Measurement concepts for bifacial PV-devices - What is really required?

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Motivation

- The exact potential of bifacial PV depends on mounting structures, system orientation, albedo etc.
- In measurement we neglect these system properties and concentrate on device properties
- **Device properties** which should be measured are IV-parameters under **standardized conditions**
- **Bifacial devices have two functional surfaces – with two different efficiencies – which are partly coupled**
- Measurements on bifacial PV-devices split up in Lab and production for cells and modules \(\rightarrow\) 4 different scenarios
Properties relevant for front and rear side efficiency

<table>
<thead>
<tr>
<th>On cell level</th>
<th>On module level</th>
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<tbody>
<tr>
<td>▪ Bulk lifetime</td>
<td>▪ Encapsulation</td>
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<tr>
<td>▪ Emitter properties (peak doping, depth)</td>
<td>▪ Front/rear glass</td>
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<td>▪ Front surface recombination</td>
<td>▪ Position of junction box</td>
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<tr>
<td>▪ Rear surface recombination</td>
<td>▪ Positioning of the ribbons</td>
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<tr>
<td>▪ Optical properties front/rear</td>
<td>▪ Cell bifacility variations due to above mentioned properties</td>
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<td>▪ Shadowing front/rear (metallization fraction)</td>
<td>▪ Spacing of cells / backsheet properties</td>
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<td>▪ Light trapping</td>
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<td>▪ Thickness variations</td>
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Marked in red: properties which act predominantly on one side of the cell
Parameters influence efficiency selectively, mainly on front or rear.

Numerical values shown depend on cell architecture and values of the parameters (e.g., lifetime is less selective above 1 ms).

PC1D simulation of efficiency changes by different parameter variations:

IV – parameters of base-cell simulated:

$V_{OC}$: 668.7 mV
$J_{SC}$: 39.56 mA/cm²
$\eta$: 22.04 %
What errors arise in single sided measurements?

- Parameter changes adjusted such, that front side efficiency reduces 0.5 % absolute.
- Front side simulation thus always gives 21.41 % efficiency.
- Depending on parameter varied, bifacial results vary between 21.28% and 21.49 %.

- PC1D simulations of front and rear side illumination.
- Front side efficiency vs. calculation of mixed efficiency from 1000W/m² front + 200 W/m² rear illumination.
Properties and bifaciality – solar modules

- On module level, the parameters impact on short circuit current.
- They tend to be either non-selective (encapsulation) or purely selective (e.g., front glass).

Diagram labels:
- Junction Box
- Encapsulation
- Front ribbons
- Front glass
- Rear glass
- Cell properties
- Rear ribbons
So what is required?

- Variations of device parameters lead to strongly differing power variations for front and rear side illumination

- Thus a **bifacial measurement of both sides** is by far more meaningful and **accurate**

- **Single side measurements** may have about **20% relative error** in determination of **changes in device performance**

- Let’s take a look on the proposed measurement methods
Measurement solutions for bifacial devices – overview

- Flash from front black rear
- Flash from front white rear
- Flash from front @ STC, bifaciality is fixed
- Flash from front with adapted insolation, bifaciality is fixed
- Flash from front mirror behind the device
- Flash from front on mirrors, device mounted horizontally
- Flash twice and switch the device (or mount the second flasher upside down)

- **Use two independent light sources**
Bifacial h.a.l.m. flasher solutions – solar cells

- One IUCT3600 electronic cabinet
- 2 flash boxes, one of them directed to the rear side of the cell via mirror
- One measurement electronic
- Light sources are synchronized and independently regulated
- Allows for maximum variability in flash sequence
Bifacial h.a.l.m. flasher solutions – solar modules

- Two IUCTM electronic cabinets
- 2 flash boxes
- One measurement electronic
- Light sources are synchronized and independently regulated
- Allows for maximum variability in flash sequence
One flash sequence allows illumination from front, rear and bifacial within 90 ms
Concerns on bifacial flashers

- Costs – for our system, the price does not double, as many components are required only once.
- Integration and/or floor space – needs to be discussed individually with equipment suppliers.
- Cross-talk – light transmission from one half-room into the other and multiple reflections – the main technical concern we hear – here comes a short analysis.
Bifacial h.a.l.m. flasher solutions – analysis of cross talk

- Assume 10% transmission in module plane: 100 W/m² enter the second half room
- At homogenization pane, 38 W/m² remain 10% reflection → 3.8 W/m² head back to module
- Due to divergence, 2 W/m² intensity reach the module
- Analysis for all surfaces yields < 4 W/m² total intensity on rear side of the module
- Black wall behind the module → 4% of 100 W/m² are reflected → 4 W/m² rear intensity
- Rear side monitor cell measures rear intensity and makes it available for correction
Wrap-up

- Front and rear side efficiency vary differently if material or process parameters are varied.
- A real bifacial measurement in one flash sequence using two independent light sources is available for precise determination of bifacial power output.
- Crosstalk between the different half-rooms of a bifacial flasher can be sufficiently suppressed by easy measures.
What is really required for measurement of bifacial PV-devices – answering the question

- Bifacial flashing is required in labs for precise determination of device properties
- Bifacial flashing has a high benefit in PV-device production for precise output power determination and process monitoring
- If Bifacial flashing shall be omitted in module production make sure no junction box is covering the cells on the rear