

# Tools for Analyzing the Daily Performance of a Photovoltaic Installation Containing Bifacial Modules

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## EXTENDED ABSTRACT

This paper presents a comprehensive analysis of online tools and models for evaluating the daily performance of photovoltaic (PV) installations, with particular focus on systems equipped with bifacial modules. The study addresses the need for accurate estimation of PV system efficiency under varying environmental and geographical conditions, which is essential for both system designers and energy management applications.

The paper begins with a review of commonly used irradiance models. It distinguishes between irradiance (instantaneous solar power per unit area) and insolation (accumulated solar energy over time), emphasizing their roles in the PV system optimization and long-term energy yield estimation. Several classes of irradiance models are discussed, ranging from simple geometric approaches, such as the Simplified Clear-Sky model, to more advanced empirical and physical models including Haurwitz, Hottel, ESRA, Bird & Hulstrom and Ineichen–Perez. The latter, implemented in the pvlib Python library, is selected for further analysis due to its balance between computational complexity and accuracy, especially under clear-sky conditions.

In addition to analytical models, the paper highlights the importance of satellite-based datasets, such as SARA and PVGIS, which incorporate real atmospheric conditions including cloud cover and local climate variability. These datasets provide irradiance components—direct ( $G_b$ ), diffuse ( $G_d$ ) and reflected ( $G_r$ ) - allowing for a more realistic representation of solar radiation, particularly relevant for bifacial PV modules where backside irradiance contributes to total energy generation.

The experimental part of the study is based on a prosumer PV installation located in northern Poland. The system consists of bifacial JA Solar modules with a total capacity of 6.46 kWp, mounted at a tilt angle of  $35^\circ$  and an azimuth of  $195^\circ$ . The installation is equipped with a three-phase inverter and a monitoring system that records operational data at five-minute intervals. This setup enables detailed comparison between measured and simulated performance. Simulation results were obtained using both pvlib-based irradiance modeling and PVGIS online tools.

The study compares calculated and measured daily power generation profiles for selected days representing different seasons. The results show that the general shape of the power generation curves is consistent between simulations and measurements. However, discrepancies are observed due to

factors such as time reference differences (UTC vs local time), limited temporal resolution of satellite data, and short-term phenomena like cloud-induced shading, which are not captured in model-based calculations.

Fig. 1 shows test results for June 24, where the red line represents measurements and the blue lines - calculations. The solid blue line represents results obtained directly from the pvlib script (UTC), while the dashed line shows the same results shifted to the installation's local time.

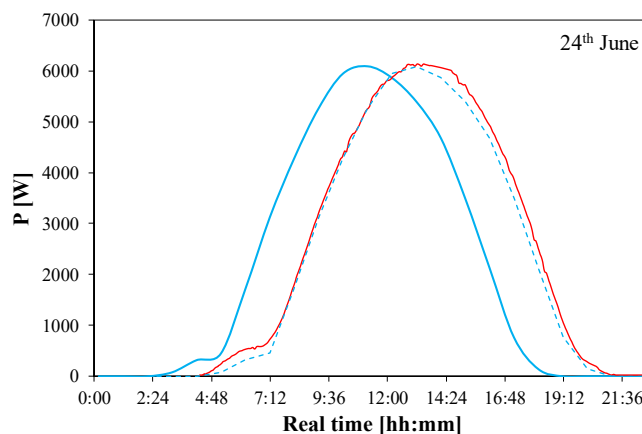


Fig. 1. Daily course of generated power on June 24.

Despite these differences, the total daily energy production obtained from simulations and measurements shows good agreement, with deviations not exceeding 10%. The analysis confirms that advanced models and satellite-based tools provide sufficiently accurate predictions for practical engineering applications. The best agreement is observed under clear-sky conditions, while larger discrepancies occur during periods of increased cloud cover.

The results demonstrate that online tools such as PVGIS, combined with appropriate irradiance models, can effectively support the design, analysis, and optimization of photovoltaic systems. Furthermore, the study highlights the importance of considering both front- and backside irradiance in bifacial modules, as well as the influence of environmental and atmospheric factors on system performance. These findings are particularly valuable for improving the accuracy of PV system simulations and enhancing decision-making processes in renewable energy engineering.