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Accurate I-V curve measurement in bifacial modules:

IEC TS 60904-1-2 standard and best practices



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Introduction

Bifacial modules capture radiation from both their front and rear sides, with albedo, or ground-reflected radiation, being a key factor in energy estimates. Ignoring this parameter can lead to overestimations or failure concealment, affecting both productivity and plant lifespan.

This article explores the importance of accurately measuring albedo using one or two reference cells, following the IEC TS 60904-1-2 standard. Additionally, we highlight how the E-1500 curve tracer, capable of measuring bifacial modules with up to two albedo reference cells and up to 200 I-V curves per hour, becomes an indispensable tool for ensuring measurement accuracy and maximizing solar plant performance.

The 2 main challenges of measuring I-V curves in bifacial modules

1. Albedo measurement

To ensure reliable results in I-V curve extrapolation, it is crucial to measure irradiance reliably and accurately. In the case of bifacial modules, the total irradiance consists of the front irradiance plus albedo. Therefore, it is essential to accurately measure albedo and its impact on rear-side production.

2. Impact of rear cell placement on albedo measurement accuracy

Albedo is less uniform than front irradiance, with notable differences between nearby points. The placement of cells on the module's rear side significantly affects measurement accuracy, especially in tracking systems where tilt angles vary. Depending on whether cells are placed at the top, bottom, or different points on the string, results can vary considerably, introducing inherent variability in measurements (see Figure 1).



Figure 1: Impact of rear cell placement on albedo measurement. The blue line corresponds to the albedo.

The figure above shows that modules 6 to 8 show higher albedo values due to increased light penetration in the gap between the tracker rows. Similarly, modules 26 to 30 exhibit elevated albedo levels as they are positioned near the aisle area, where light reflection is more pronounced.



Extrapolating I-V curves to standard test conditions (STC)

Unlike controlled I-V curve measurements, such as with a flash tester, field I-V curve measurement under variable operating conditions requires extrapolating measured curves to standard test conditions (STC) to obtain nominal values.

This extrapolation to STC not only enables system performance evaluation but also allows comparison of measured values (V_{oc} , I_{sc} , V_{mp} , I_{mp}) with the manufacturer's specifications. Significant deviations may indicate issues or excessive module degradation.

For I-V curve measurements with the E-1500 device, the extrapolation to STC is performed according to IEC 60891:2021. This complex process involves many variables, such as current and voltage variation coefficients with temperature, series resistance, and the thermal voltage of the diode. For simplicity, we assume that the cell temperature during measurements is 25°C and that series resistance and diode thermal voltage effects are negligible.

Although these assumptions aren't fully realistic, they apply equally to monofacial and bifacial modules, without affecting the purpose of this explanation.

With these assumptions, the equations simplify, so that power depends linearly only on irradiance, mainly affecting current. Below are the calculations and variables associated with this procedure.

1. The equation for extrapolating current is as follows, where assuming a temperature of 25°C eliminates part of it:

$$I_{sc,STC} = \frac{1.000Wm^{-2}}{G_1} \times \frac{I_{sc}}{[1 + \alpha_{rel} \times (T_1 - 25^\circ C)]}$$

This simplifies to:

$$I_{mpp,STC} \approx I_{mpp,measured} \times \frac{G_{STC}}{G_{measured}}$$

where:

- ☛ $I_{sc,STC}$ is the short-circuit current at STC
- ☛ $I_{mpp,STC}$ is the current at maximum power at STC
- ☛ $I_{mpp,measured}$ is the measured current at maximum power
- ☛ α is the short-circuit current temperature coefficient (typically in % / °C)
- ☛ G_{STC} is irradiance at STC
- ☛ $G_{measured}$ is measured irradiance

2. For temperature, we have the following equation, which also loses many terms based on the assumptions made.

$$V_2 = V_1 - R_s \times (I_2 - I_1) - K \times I_2 \times (T_2 - T_1) + \beta \times (T_2 - T_1)$$

Simplified, it becomes:

$$V_{mpp,STC} \approx V_{mpp,measured}$$

where:

- ☛ $V_{mpp,STC}$ is the voltage at maximum power at STC
- ☛ $V_{mpp,measured}$ is the measured voltage at maximum power



3. Therefore, since power is $V_{mpp} * I_{mpp}$, we have the following simplified equation where power only depends on irradiance.

$$P_{m_{pp_STC}} \approx P_{m_{pp_measured}} \times \frac{G_{STC}}{G_{measured}}$$

where:

- $P_{m_{pp_STC}}$ is the maximum power at STC
- $P_{m_{pp_measured}}$ is the measured maximum power

Note: During the development of the examples and applied cases in this article, we use this final equation, assuming a module temperature of 25°C and a simplification of the equations.



To illustrate the STC extrapolation process for I-V curves, here's an example: We measure a module with a nominal rating of 600W using an E-1500 curve tracer ⁽¹⁾ under an irradiance (G) of 800 W/m² and a cell temperature of 25°C.

¹The E-1500 curve tracer performs this extrapolation automatically as per IEC 61829.

The E-1500 measures 464W, **and extrapolating to STC yields a power of 580W, the result of:**

$$464W \times \frac{1.000W/m^2}{800W/m^2} = 580W$$

reflecting the module's actual STC rating. **This result is 3.3% below the nominal rating**, underscoring the importance of extrapolating values to compare with spec sheets and avoiding misinterpretations about the module's actual power.

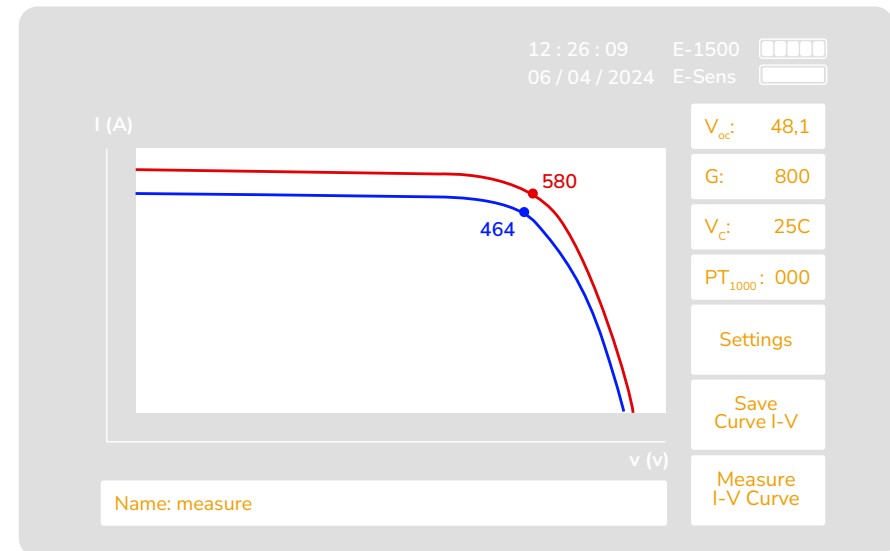


Figure 2: I-V Curve measurement Screen, E-1500 curve tracer.

Now, for bifacial modules, the scenario becomes more complex as both front irradiance and albedo need to be incorporated.

Why consider albedo when measuring I-V curves in bifacial modules?

Albedo is crucial in measuring I-V curves in bifacial modules because these modules generate energy from both direct radiation on the front and ground-reflected radiation on the rear side. High-albedo surfaces like white or snowy grounds significantly boost energy generation. Therefore, omitting this factor in measurements could lead to inaccurate estimates of the modules' effective power. The following section demonstrates albedo's importance in an applied case.

Applied case: Quality control in large solar plants

A solar park owner suspects something is wrong with their plant as it's underperforming and has hired a Testing Lab to measure module power (all bifacial modules with a nominal rating of 600W per manufacturer).

Note: The reality is that these modules are defective and average 550W, but neither the owner nor the service provider is aware of this yet, hence the need for a measurement campaign.

To demonstrate albedo's importance, let's use an example from the campaign under the following weather conditions:

- ✔ Front G: 800 W/m²
- ✔ Rear-side G: 80 W/m²
- ✔ Total G: 880 W/m²
- ✔ Cell temperature 25°C (an unrealistic temperature for simplicity in the example)

Under these conditions, the 550W modules measured **484W** due to $550W * (880W/m^2 / 1000W/m^2)$. Below are the results when extrapolated to STC, with and without albedo measurement.

1. Power extrapolated only considering Front G of 800 W/m² is $484W * (1000W/m^2 / 800 W/m^2) = \mathbf{605W}$, 1.0% above the nominal. Here, the Testing Lab might conclude that the modules are in optimal condition, leading to an investigation of other components while ignoring the actual issue right in front.
2. Power extrapolated considering both front G of 800W/m² and rear-side G of 80W/m² is $484W * (1000W/m^2 / 880 W/m^2) = \mathbf{550W}$, revealing the true value, **8.3% below nominal**.

This quality control highlights low module power and the root cause of the problem.

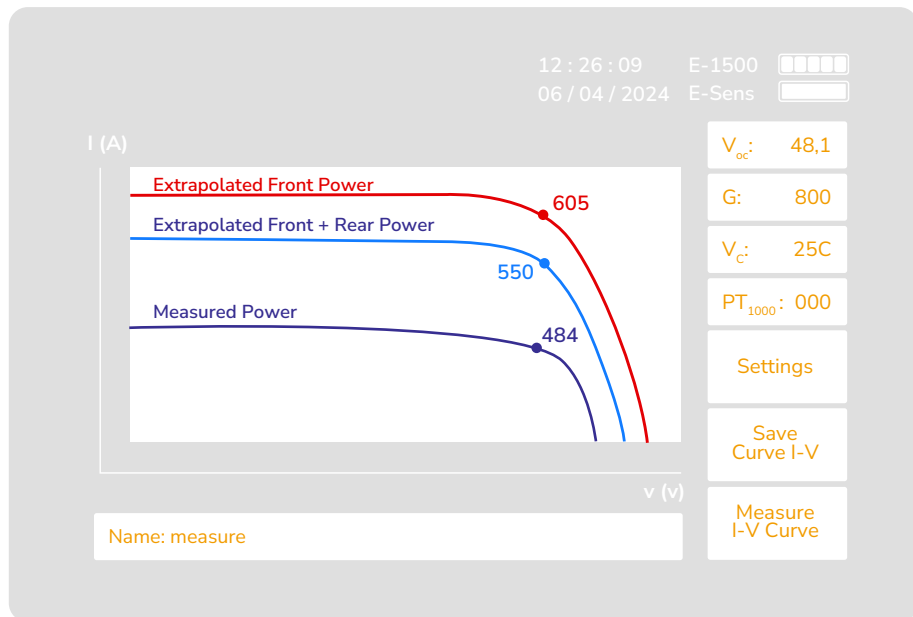


Figure 3: I-V curve measurement screen, E-1500 curve tracer, bifacial module.



This example shows the importance of incorporating both front and rear-side irradiance for correct STC extrapolation of I-V curves. Comparing power values reveals:

⚠ Considering panel power only by extrapolating Front G (without rear-side G measurement) overestimates extrapolated power, possibly exceeding nominal values.

⚠ The power calculated using both front and rear irradiance gives the true power of the module. Here, with an extrapolated power of 550W, **the module reaches 92% of its production capacity, meaning it is outside warranty limits.**

⚠ Ignoring albedo measurement overestimates results, potentially overlooking module defects. In the quality control example described in this article, the difference between measuring with or without the albedo cell results in a **10% discrepancy in outcomes.**

Albedo measurement with one or two cells according to IEC TS 60904-1-2

The previous section highlighted the importance of albedo measurement. However, unlike front irradiance, albedo measurement is complex, as it varies based on ground characteristics, plant location, or module tilt. Proper reference cell placement is crucial to avoid errors in results.

Albedo can be measured using one or two cells, with two cells providing a more accurate and representative approach. The single-cell method suits homogeneous terrains, where albedo variations are minimal. However, in uneven terrains or tracking systems, which constantly alter the modules' tilt angle, this method may be insufficient.

For string measurements, selecting an average point on the string is essential. If using a single cell, it should be placed at least three modules away from the string start and mid-height. Using two cells—one at the top and one at the bottom of the module—offers a more detailed view of albedo behavior, averaging measured albedo across different module zones, reducing uncertainty and improving performance calculation accuracy.

IEC TS 60904-1-2 supports this approach by specifying the

importance of measuring irradiance on both sides of bifacial modules and recommends using at least two cells to capture rear-side irradiance.

This ensures that albedo measurement is representative, especially on heterogeneous terrains or in solar-tracking systems where albedo variability can be significant. **IEC TS 60904-1-2 suggests that cells should be positioned at a similar height to the bifacial module plane, as this affects the irradiance value obtained.**

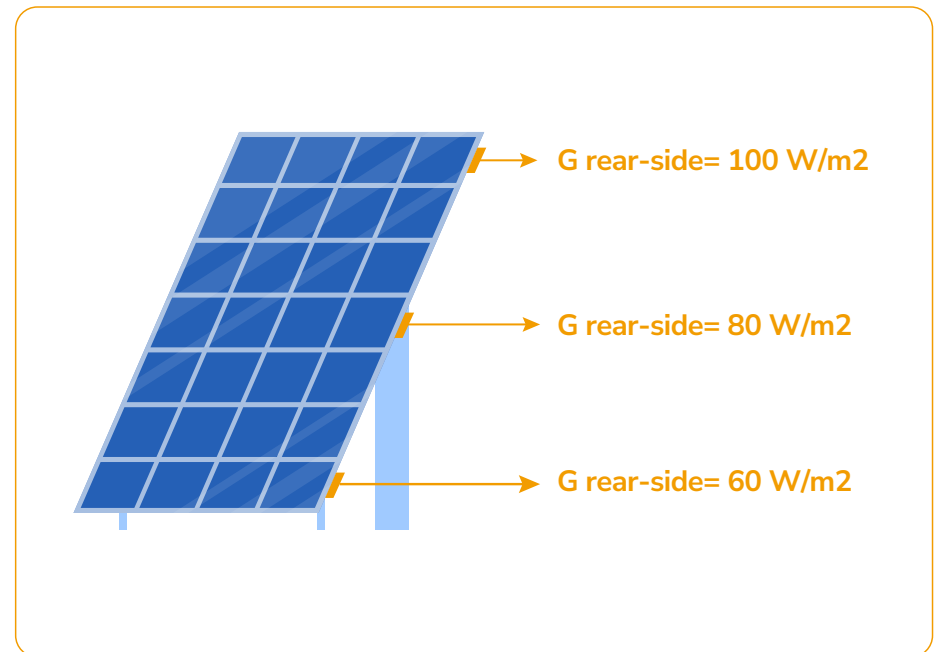


Figure 4: Rear-side irradiance measurement with different cell positions.

Based on the different rear-side G values obtained depending on cell positioning on the module's back (Figure 3), a new extrapolated real power calculation can be made.

Using the previous example, if three possible albedo measurements of 100W/m², 80W/m², and 60W/m² are considered (with 80 W/m² being the actual value), and a frontal G of 800W/m², the following results are obtained:

- ✔ **Rear-side G:** 100 W/m²; Total G: 900 W/m²; extrapolated real power is equal to 538W, the result of $484W * (1000 W/m^2 / 900 W/m^2)$, or a **-2.2%** error from actual power.
- ✔ **Rear-side G:** 80 W/m²; Total G: 880W/m²; extrapolated real power is equal to 550W, the result of $484W * (1000 W/m^2 / 880 W/m^2)$.
- ✔ **Rear-side G:** 60 W/m², Total G: 860W/m²; extrapolated real power is equal to 563W, the result of $484W * (1000 W/m^2 / 860 W/m^2)$, or a **+2.4%** error from actual power.

The example above shows the sensitivity of albedo measurement to final extrapolated power results and demonstrates how albedo cell placement can influence the outcome.

However, the error caused by incorrect cell placement (2.4%) is much smaller than the error from omitting the cell entirely (10%).



New guidelines for ground albedo measurement

The PV Magazine article "[New Guidelines for Ground Albedo Measurement](#)" reinforces the importance of establishing best practices for albedo measurement in bifacial solar plants. Researchers from the Universidad Politécnica de Madrid and experts from our company, Qualifying Photovoltaics, have proposed practical guidelines that reduce albedo measurement uncertainty to just 1.5%, which is essential for accurate yield estimates of utility-scale bifacial solar plants.

These recommendations, aligned with best practices mentioned in IEC TS 60904-1-2, highlight the need for using two sensors or measurement cells to capture albedo variability adequately. Using configurations with a reference cell and a pyranometer, as suggested in the article, is a cost-effective solution that does not compromise measurement accuracy.

To measure albedo in a string, the cell should be placed in the center of the string to obtain values that best represent real conditions. Placing the cell at the ends of the string can yield non-representative values due to the higher irradiance received by the modules at these positions.

The following graph shows measurements from four real cases ⁽²⁾, in which individual module curves were measured with cells positioned both at the string ends and the center.

The measurements confirm that modules at the string ends (25-28) and at the intersection between trackers (6-8) show increased albedo and, consequently, increased module power. As the cell is moved toward the center, albedo stabilizes.

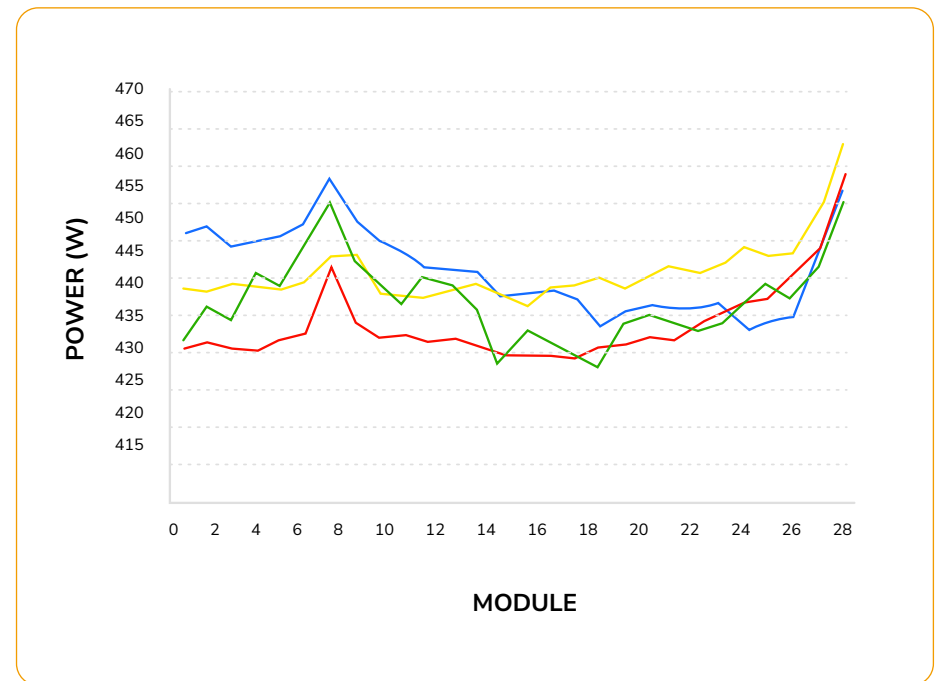


Figure 5: Curve measurement in a four-case real string

² Real measurements from field projects conducted by the Consulting & Testing Lab team at Qualifying Photovoltaics.

Final observations

This article not only highlights the technical importance of albedo measurement but also reinforces the need for a more rigorous and standardized approach to managing bifacial solar plants to maximize their performance and longevity. IEC TS 60904-1-2 provides clear guidelines to ensure representative measurements, which are essential for optimizing energy production in solar plants.



Importance of measuring albedo:

Albedo can represent a significant portion of irradiance on the back of bifacial modules, and omitting it can lead to overestimations in power and diagnostic errors. **In the quality control example, the error from neglecting albedo was 10%**, which could be higher on reflective soils. Extrapolating this data to STC is crucial to obtain values that reflect the real module performance.

Accurate albedo measurement:

In the example of albedo measurement using one or two cells, an incorrect cell placement error can be 2.4%, smaller than if no cell were used. **IEC TS60904-1-2 suggests precise placement or using two cells to minimize this error.**

Impact on solar asset management:

Tools like the E-1500 I-V tracer enable module failure detection and better decision-making. Its ability to measure up to 200 curves per hour and integrate albedo measurements with one or two cells increases accuracy and reliability in quality control.

About Entec Solar

Founded in 2016 by a group of solar engineering PhDs with over 15 years of experience in photovoltaics, Entec Solar's mission is to develop and market the most advanced equipment for photovoltaic plant monitoring, including SCADA systems, data loggers, and IoT solutions, designed to maximize operational efficiency and ensure optimal solar asset performance.

I-V Curve Tracer, E-1500

The E-1500 is an I-V curve tracer device designed to provide 0.5% accuracy at maximum power point (MPP) and less than 3% in the final CEM result. This high-precision instrument can measure up to 200 I-V curves per working hour, whether for photovoltaic modules or strings up to 1500V and 35A.

It has features that capture both direct and reflected irradiance under changing conditions, ensuring the measured I-V curves are accurate and can be extrapolated to standard measurement conditions. Its advanced technology not only allows precise measurement of bifacial module electrical parameters but also complies with IEC TS 60904-1-2 for albedo measurement.



E-Dust Soiling Sensor

E-Dust calculates soiling losses based on real power losses in photovoltaic plants, unlike traditional methods based only on short-circuit current measurements. By comparing maximum power between clean and soiled photovoltaic modules, we can accurately determine optimal cleaning times, following IEC61724-1.

All data is automatically processed and available on our online platform PVET®, allowing daily, weekly, and annual monitoring of these losses.

Reference Module Data Loggers E-Ref/01 and E-Ref/03

Using an E-Ref combined with a reference module provides the most accurate measurement of photovoltaic plant operating conditions: effective irradiance, front and rear-side irradiance, and cell temperature.

The E-ref measures short-circuit current (ISC) and open-circuit voltage (VOC) of a reference module, calculates the corresponding irradiance and cell temperature values, and communicates them directly to SCADA via ModBus. It is available for monofacial (E-Ref/01) and bifacial (E-Ref/03) reference modules.

