Bifacial solar modules: how to measure them in production

Abstract

Bifacial modules are entering the large-scale solar installation market. This article briefly describes the technology behind bifacial modules and focusses on what is needed to measure them with a sun simulator to show the extra power gain they provide. The procedures described here are based on the Technical Specification IEC 60904-1-2:2019, touching also on the procedure needed to create a bifacial reference module.

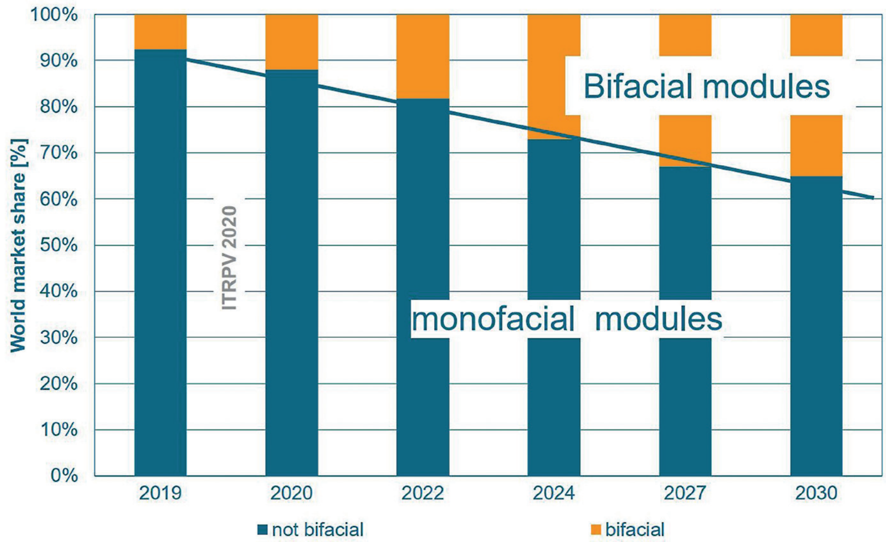

Figure 1: The market share of bifacial modules is expected to grow to 35% in 2020 (Source: ITRPV VDMA Market Maturity Report 2020)

Bifacial modules have been available in the market for quite a while. But since 2019 a noticeable rise in market share can be seen.

When bifacial modules entered the market, they were found in very specific areas, starting with space applications, smaller solar farms and as BIPV (building integrated PV). Having a transparent back side and generating power on both sides, providing around 15% to 30% more power depending on the installation, they were used for example on satellites, to additionally collect the light back reflected from earth, or in the area of BIPV where they can be found on flat roof tops using bright underground for back reflecting light. Further examples are coverages on walkways or parking lots using the concrete underground as reflective source or the vertical installation e.g., along highways as sound barriers to name only a few.

Lately, also due to the fact that the cost for producing bifacial modules has decreased, there is interest from a much wider market. Bifacial modules are entering the market for large scale solar farm installations. One example is the large-scale tilted installation of bifacial modules on sandy or snow-covered grounds in otherwise, e.g., agricultural, unusable areas, benefitting from the light back reflected form the ground to generate extra power. Another interesting possibility is the large-scale vertical installation, using an east west orientation to capitalize on the sun's daily movement, creating 2 energy peaks in one day. The vertical installation additionally prevents the deposition of snow or dirt on the modules and can provide possibilities for double use of the ground.

In the general strive to get more power out of a module, while keeping cost and dimension in a manageable range, bifacial modules in combination with new solar park setups can provide significant boosts in the overall power output.

The good thing is that existing cell technologies and module layouts can be used. The nevertheless needed changes in the modules BOM (bill of material) are manageable due to the gain in power achieved. The ITRPV roadmap expects the market share of bifacial modules to rise up to ~35% until 2030, see figure 1.

How does a bifacial module work?

A bifacial module is a module that can accept light from the front and rear side to generate energy. In contrast, the common monofacial

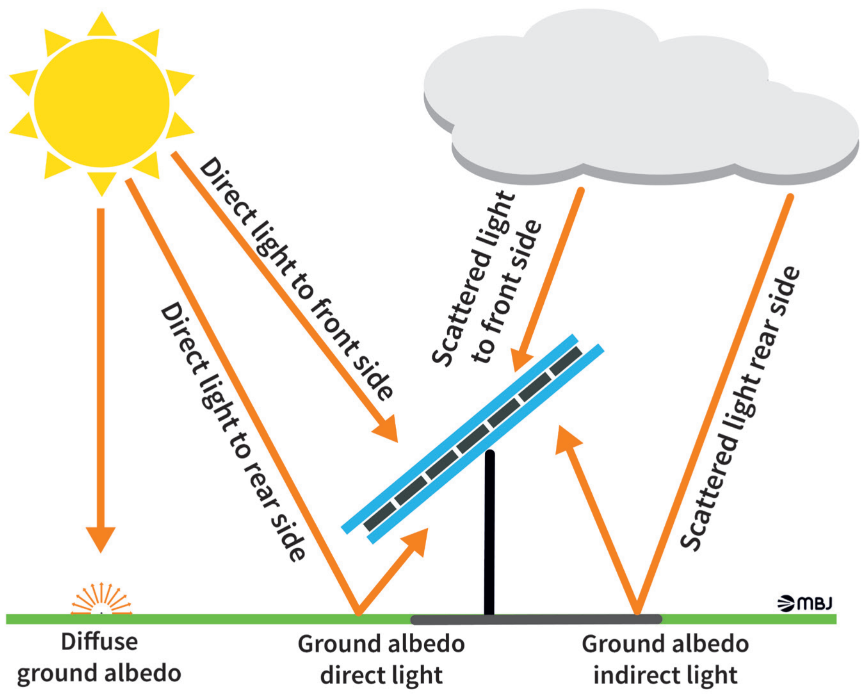

Figure 2: Light collection of a bifacial module is dependent on the module orientation, the type of the underlying ground and the resulting albedo value

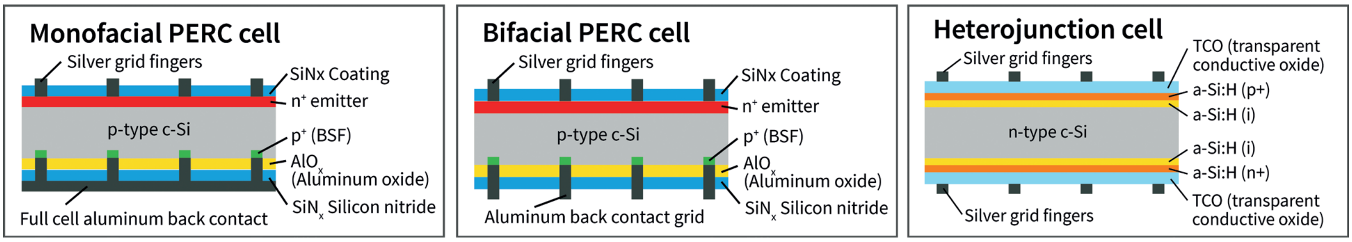

Figure 3: Example of different solar cell structures, monofacial and bifacial. The monofacial PERC cell has a full coverage aluminum back contact preventing light to enter the cell from the rear. Bifacial cells use grids on both sides instead.

modules are only light sensitive on the front side, the rear side is covered with a white or black opaque back sheet, sheltering the individual solar cells from oxidation and environmental influences like rain or dirt but consequently also from light.

In a bifacial solar module, the opaque back sheet has to become transparent, either in form of a second glass layer or as a transparent back sheet. This enables the sun light to additionally enter the solar module from the rear side. Any light back reflected from the ground or the underlying structure can enter the module to reach the solar cells and can generate extra power. Or in a vertical east/west setup, can enter the rear side of the module directly in the second half of the day when the sun has moved from east to west.

How much light will be back reflected from the ground is defined in the albedo value. The albedo value describes the diffuse reflection of sun light from the ground. It is the ratio of the light hitting the ground and the amount of light coming back from the ground by reflection, see figure 2.

The value zero would be total absorption, no light is back reflected and a value of one is total reflection: 100% of the incoming light is back reflected. The value varies depending on the material of the ground, e.g., green grass has an albedo of around 23%, concrete around 16%, white paint on concrete or a white shiny roofing membrane can have around 70% to 80% and snow can provide up to 90% back reflection. Depending on the underlying surface a lot of light is available for further energy creation when the solar module is bifacial and can accept it.

Next to changing the back cover some more changes need to be done to create a bifacial module. The solar cells themselves need to be able to collect light from the rear side. So far, the standard silicon solar cell had a full cover aluminum back layer through which no light could pass. Some small modifications in the cell production process can change former monofacial solar cells into bifacial cells. Some of the newer cell technologies are even bifacial by nature.

Some of the following cell technologies are used for bifacial modules: PERC (Passivated Emitter Rear Contact) cells, PERL (Passivated Emitter Rear Locally Diffused) cells, PERT (Passivated Emitter Rear Totally Diffused) cells, TopCon (tunnel oxide passivated) cells, IBC (Interdigital Back Contact) cells and HJT (Heterojunction with intrinsic thin layer) cells, see figure 3 for an example of the cell structure.

While PERx, IBC and TopCon cells are not intrinsically bifacial, a few changes in the cell process make them so. Heterojunction cells are naturally bifacial due to the similar layer design for front and rear side. The bifaciality of the different cell technologies, meaning the difference in power that can be generated when illuminating from the front or the rear side, ranges from 65% up to 90%. The PERx/TopCon cell technologies are at the moment still named as the main cell technology used in the market, but other cell technologies are gaining market share, according to the ITRPV/VDMA International technology roadmap for Photovoltaic, 12th edition 2021.

Additional changes have to be made on module level: the size and the placement of the junction box and the size of a frame, when one is used, has to be reconsidered to avoid shadowing and collect as much of the available additional light.

All advanced module layout technologies can be used in the same way as they are used with mono facial cells: multi-busbar layouts, half-cell designs and shingling are possible in just the same way. These allow to add some extra gain to the overall module power while keeping production cost at a manageable level.

A how to measure a bifacial module in production.

In theory a bifacial module can deliver a significant power gain around 10% to 30% but how much is that exactly? And how can it be measured and made transparent to the customer?

At the moment there is no worldwide standard on how to measure the gain of power from a bifacial module. There is no common rule on how to label these modules to state the devices bifaciality and with it the expected gain in power.

Since 2019 a technical specification from the IEC describes the technique to measure and label bifacial modules. The technical specification is on its way to become the new standard in the next years and will be a large step forward towards more transparency in

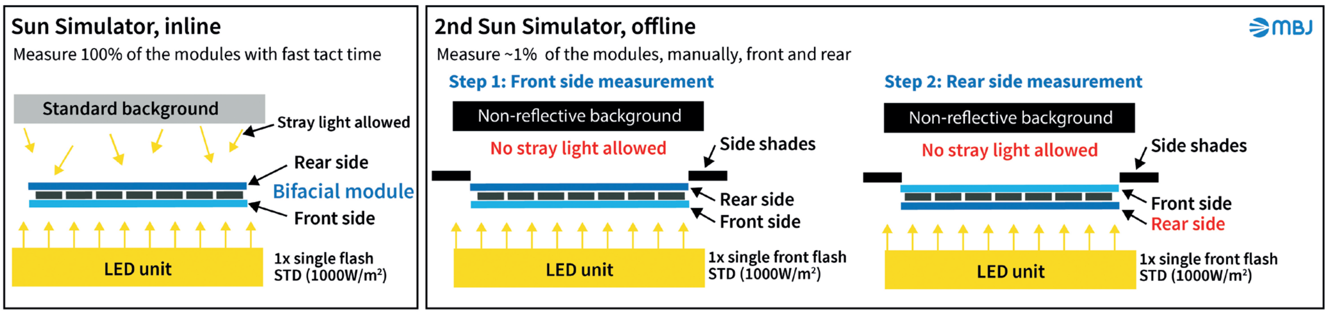

Figure 4: The recommendation for a bifacial module line is to use two sun simulators, one inline and one offline. The offline sun simulator verifies by sample testing >=1% of all produced modules that the bifaciality matches the bifaciality of the reference module

labeling the bifacial effect in the market.

The IEC Technical Specification 60904-1-2:2019 recommends the addition of three distinctive values to be added to the name plate of a bifacial module: The PmaxBiFi100 and PmaxBiFi200 and the bifaciality factor. The values represent the extra gain in power through the bifaciality of a module as additional power to the standard front power measured at Pmax STC (standard test conditions). The additional power is expressed as the plus at 100W/m² and 200W/m² irradiation received from the rear side.

The process has three separate steps:

Step 1: The characterization of a reference module in an authorized independent test lab

Step 2: The referencing of the sun simulator with the bifacial reference module

Step 3: The process of measuring modules

Step 1: Characterization of a bifacial reference module

The bifacial reference module is needed to later enable any sun simulator in production or in a lab to measure other modules of this type.

To calculate PmaxBiFi100 and PmaxBiFi200 an additional factor, the bifacial factor (BiFi factor), has to be determined. To determine the bifacial factor a measurement of the front side IV-curve has to be done separately from a rear side IV-curve measurement, while preventing any stray light or reflective influence from the other side of the module. The bifaciality can then be calculated, eliminating any side influence.

A sun simulator with adjustable irradiation levels and irradiance up to 1200W/m² needs to be used for the characterization. This can also be a double side sun simulator when both light sources have individual adjustable irradiation levels and the irradiation non-uniformity is below 5% for all irradiation levels used in the measurement.

Additionally, the sun simulator has to have a non-reflective background to get a valid measurement for the BiFi factor. In the technical specification a background is considered to be non-irradiated when the irradiance does not exceed 3 W/m², at any point, on the non-exposed side of the bifacial module under test. This is especially important when using a sun simulator with two light sources: the exact proportion of light from front and rear side needs to be known, ideally with no impact from front to rear side.

The key values to measure with an irradiance of 1000W/m² under STC on front and rear side are: the bifaciality of the short circuit current Isc [A], the bifaciality of the open circuit voltage Voc [V], the bifaciality of the maximum power point Pmax [W] and the fill factor.

The bifaciality for the Isc is then the measured Isc rear value divided by the measured Isc front value. Accordingly, for the bifaciality of Pmax, Pmax rear is divided by Pmax front and the same for calculating the bifaciality for the open circuit voltage.

When measuring with a single sided sun simulator the equivalent front side irradiation

Figure 5: LED Sun Simulator from MBJ Solutions, available with single- or double-sided light source and for large module sizes resulting from M6, M10 or M12(G12) size solar cells

The latest generation of MBJ sun simulators can support all challenges arising from a bifacial module production.

for the measurements has to be calculated, equivalent to the power measured in a front and rear side illuminated module in a double-sided sun simulator. The equivalent front-side only irradiation Ge is calculated using the bifaciality, which is in this case the minimum value between the bifaciality value of Isc and Pmax.

Ge= 1000 W/m^2 + bifaciality * Gr

With Gr being the additional rear side irradiance. Ge represents the additional power to use when measuring with a single sided light source for any given additional rear side light Gr. The calculated equivalent front side irradiation Ge is needed for evaluating PmaxBiFi100 and PmaxBiFi200:

Assuming a bifaciality of 0.8 and an additional 100W/m^2 rear irradiation the equivalent front side irradiation to use for the measurement is: 1000 W/m^2 + 0.8 x 100W/m^2 = 1080 W/m^2.

With this formula, the Pmax for a series of different rear irradiations Gr should be measured for the reference module creation. The 'Rear irradiance driven power gain yield value' (BiFi value), is then the slope derived from the linear fit of the Pmax values as a function of the Gr data series.

Step 2: Referencing a sun simulator for bifacial modules in production

With such a bifacial reference module, characterized from an independent test lab, a standard single sided sun simulator has to be referenced to its 1000W/m^2 STC front side characteristics.

Step 3: The process of measuring modules in production

The recommendation for a bifacial module line is to use two sun simulators, one inline and one offline. Inline 100% of the modules are measured while the offline sun simulator verifies a sample >=1% of all produced modules for a match of their bifaciality to the bifaciality of the reference module.

All modules in production will be measured once with one standard STC front side flash. To the flash result the bifacial factor, specified by the independent test lab, will be added:

PmaxBiFi100 = PmaxSTC + BiFi x 100

PmaxBiFi200 = PmaxSTC + BiFi x 200

Additionally, a sample of >=1% of the produced modules will be measured again with the second well referenced standard single side sun simulator. The modules have to be measured from both sides, manually turning them between flashes, to present once the front side and secondly the rear side to the light source. The second sun simulator has to have a non-reflective background to avoid any irradiation influence caused by internal reflection to the module side not measured at that time, see figure 4.

The deviation of the bifaciality of a production module to the reference module should be less than 5% to ensure that the bifaciality of all modules produced match the measured bifaciality of the reference module.

The latest generation of MBJ sun simulators can support all challenges arising from a bifacial module production. The LED light source is certified according to the new IEC 60904-9 Ed.3 standard as triple A+ sun simulator. With 13 different LED types, a very close representation of the solar spectrum is achieved. With the expansion of the spectrum into the ultra violet and infrared spectrum the precise measurement of a wide variety of module types, including thin-film is possible. The extended range is especially needed for PERC and HJT cell-based modules. These cells show a stronger spectral response in the ultra violet and near infrared area which has to be measured to translate the full potential of these modules into the correct power class.

Some of the newer module types have capacitive effects when only shortly exposed to light. This effect has a direct influence on the power measurement. The MBJ LED sun simulator 4.0 uses step wise measurement to precisely measure modules with capacitive effect without the need of an extra-long pulse width. During the measurement the voltage is controlled in even steps while measuring the current only at the end of each steps time, when the capacitive effect has leveled out.

For measuring bifacial modules in production, we recommend to use a standard single sided light source LED sun simulator with high throughput and automatic contacting. A calibration with a bifacial reference module of the same BOM (bill of material) as the modules in production will provide accurate results. No special measures to avoid internal light reflection are necessary, as the same reflections and stray light conditions have been present during the referencing of the system. Important is, that the measurement conditions do not change between referencing and production.

To regularly and efficiently confirm that the bifaciality on >=1% of the modules is within the allowed range of 5% versus the bifaciality of the reference module we recommend one additional sun simulator next to the production line, featuring a special non-reflective background. This setup is especially efficient when regarding the tact time impact the confirmation of >=1% of the modules would have on the inline system.

Although we advise to use a setup with two sun simulators for a bifacial production, MBJ can provide a bifacial sun simulator with two light sources for measuring front and rear side of bifacial module simultaneous. The bifacial sun simulator provides freely adjustable relations between front and rear irradiance and is available in different sizes to support modules made from M6, M10 or M12 (G12) size cells.

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