IEC 60904-1-2: Measurement of current-voltage characteristics of bifacial photovoltaic devices

bifi PV workshop 2016, Miyazaki, Japan
Vahid Fakhfouri (Pasan); IEC project team
Outline

- Motivations and Challenges
- IEC project team’s approach
- Project status and historical background
- Equivalent Irradiance ($G_E$) method
  - Method description
  - In practice
- Conclusions and Outlook
Main need: assessment of the bifacial PV devices

- How to “label” bifacial devices?
- How to value the Bifacial gain?

Particularities:

- Different needs in laboratory and production environments
- Different possibilities in laboratory and production environments

Comparability and measurement accuracy to be guaranteed

- “Apple-to-Apple” comparison
Bifacial power generation

Complexity

\[ \text{Isc}_1 = \int E(\lambda) \cdot R_1(\lambda) \cdot SR_{BS}(\lambda) \cdot d\lambda \]

\[ \text{Isc}_2 = \int E(\lambda) \cdot SR_{FS}(\lambda) \cdot d\lambda \]

\[ \text{Isc}_{T2} = \int E(\lambda) \cdot T_{DUT}(\lambda) \cdot R_2(\lambda) \cdot SR_{BS}(\lambda) \cdot d\lambda \]

\[ \text{Isc}_3 = \int E(\lambda) \cdot T_{Enc.}(\lambda) \cdot R_2(\lambda) \cdot SR_{BS}(\lambda) \cdot d\lambda \]

\[ \text{Isc}_4 = \int E(\lambda) \cdot R_2(\lambda) \cdot SR_{BS}(\lambda) \cdot d\lambda \]

\[ \text{Isc} = \text{Isc}_1 + \text{Isc}_2 + \text{Isc}_{T2} + \text{Isc}_3 + \text{Isc}_4 \]

- \( E(\lambda) \): is the irradiance.
- \( SR_{xx}(\lambda) \): is the spectral response (BS: of the back side, FS: of the front side).
- \( T_{yyyy}(\lambda) \): is the transmission (DUT: of the PV device under test, Enc.: of the encapsulant).
- \( R_z(\lambda) \): is the reflectivity of different objects

The DUT's intrinsic properties are underlined.
Bifacial power generation

**Environmental dependencies**

- Installation-specific conditions:
  - Albedo
  - Height
  - Tilt
  - Distance between modules
  - Orientation
  - …

- There is no “standard bifacial installation/use condition”.
Focus on **Power rating** in the frame of this project (vs. Energy rating)

“Common playground” for power assessment

- **Reproducible** measurement procedures and conditions
- In accordance with existing IEC standards

**Practical**

Value the bifacial gain

- **Comparability** vs. power plant simulation
- **Transparent** distinction of the “Bifacial gain”
### BiFi standardization

#### Short status

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Key information</th>
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<tbody>
<tr>
<td>January 2016</td>
<td>NWIP circulation and voting</td>
<td>The NWIP was accepted. A group of 15 experts was nominated to write the <strong>IEC 60904-1-2</strong>. Pasan is managing the IEC project.</td>
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<td>March 4(^{th}) 2016</td>
<td>1(^{st}) Conference Call, 12/15 participants, 6 guests</td>
<td>Two approaches discussed; 1(^{st}) poll; Experimental validation of the <strong>G(_{\text{comp}})</strong> approach launched, theoretical study for AOSG initiated.</td>
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<td>May 11(^{th}) 2016</td>
<td>2(^{nd}) Conference Call, 8/16 participants, 7 guests</td>
<td>Experimental validation results for <strong>G(_{\text{comp}})</strong> presented; Simulation partial results presented for AOSG. A major improvement to <strong>G(_{\text{comp}})</strong> suggested: <strong>G(_{\text{E}})</strong></td>
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<td>June 2016</td>
<td>3(^{rd}) meeting</td>
<td><strong>G(_{\text{E}})</strong> approach presentation and discussion</td>
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<td>October 2016</td>
<td>IEC-WG2 meeting</td>
<td>Project team draft presentation</td>
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$G_{\text{comp}}$ approach
The 1st IEC standard method proposal

Overexposure based on the bifaciality

Step 1
$G = 1 \text{kW/m}^2$
$I_{\text{sc front}}$

Step 2
$G = 1 \text{kW/m}^2$
$I_{\text{sc rear}}$

Step 3
$G_{\text{comp}}$
$I_{\text{sc comp}}$

$I_{\text{sc comp}} = (1 + 0.2 \times \text{Bifaciality}) \times I_{\text{sc front}}$

$G_{\text{comp}} : \text{reflectivity-compensated irradiance, when } I_{\text{sc}}=I_{\text{sc comp}}$

Non-reflective surface = backside illumination below 3 W/m$^2$
Findings: Outdoor STC measurement

- Indoor 1-sided and outdoor 2-sided methods are consistent (within measurement uncertainty)
New proposals

1. Improvement of the $G_{\text{comp}}$ approach for power assessment:
   I. Power assessment at STC without the backside contribution
   II. Bifaciality coefficients determination for $I_{\text{sc}}$, $V_{\text{oc}}$ and $P_{\text{max}}$
   III. Indoor with overexposure or Outdoor with backside illumination measurements at different irradiance levels

2. New energy rating standard for bifacial devices
Equivalent Irradiance (G_E) method

Step 1: Bifaciality determination at STC

- Bifaciality coefficients:

\[ \varphi_{Isc} = \frac{Isc_r}{Isc_f} \]

\[ \varphi_{Voc} = \frac{Voc_r}{Voc_f} \]

\[ \varphi_{Pmax} = \frac{Pmax_r}{Pmax_f} \]
**Equivalent Irradiance (G_E) method**

**Step 2: Bifacial gain determination**

- **Outdoor:** at 1kWm\(^{-2}\) or corrected to 1kWm\(^{-2}\) on the front side plus different backside irradiations \(G_{R_i}\) (at least 3 levels)

  or

- **Indoor:** at Equivalent 1-side irradiance levels \(G_{E_i}\) (at least 3):

  \[
  G_{E_i} = 1000W m^{-2} + \varphi_{Isc} \cdot G_{R_i};
  \]

  \(i = 1, 2, 3, ...\)

Example: For \(\varphi_{Isc} = 80\%\), \(G_{R_1} = 200W m^{-2}\),
\(\rightarrow G_{E_1} = 1160W m^{-2}\)

- **Pmax reporting with 2 specific bifacial gains; interpolation of the data:**
  
  - \(P_{max_{BiFi10}}\) with 1kWm\(^{-2}\) on the front and \(G_{R=100Wm^{-2}}\) or at \(G_{E} = 1kWm^{-2} + \varphi_{Isc} \cdot 100Wm^{-2}\)
  
  - \(P_{max_{BiFi20}}\)

- **Alternative method, double-side illumination (for research purposes or in some laboratories)**
**GE method**

**Requirements**

- \(<3\text{Wm}^{-2}\) of irradiance on the non-exposed side
  - For Cells; extrapolation may be required to compensate.
- Non-uniformity \(<5\%\) outdoor and for double-side illumination; \(<2\%\) for single-side

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Hohl-Ebinger et al.: Mounting chucks for bifacial solar cells
### Power rating of Bifacial PV devices

#### In practice

<table>
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<tr>
<th>Modules</th>
<th>Cells</th>
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| **PV Laboratories** | • STC measurement of both sides, without back reflection  
|                  |   → Bifacialities  
|                  |   → I–V characterization vs. backside illumination  
|                  | • STC (monofacial) reporting of the key data  
|                  |   → Reference module  
|                  | • BiFi coefficients and I–V characterization vs. backside illumination reporting  
|                  | **Cells**  
|                  | • STC measurement of both sides without Back Reflection (BR-compensated)  
|                  |   → Bifaciality  
|                  |   → I–V characterization vs. backside illumination  
|                  | • STC (monofacial) reporting of the key data  
|                  |   → Reference cell  
|                  | • BiFi coefficients and I–V characterization vs. backside illumination reporting  
| **PV Production** | • Calibration using the Reference module; IV measurement at STC  
|                  | • Bifacialities and I–V characterization vs. backside illumination reporting in the datasheet  
|                  | • Specific BiFi rating with clear denomination $P_{\text{max BiFi10}}$ and $P_{\text{max BiFi20}}$  
|                  | **Cells**  
|                  | • Calibration using the Reference cell; IV measurement at STC  
|                  | • Bifacialities and I–V characterization vs. backside illumination reporting in the datasheet  
|                  | • Specific BiFi rating with clear denomination $P_{\text{max BiFi10}}$ and $P_{\text{max BiFi20}}$  

A standard method for the power rating of bifacial devices is proposed:

- Applicable to cells and modules
- No practical change in production environments
- Compatible with STC measurements

Outdoor 2-sided measurements are consistent with Indoor 1-sided measurements with proportional overexposure.

Double-side illumination considered as alternative method

There is a need for an “Energy rating” standard for bifacial devices.

The IEC project team needs your support: your valuable feedbacks and positive votes.

Next
- Draft to be submitted in October
- Energy rating standard
IEC project team

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Thank you for your attention

Pasan’s new BiFi-compatible module tester

Meyer Burger’s HJT bifacial modules with busbarless cells on CSEM’s facade
Additional slide
Why outdoor measurements are consistent with Indoor 1-sided measurements?

\[ G_{Ei} = 1000W m^{-2} + \varphi_{isc} \cdot G_R \]

\[ G_R = a \cdot 1000W m^{-2} \]

\[ \varphi_{isc} = \frac{Isc_r}{Isc_f} = \frac{\int G \cdot SR_r \cdot d\lambda}{\int G \cdot SR_f \cdot d\lambda} \]

\[ Isc_{out} = Isc_f + Isc_b = Isc_f + \int a \cdot G \cdot SR_r = Isc_f + a \cdot \int G \cdot SR_r = Isc_f + \varphi \cdot a \cdot Isc_f \]

Hypothesis: RC’s spectral response is close to the DUT’s.