsheet by ECT and thermal model methods are studied. The I-V curves of the module were obtained under clear days using the Photovoltaic I-V profile tester, PV200, while a thermocouple sensor was attached to the back of the module to obtain the backsheet temperature, and a meteorological tester was used to measure the ambient temperature and POA irradiance. After concluding the outdoor measurements, this module was measured in the solar laboratory to determine the coefficients B_1, B_2, and β_{rel} that were used to calculate the ECT. A set of 1200 outdoor data measurements were used to analyze the ΔT between the junction and backsheet temperature by two different methods: IEC 60904:2021 and mathematical model. Since irradiance rises and falls throughout the day, the comparison was only done with data when the irradiance decreased monotonously, i.e., only using every day's data measured from 12:00 to 17:00. The four days comparison between the both models are shown in Fig.1 and show excellent agreement for irradiance levels between 400 and 800 W/m^2.

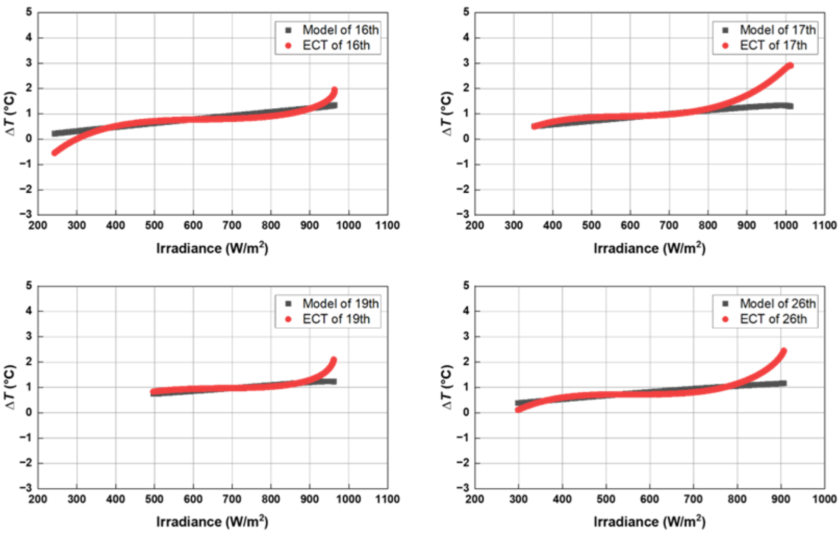

Figure 1. *ΔT is affected by irradiance from 12:00 to 17:00 of four days data*

4. Conclusion

A very important parameter of PV modules is the junction temperature. The accurate determination for T_j could decrease the error in relevant works. The present study develops a thermal steady state model of PV modules to determine the solar cell's junction temperature which based on outdoor condition. The difference between T_j and T_{back} has been analyzed by two methods: ECT in IEC 60904:2021 and our thermal model. The scope of application of both methods is studied and both models give the same T_j in the range of 400-800 W/m^2 irradiance. The effects of different environmental factors on equilibrium are revealed, i.e. G influences the ΔT and T_a control the time to reach steady state. The obtained results in this paper provide useful insights into performance evaluation and power generation forecasting of solar modules.

Data availability statement

The data presented in this study are available on request from the corresponding author.

Author contributions

Conceptualization: Zewen Chen and Hong Yang; Methodology: Hong Yang; Validation: Zewen Chen and Yang Yuehua; Formal Analysis: Zewen Chen; Resources: Hong Yang; Data Curation: Yuehua Yang, Haibo Niu and Youzhang Zhu; Writing – Original Draft Preparation: Zewen Chen; Writing – Review & Editing: Mingzhe Yu and Xixiang Xu; Visualization: Zewen Chen; Supervision: Hong Yang; Project Administration: Hong Yang; Funding Acquisition: Hong Yang.

Competing interests

The authors declare no conflict of interest.

Funding

The authors would like to thank the support of the KY-C-2023-GF10 of SPIC.

References

[1] B. Jiayu, W. Xingang, X. Chaoshan, Y. Zhiyong, T. Shoutao and C. He, "Development Status and Measures to Promote the Development of Renewable Energy in China," 2021 3rd Asia Energy and Electrical Engineering Symposium (AEEES), Chengdu, China, 2021, pp. 1102- 1107.
[2] Kawagoe K, Hishikawa Y, Yamada N, Outdoor Direct STC Performance Measurement of PV Modules Based on a Sun-Shading Technique. IEEE Journal of Photovoltaics2017, pp. 7, 172.
[3] Kota Takeguchi, Jakapan Chantana, Nakayama K, Kawano Y, Nishimura T, Yoshihiro Hishikawa, et al. Accurate estimation of outdoor performance of photovoltaic module through spectral mismatch correction factor under wide range of solar spectrum. Current applied physics.2021, pp. 28, 59.
[4] Dobreva P, van Dyk EE, Vorster FJ, Irradiance and temperature corrections of current-voltage curves—Quintessential nature and implications, Solar Energy,2021, pp. 227, 116.
[5] Li B, Migan-Dubois A, Delpha C, Diallo D, Evaluation and improvement of IEC 60891 correction methods for I-V curves of defective photovoltaic panels. Solar Energy,2021, pp. 216, 225.
[6] Yogeswara Rao Golive, Singh HK, Anil Kottantharayil, Vasi J, Narendra Shiradkar, Investigation of Accuracy of various STC Correction Procedures for I-V Characteristics of PV Modules Measured at Different Temperature and Irradiances.2019.

[7] Hishikawa Y, Takenouchi T, Higa M, Yamagoe K, Ohshima H, Yoshita M, Translation of Solar Cell Performance for Irradiance and Temperature From a Single I-V Curve Without Advance Information of Translation Parameters. IEEE Journal of Photovoltaics, 2019, pp. 9, 119.
[8] Trentadue G, Pavanello D, Salis E, Field M, Harald Müllejans, Determination of internal series resistance of PV devices: repeatability and uncertainty, Measurement Science and Technology, 2016,pp. 27, 055005.