An economic analysis of bifacial PV device output power measurement

With bifacial PV devices a large gain in solar power generation in the range of 10%-20% can be achieved in the field. Despite this, selling bifacial devices at higher prices is still a difficult task. With peak-performance of solar cells and modules at standard testing conditions being the price meter, true bifacial testing is a key step to achieve bifacial pricing in the future of PV. We present deeper insight into bifacial testing and analyse the economic impact of different approaches.

Large-scale production of bifacial solar cells and modules has become possible mainly by three developments over the last few years – dielectric passivation layers on both sides of the solar cells, thinner glass for solar modules and alternatively transparent backsheets. Offering a major increase in electricity generation at a comparably low increase in costs for device manufacturing, bifaciality has become one of the largest industry trends in photovoltaics in the recent years.

Bifacial devices achieve a gain in power generation of 10% – 20% compared to monofacial references [1-5], depending on system design, albedo of the systems’ location as well as the bifaciality coefficient of the modules. This gain, which corresponds to 2% – 4% higher solar cell efficiency, is larger than the gain achieved by the PERC process implementation. Though the bifacial gain is not put into question, manufacturers still struggle with the incorporation of the rear-side power in pricing of PV devices. One reason is clearly that the effective benefit of bifaciality depends on the details of the solar module mounting and the configuration of the solar system and cannot be precisely predicted when solar cells or modules are produced. Whereas this pricing barrier is hard to overcome, a second issue can easily be solved.

The power output of bifacial PV devices is often measured with front-side illumination only, thus no value for their individual bifacial performance exists. This is contradictory to the long-lasting tradition of selling PV products by Wpeak – a price meter relying on direct measurement of the output power of each individual cell or module. This issue is solved by using two independent light sources in measurement systems used for bifacial PV production and defining standard conditions for measuring the bifacial power output. In the following we analyze economic impacts of bifacial vs. single-side illuminated rating of bifacial PV devices, addressing system cost, operating cost, direct economic benefit and indirect benefit through process optimization and customer trust.

Figure 1: Illumination of bifacial PV devices either from both sides or with increased equivalent intensity from the front side
From a technical point of view, the main difference between measurement technologies for bifacial PV devices is the illumination of the device either just from one side or from both sides (see Figure 1). The single-sided approaches thereby rely on a constant bifaciality in production, the main assumption of these technologies. A further assumption is that the devices behave in an identical way under increased irradiation from the front and when additionally irradiated from the rear. Bifacial illumination on the other hand, requires two light sources and thus the system investment is increased. As additional operating costs, flash tube consumption on the rear side and electric power for the rear-side flash box add up to costs which are not expected to exceed 4500 $/year.

To decide which technique is best suited, the additional investment required for more precise technologies needs to be rated against the advantages delivered by the more precise measurement along the value chain. These advantages comprise the direct gains achieved by proper sorting of the cells as well as indirect gains like better process control and optimization or higher trust of customers.

To validate or vitiate the main assumption of single-side illumination techniques namely the constant bifaciality in production, we investigate 4 groups of solar cells obtained from 4 different solar cell manufacturers. Three of these cell groups, which each consisted of a little more than 100 cells, were taken out of production prior to sorting and represented a production time slot of about 2 min each. The fourth group consisted of presorted cells taken from two BIN classes. All cells were then measured on a cetisPV-IUCT-BF system integrated with an adapted cetisPV-Celltest3 which provides a dark chamber for the measurements (see Figure 2).

The system consists of a single electronic cabinet to control the two flash boxes, which provide the illumination of front and rear side of the solar cell, the dark chamber with the flash boxes and cell contacting and the measurement electronics. One of the flash boxes is mounted horizontally, the light being directed to the rear of the solar cell under test, using a mirror. A black passe-partout around the cell is used to minimize light protruding from the front side into the half room of the rear side and vice versa (crosstalk). Both light sources are controlled by one single controlling unit and can be adjusted individually in both light intensity and flash length, allowing for user-defined flash curves and intensities.

For our measurements we use a setting which provides a 1000 W/m² flash from the rear side first, a 200 W/m² flash from the rear side together with a 1000 W/m² flash from the front side in a second step and a 1000 W/m² flash from the front side in a third step, each of the steps being 30ms in length. IV curves are recorded in each of the three sections using halm’s advanced-hysteresis evaluation in order to account for capacitive effects of the solar cells under test.

Both light sources are rated AAA according to the IEC standard 60904-9 ed. 2.0. Light intensities from both illumination sources are monitored independently using two monitor cells. An intensity correction is performed for the measured IV curves, using the flash intensity data for each point of the IV measurement. In this way, any crosstalk between the two half rooms is monitored in the measurement and automatically corrected.

The results for the correlation of front- and rear-side current are displayed in Figure 3. As is obvious at first sight, there is no correlation between front- and rear-side current. Thus, no constant bifaciality can be assumed on these batches. To examine the degree of variation, the relative width of ISC variations is compared for front and rear side in Table 1. This allows a quantitative examination of the degree of variation in bifacial power output caused by current generation from either side of the cells.

Figure 2: cetisPV-IUCT-BF implemented into a cetisPV-Celltest3 system to perform laboratory bifacial IV measurements.

Figure 3: Normalized values of short-circuit current for cell batches from manufacturer A-D. The front current is plotted as a function of the rear current in order to show the degree of correlation.
The analysis of the data indicates significant variations in the short-circuit current of the rear side. The variation is independent of the front-side performance and has about 6.5 (std-dev) – 7.1 (max-min var) times the magnitude of variations observed on the front side of the cell. Keeping in mind that rear-side irradiation is about one-sixth of the front side irradiation, this result shows that variations from both sides contribute equally to the total variation of bifacial current generation and thus bifacial power output. With similar results obtained on all 4 batches this behavior seems to be of rather general applicability. As both sides of the cell contribute equally and independently to variations in current generation, it follows directly that the measurement of both sides is of comparable importance and thus a bifacial measurement is required in solar cell production.

Besides this obvious requirement of measuring solar cells from both sides in order to judge their bifacial power output, the value of true bifacial measurements shall as well be rated in economic terms. Having only monitored a very short time of production in our experiment, we assume that a manufacturer using single-side illumination technique can only safely claim that a manufacturer using single-side production in our experiment, we assume a reduction of variations in the short-circuit current of the rear side. The variation is independent of the products is underestimated.

The average loss per cell in the 4 groups ranges from 15 mW to 65 mW (corresponding to 0.06% - 0.27% efficiency) per cell. This adds up to losses of 45,000 – 194,000 $/year, assuming a production capacity of 2400 cells/hour operated at 95% total uptime and a sales price of 0.15 $/W. Taken alone, these numbers will lead to payback times of bifacial flasher systems, which are in the range of 1 year or below. Additional process optimization gains and better reputation achieved with a true bifacial measurement add to this.

To estimate the economic impact of process optimization achievable by monitoring the cells rear-side performance we assume a reduction of variations in bifacility. An increase in bifacial power output of the cells by about 20 mW per cell in average, adding another 60,000 $/year, seems feasible, regarding only the variations on short time scale visible in Figures 3 and 4. Last but not least, increased confidence in bifacial power output of customers achieved by measuring the bifacility may be a key factor in achieving real bifacial pricing.

In conclusion, we find that bifacial measurements of bifacial PV devices are necessary for precise assessment of the bifacial power output and cannot be substituted by single-side illumination with increased irradiation. Already the direct economic benefit achieved by proper rating of the bifacial power justifies additional expenses for the bifacial measurement systems.

Besides the direct economic benefits, pricing bifacility without directly measuring it would contradict the tradition of selling PV products based on a measurement of their power output. In order to achieve customers’ trust in bifacial power generation, we propose measuring the bifacility of each device, as one important parameter for power generation and price finding or in other words: Measure what you want to sell!

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References:

Table 1: Comparison of variation widths of front-side ISC and rear-side ISC values for groups of solar cells from 4 manufacturers

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Variation width total (front)</th>
<th>Variation width total (rear)</th>
<th>Standard deviation (front)</th>
<th>Standard deviation (rear)</th>
<th>Ratio of variation widths</th>
<th>Ratio of standard deviations</th>
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<tr>
<td>A</td>
<td>1.26%</td>
<td>10.25%</td>
<td>0.29%</td>
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<td>B</td>
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<td>7.22%</td>
<td>0.21%</td>
<td>1.35%</td>
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<tr>
<td>C</td>
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<td>4.966%</td>
<td>0.158%</td>
<td>0.979%</td>
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<tr>
<td>D</td>
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<td>9.85%</td>
<td>0.34%</td>
<td>1.71%</td>
<td>6.23</td>
<td>5.02</td>
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</table>

Figure 4: Difference of bifacial measured $P_{MPP}$ ($P_{MPP}^{BF}$) and $P_{MPP}$ measured using a single-side illumination approach ($P_{MPP}^{SS}$). A black horizontal line indicates a safe-sales value for bifacility deduced from the respectively cell batches. Bifacial power above this line would be lost for sales without bifacial measurement.

The measured bifacility, in order to avoid complaints from customers. This is illustrated in Figure 4. Thereby, part of the power output is not rated and the value of the products is underestimated.