

Bifacial PV Technology

Ready for Mass Deployment

The deployment of bifacial PV technology is growing rapidly. Although the concept is not new, it has been a niche technology for many years with uncertainties in predicting performance and optimizing installations. This paper provides a comprehensive introduction into all aspects of bifacial PV technology with a special focus on risks industry buyers and investors should pay attention to. For advice and assistance with bifacial PV technology please contact your local PI Berlin representative or send an email to info@pi-berlin.com.

Introduction

Bifacial solar cells are not a new concept. In principle every solar cell is bifacial as long as its rear side is not coated in any way that prevents light passing through. The very first solar cell ever presented to the public in 1954 was in fact bifacial.

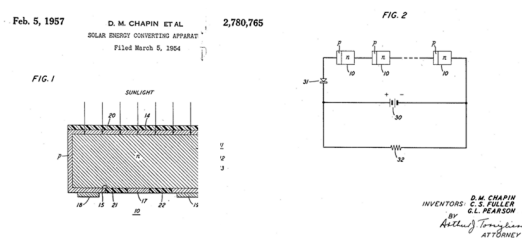


Figure 1: Patent application solar energy converting apparatus from 1954.

The fact that a lot of people believe bifacial PV is a new concept is due to the fact that for more than a decade the 'aluminum back-surface field' (Al-BSF) has been the predominant solar cell technology. Al-BSF cells do not let light through the thick aluminum layer on the backside of the cell. However, the first active bifacial solar cells were produced 10 years ago and were commercially available as bifacial modules. Most bifacial development at that time was conducted by Japanese companies like Hitachi or PVGS - a pioneer in bifacial technology. Some small producers, such as SolarWind from Russia, tried to push "bifaciality" into the PV market. Some large solar players were also working on bifacial technology: Siemens, SunPower and Panasonic, for example.

- A good overview on the history of bifacial PV can be found in a presentation by Cuevas called 'The Early History of Bifacial Solar Cells'¹. In the late 1990s Siemens Solar, then one of the top PV module producers in the world, was producing a 4" mono-crystalline solar cell in large volumes that also happened to be bifacial. The feature was however never used or promoted or even mentioned – but the solar cell was in fact bifacial.
- Around 2004 SunPower was working on a bifacial version of its famous A-300 cell. A prototype series was produced but never made it to mass production.
- Before 2010 Panasonic offered a bifacial version of its hetero-junction technology based solar module and sold under the brand SANYO at the time.

Bifacial Solar Cell Technologies

In the PV industry today, bifacial technology is one of the key ways to further improve annual energy yield of a PV system and further reduce the levelized cost of energy (LCOE). This is driven by the fact that all advanced solar cell technologies beyond Al-BSF are bifacial, or can be made bifacial with very minor changes. One of the key factors in achieving higher solar cell efficiencies is an effective passivation of the solar cell rear side. Most passivation layers such as Si_3N_4 or Al_2O_3 are also transparent. However, the rear side efficiency of the bifacial cell can vary significantly - differences in solar cell technology influence bifacial properties. There are three dominant technology concepts² that have unique bifacial properties: p-PERC, n-PERT and Hetero-Junction technology (HJT).

¹ Andres Cuevas et al.: The Early History of Bifacial Solar Cells, 20th PVSEC

² There are several more concepts in series production such as p-PERT or n-PERL but at least for now these are more uncommon approaches

p-PERC technology

p-PERC has quickly become the dominant solar cell technology. Only minor changes in manufacturing processes are required to achieve a bifacial p-PERC solar cell. However, a fine grid of aluminum (Al) still needs to be printed on the rear side of the cell in order to ensure impurity trapping where the Al is in contact with the p-type Si wafer. These Al ‘fingers’ lead to some shading of the solar cell’s rear side, and limit the bifacial coefficient¹ to 70 to 80 % for p-PERC based solar cells.

n-PERT technology

N-type wafers have some conceptual advantages over p-type wafers such as a longer carrier lifetime and the absence of boron in the bulk wafer material which avoids light-induced degradation. This is why n-type solar cells typically achieve higher conversion efficiencies than p-type cells. No Al is required on the rear-side of the solar cell which makes all n-type solar cells bifacial by nature. Nevertheless, since n-type wafers are more expensive and the cell manufacturing processes are less widely applied, n-type solar cells are sold at a premium. For most n-type solar cells, the bifacial coefficient is however in the range of 90 % which is 10 to 20 % higher than p-PERC type cells.

Hetero-Junction technology (HJT)

HJT solar cells have a very different architecture. Although the number of manufacturing steps is low, the Cost of Ownership (COO) is high because more sophisticated and expensive production equipment is required. The process also requires high-quality, more expensive n-type wafers. However, HJT cells are very attractive because they have higher efficiencies than other p- or n-type technologies as well as a very high bifacial coefficient of >90 %. According to a recent article in *TaiyangNews*,² Sunprime’s product leads all commercial bifacial modules today with a bifacial coefficient of 95%.

The former SANYO (now Panasonic) HIT module was the first commercially successful HJT module. A bifacial version was commercially available back in 2000. After patents on the technology expired in 2010 other companies launched R&D programs for

the development of HJT-based products and turn-key production lines are now available. It is expected that with an increasing volume of HJT solar cells, costs for the manufacturing equipment will also come down. Along with the fact that the cost for n-type wafers is getting closer to that of standard p-type wafers, many believe that HJT technology will in the long run become the dominant solar cell technology.

Design Options for Bifacial PV Modules

Most bifacial modules are designed with a double-glass construction. This has been an industry trend developing in parallel with bifacial PV. Double-glass modules do not need to be equipped with a supporting aluminum frame because the double-glass laminate itself is mechanically very stable. Removing the frame can be a cost advantage for the manufacturer over the standard module design, but care must be taken in packaging, handling, racking and installation of the module to avoid damage and cracking of the glass edges. Tempered safety glass is tough against mechanical impacts on the front-side but the edges are sensitive to catastrophic fracture of the glass. This is a reason why the more conventional design approach with a single front glass and a (transparent) backsheet together with an aluminum frame has been adopted by some bifacial module manufacturers.

There is no obviously better design between double glass or single glass with a transparent back-sheet. Both options have pros and cons, and the total system design and installation process must be considered in making a decision.

Specific attention must be paid to the electrical terminations and junction box on the module. Early commercial bifacial modules were equipped with one regular, large junction box which covered the rear-side of some of the solar cells. Nowadays almost all bifacial modules are equipped with three small boxes on the edges of the module which prevents any partial rear-side shading of the bifacial cells.

¹ bifacial coefficient: Ratio of efficiency of the front-side of a bifacial cell relative to the rear-side

² *TaiyangNews: Bifacial Solar Module Technology (Edition 2018)*



Figure 2: typical arrangement for junction boxes on bifacial PV modules.

In order to retain the typical 1 to 3 % boost in front side power resulting from light being reflected from the ‘white’ space between the cells in standard modules, a recent trend in bifacial modules has been to use a rear glass with a white reflective pattern. This is a simple and low-risk way to keep a transparent rear-side without compromising front side performance.



Figure 3: rear glass with a white pattern – available both for full-size cells (right) and half-cut solar cells (left).

Market Overview of Bifacial PV Modules

The commercially available bifacial modules can be grouped according to their expected performance. Most important in terms of performance is usually the STC efficiency and the bifacial coefficient. For both these parameters, modules using hetero-junction solar cell technology are the undisputed front runners. The most prominent brands are Panasonic and Sunpreme with module area efficiencies well above 20 % and bifacial coefficients >90 %. However, smaller and less known brands such as Hewel (Russia) or CIE (China) offer similar high-performance bifacial modules. The latest market entrant is 3SUN, a subsidiary of the Italian utility company ENEL. However it is likely that these modules will be

used exclusively for ENEL projects and may not be available to the open market. HJT-based modules are usually offered at a higher price point than other modules which makes them potentially less attractive for large investor-driven projects but more attractive for smaller scale residential or commercial systems where bifacial makes sense.

Currently the most common type of bifacial modules are based on mono-crystalline p-PERC technology. Almost all major brands have such a module available. After a slow start with p-PERC bifacial modules, with SolarWorld the first to introduce them at a reasonable commercial scale, most mainstream manufacturers are now convinced about the market potential of bifacial modules with some now driving intensive marketing campaigns.

Although not the highest performing bifacial modules in terms of efficiency and bifacial coefficients, the fact they are produced in larger volumes gives p-PERC-based bifacial modules the highest market share of all bifacial technologies, as well as the most credibility among financing entities.

The “middle class” in terms of performance (and also price positioning) are the n-type based bifacial modules. They have slightly higher solar cell efficiencies than p-type cells as well as other advantages such as lower temperature coefficient and the absence of any boron-oxygen based light induced degradation (LID). This makes such modules an interesting compromise between the mainstream p-PERC and the more expensive HJT modules.

The pioneer, and probably still largest producer, in this category is LG. However various other companies have n-type based products commercially available. From the global top 10 producers only Jinko and Yingli are active in this field and n-type technology still represents only a small volume product. Some other smaller producers have strategically decided to put their focus on n-type technology, with the predominant players being Adani, Linyang and Jolywood who have annual production capacities greater than 300 MWp for n-type bifacial modules. SPIC is one of the Chinese pioneers in bifacial PV technology, with different bifacial cell technologies in series production. The producers

SPIC and Solitek based in Vilnius (Lithuania) have announced the first bifacial interdigitated back contact (IBC) cells to be in production by the end of 2019.

All manufacturers are using mono-crystalline cells for bifacial modules – with one exception: Canadian Solar (CSI) is offering a bifacial module based on p-type multi-crystalline PERC technology. CSI regularly publishes news about this product and where it is used, so it does appear to be generating some market interest. It appears to be mostly used for projects where CSI is the developer and sometimes also the EPC.

Advanced Module Designs

Most bifacial modules use conventional solar cell interconnection technology (full-size cells with a five busbar interconnect design). However, manufacturers are also trying to make use of advanced module concepts such as half-cut cells, multi-wire interconnections and shingled-cells. At the SNEC trade show in China in 2018 a bifacial module was presented using back-contact cells. There is no reason not to co-use advanced module designs in combination with bifacial solar cells. All the advantages of such module designs also apply to bifacial modules.

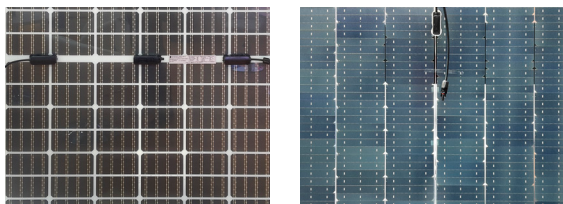


Figure 4: still exotic but developing are bifacial modules with (half-cut) back-contact cells (left) and shingled cells (right).

Bifacial System Concepts

Just as there are different concepts for installing regular modules in conventional PV systems there are also different concepts for installing bifacial modules. However, module orientations which are normally not very efficient in terms of performance yields can become interesting with bifacial modules. If sufficient solar radiation can reach the module rear side, then it can more than offset reduced radiation on the front side. This is most obvious for the vertical installation of a bifacial module, but also for “normal” tilted modules. The optimum tilt angle will

most likely be higher if the module rear side contributes to energy production. An overview of how daily energy production depends on installation orientation is given in figure 5.

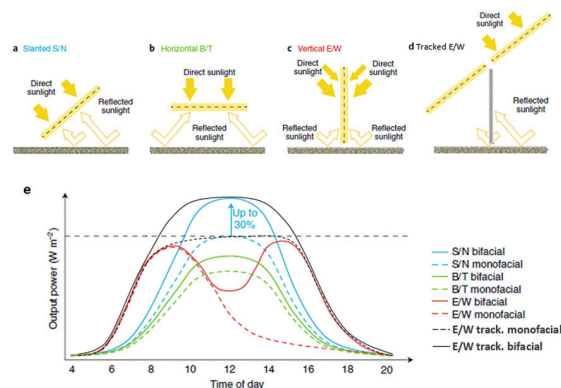


Figure 5: different concepts for the installation of bifacial PV modules and the resulting energy production characteristics over the day¹.

Influence of Design on the Yield Gain of Bifacial Systems

More variables influence the energy production for bifacial PV systems compared to regular mono-facial systems. Although it sounds simple - consider the light falling onto the rear side of the module – in reality the actual calculations are much more complicated. The most relevant parameters which determine the actual energy gain from the module rear-side are the following:

Bifacial coefficient of the module

It is obvious that the energy gain scales with the relative efficiency of the rear-side of the module compared to the front. A measure of this is known as the bifacial coefficient. The additional yield is strictly proportional to the bifacial coefficient.

Ground reflectivity

It may make sense that the energy gain also scales linearly with the ground albedo (light reflected from the ground or surface below the module) – but this is actually not the case. The reason is that only a portion of the rear-side illumination actually results from ground reflection. Light is also scattered from the sky directly onto the module rear-side.

¹ R. Kopecek et al., Nature Energy (volume 3), P 443ff

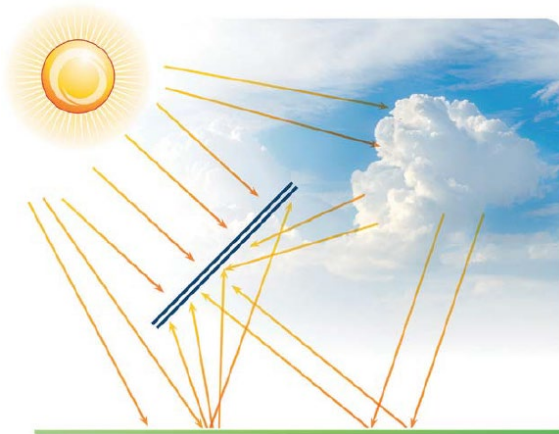


Figure 6: Illumination of the module rear side is due to ground reflection as well as to light scattered from the sky. Illustration from ¹

Height of the module above ground

As Figure 6 already suggests, the installation height above the ground is also an important factor. The graph below shows this dependency based on experiments conducted by SolarWorld.

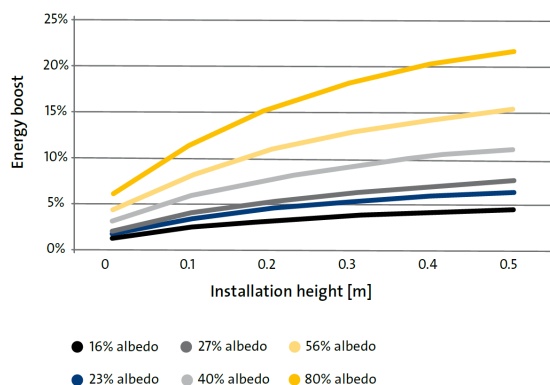


Figure 7: Energy gain of bifacial PV systems depending on installation height (lower module edge) and ground albedo². Module bifacial coefficient amounts to 65% (only).

Module row spacing

The amount of light hitting the module rear side is also determined by the spacing between the modules. The larger the spacing the more light may reach the back of the module, although beyond a certain spacing the additional gain is negligible.

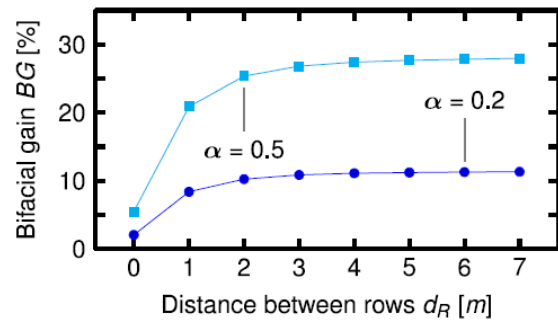


Figure 8: Dependence of energy gain of a bifacial PV systems on row spacing for different ground albedos of $\alpha = 0.2$ and 0.5 , respectively³.

All of the above examples were for fixed-tilt installations. Similar considerations apply for tracking systems.

There are other 2nd-order factors which play a role such as the racking configuration (no rails or other physical obstructions should cover the module rear side), module orientation (portrait versus landscape) and row length, but such factors require more detailed modelling.

Yield Simulations for Bifacial Systems

Yield simulation studies for bifacial solar systems are more complex than for mono-facial arrangements. As described in the previous section, more module and system design factors influence energy yields.

However, over the past years there has been significant progress in energy forecasting tools for bifacial systems. Today there are two software tools available which have been proven to give reasonably accurate yield forecasts.

PVSyst

The Swiss software tool PVSyst is the global benchmark for PV yield simulation forecasting. PVSyst introduced the first bifacial features in 2016. However, it turned out that even for energy yield experts the calculations were not simple. PVSyst acknowledged that the first commercial versions underestimated the energy gain⁴. PVSyst claims that their software version 6.75 will be more accurate for

¹ PV PowerTech, Volume 12 (2017), page 23

² SOLARWORLD White Paper: "Calculating the Additional Energy Yield of Bifacial Modules"

³ I. Shoukry et al.: "Modelling of Bifacial Gain for stand-alone and in-field installed

Bifacial PV Modules"; 6th International Conference on Silicon Photovoltaics, SiliconPV 2016

⁴ (private communication)

bifacial PV systems. This was verbally confirmed by several scientists during the latest “Workshop on Bifacial PV 2018”.

SAM

A different approach is used by the software product called SAM. Whereas PVSYST is a commercial software, SAM is continuously developed and optimized by the US National Renewable Energy Lab (NREL) and is available for download free-of charge. A detailed description of the model and the functionality of the software – as well as its limitations – is given in Nicolas DiOrio’s paper¹.

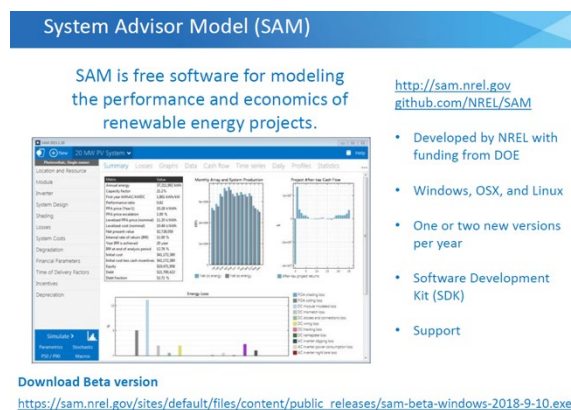


Figure 9: Overview of SAM²

SAM uses the Perez model for calculating irradiation and applies the so-called *view factor model* to calculate the irradiation on the module rear side.

The actual electrical characteristics of the PV module are calculated using the one-diode model which is a suitable approximation.

SAM can be used for yield studies for various bifacial system designs, including the following:

- Fixed-tilt or horizontal single-axis tracker
- Single or multiple rows of modules on one rack
- Different spacings between different racks (which may lead to partial shading)
- Different clearance heights of the modules above ground

NREL evaluated the differences between PVSyst V6.75 and SAM. The PVSyst forecasts are slightly higher than those from SAM. This agrees with statements from other industry specialists who have worked with both systems².

However, the discrepancy is only in the range of 1 % and is therefore likely due to small differences in the methods used in both tools; the credibility of each system is likely high. Neither tool can consider 2nd-order influence factors such as partial shading of the module rear side due to the racking structure or different irradiation conditions at the end of a racking table.

Some large US developers, such as Cyprus Creek Renewables, have studied such effects by means of more sophisticated software (e.g. PV-Lighthouse³). Such results may have scientific relevance and be useful for specific cases, however for most commercial system designs, a yield study using PVSYST or SAM should be sufficient.



For some period of time software was developed based on an initiative by SolarWorld. Details of the model and some simple approximations are described in another white paper⁴. However, due to the insolvency of SolarWorld this work stopped and the tool is no longer available.

Realistic Energy Gain for Commercial Bifacial Systems

There are many publications where energy gains with bifacial modules of more than 30 % are claimed. Be careful! A lot of these studies are from the early years of bifacial PV research and have been conducted under circumstances which are not realistic for commercial systems. Most concerning are reports related to measurements based on single modules. As mentioned earlier the surrounding of the module has a strong influence on the energy yield, and for a stand-alone module, this leads to unrealistically high illumination of the module rear side.

¹ Nicolas DiOrio et al.: *Bifacial Simulation in SAM; Workshop on Bifacial PV 2018 (Denver, USA)*

² Jenya Meydbray (private communication)

³ Jenya Meydbray: *Barriers to Financing Bifacial PV Projects; Workshop on Bifacial PV 2018 (Denver, USA)*

⁴ SOLARWORLD White Paper: “Calculating the Additional Energy Yield of Bifacial Solar Modules”

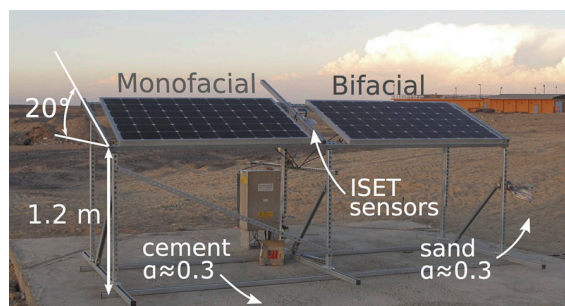


Figure 20: typical test setup which will NOT provide realistic field data for a comparison between mono-facial and bifacial energy yields¹.

It is also important to be skeptical about reports collected during a short period of time. Both weather as well as seasonality have a significant impact on the bifacial gain². If data is not collected over a full year, no valid statement can be made about the “bifacial gain” of a specific site and system configuration.

That said, there are many publications available that allow for reasonable estimations for commercial installations. There are many influencing factors and therefore the range of potential bifacial gain is wide. A good comprehensive overview can be found in Kopecek’s paper³.

Fixed-tilt installations

For fixed-tilt installation, it is important to separate rooftop systems from ground-mount systems because the installation level above ground plays a significant role. Due to roof load considerations, the installation height of the modules above the surface for rooftop systems is usually limited, which also limits the bifacial yield. Depending on the module tilt angle and the albedo radiation, an additional yield for rooftop systems of about 10 % can be expected – with 5% being conservative and 15 % being optimistic if there are performance enhancing conditions such as a white roofing membrane.

For large ground-mount systems with modules installed at a minimum 0.8 m (2.6') above ground,

real-world gains up to 30 % gain have been reported. This however requires truly optimized conditions such as white gravel to create a high-albedo surface under the modules. A gain of 10 % can usually be achieved with a limited amount of effort.

Tracking installations

The combination of bifacial modules with horizontal single-axis tracking (HSAT) has raised a lot of interest in the solar community. An interesting study on the comparison of two 100 kWp systems has been published by S. Ayala⁴. For a system which has not been optimized (i.e. racking beams along the rear side of the modules; ground with grass and an albedo of only 20 %), the measured bifacial gain was 7 %. This indicates a good lower limit of the gain which can be expected under sub-optimal conditions.

The combination of bifacial modules and HSAT offers the advantages of both technologies. As a rule of thumb, the expected gains are additive, enabling total energy gains in the range 20 %, while potentially reaching almost 45 % for optimized system designs.

Table 1: Range of realistic bifacial gains for commercial installations. Data have been extracted from multiple publications. The given ranges are wide because different factors influence the bifacial gain.

	Mono-facial	Bifacial
Fixed-tilt (rooftop)	100% (ref.)	105 – 115%
Fixed-tilt (ground)	100% (ref.)	107 – 130%
HSAT	110 – 122%	117 – 145%

Risks Associated with Bifacial Systems

The main risk for a bifacial PV system is that the expected energy gain is not achieved and the projected investment returns are not met. Lower-

¹ I. Shoukry et al.: “Modelling of Bifacial Gain for stand-alone and in-field installed Bifacial PV Modules”; Workshop on Bifacial PV 2016 (Chambery, France)

² L. Podlowski et al.: Yield Study on Identical Bifacial Rooftop Systems Installed in the USA and in Germany; Workshop on Bifacial PV 2017 (Konstanz, Germany)

³ R. Kopecek: “Bifacial World – History and Status”; Workshop on Bifacial PV 2017 (Konstanz, Germany)

⁴ S. Ayala et al.: “Single-Axis Tracked Bifacial System Results”; Workshop on Bifacial PV 2018 (Denver, USA)

than-predicted gains for any PV system (not specific to bifacial) are usually caused by the following:

- a technical malfunction of a particular component;
- the selected components do not work well together; and/or
- an over-optimistic yield forecast.

The same applies to bifacial systems, but an additional risk arises:

- the ground albedo has a lower value than predicted - either from the very beginning or the albedo reduces (more than expected) over time.

This “albedo risk” is fairly complex when studied in detail, as the albedo can vary throughout the day, seasonally and year to year¹. However, no software tool can realistically consider such effects. It is the design engineer’s responsibility to enter a reasonable average value for the albedo over time into the simulation tool. The selection of a reasonable albedo value remains the real art of bifacial energy gain modelling – along with practical work done to ensure and maintain albedo values in the field.

The risk of component failure for bifacial projects is in principal no higher than for any other PV project. So the incremental risks are that either the existing PV components do not work well with the bifacial module or the yield forecasts were not accurate.

Conceptually, the risks in a bifacial project are manageable in the same way as for a mono-facial project. A knowledgeable EPC company with informed, well-educated staff working bifacial PV systems should be selected, to ensure that:

- a reasonable short-list of potential PV modules can be suggested;
- a realistic yield forecast is provided (based on realistic assumptions for ground or surface albedo);
- a suitable racking and installation system is chosen; and
- the right inverter size is selected to match with the expected performance window of the system.

Unless the EPC has a proven track record for bifacial systems it is recommended that an expert technical advisor is hired to assist in evaluating and optimizing the system design and performance projections. As the industry installs more bifacial systems, more field data will also be available to validate performance predictions.

The important role of module factory audits in bifacial projects

Manufacturing of bifacial PV modules is similar to conventional mono-facial modules so the risk of procuring poor quality bifacial modules is in principle no different. However, there are a few specific manufacturing quality risks which should be considered when sourcing bifacial PV modules:

- The bifacial coefficient of the cell depends on the consistency and quality of the cell manufacturing process. An independent audit of the cell manufacturing process is therefore usually warranted.
- Bifacial modules are, in most cases, double glass modules. Production of double-glass modules requires some modifications compared to conventional single glass module production including extra care in the lamination processes. Lamination is a critical process for long-term reliability. The production line should be checked to ensure it is properly prepared to handle double glass modules.
- The additional energy gain depends on the efficiency of the module rear-side. Most manufacturers are still not providing proper and clear specifications (or guarantees) for rear-side module power, nor checking it regularly in their production processes. It must be understood how the manufacturer can assure a consistent rear side module power and how it is monitored in live production. Is a minimum bifacial coefficient defined in the power binning categories, for example?

¹ Ben Bourne: „Ground Albedo Field Measurements“; Workshop on Bifacial PV 2018 (Denver, USA)

- Special care must be taken to determine the front side power under standard test conditions (STC). Any light reaching, or coming through from the rear-side of the module, during front side power testing will lead to an additional current and an over-estimated power. The flash testing portion of the production line requires special attention to exactly how the front- and rear-side power of the module is tested and calibrated.
- For frameless modules the packaging is a more sensitive consideration than for conventional framed modules. The packaging method needs to be checked and tested according to appropriate transportation standards. Consideration also needs to be given to the fact that additional packaging may be needed which will generate more packaging waste on site that needs to be managed.

Conclusion

Using bifacial PV modules is rapidly becoming one of the easiest and most inexpensive ways to further enhance the energy yield of PV systems. Even with no special attention to system design, gains in the range of 4 to 5% (for rooftops) and 7 to 10% (for ground-mount) can be expected. With some attention to details - e.g. module row spacing, tilt angles, level above ground and racking design, an energy gain of 12 to 20% can be achieved in fixed-tilt ground-mount systems (depending mostly on the ground albedo). Gains higher than this are possible but require expert system design and close attention to the ground or surface material. A high reflectivity should be maintained over the economic lifetime of the system. Combining bifacial modules with horizontal single axis tracking has the advantage of combining the performance gains of both technologies, enabling energy gains in the range of 20 to 45%.

For bifacial modules it is important to conduct audits of the cell and module factories before accepting the modules in order to ensure the modules will fundamentally deliver the basic bifacial gains that are promised and expected.

In summary, the risks with bifacial PV systems are not significantly higher than for standard systems

but do need to be considered carefully. The potential benefits can be realized when proper attention has been paid as outlined in this paper.

About the Author



Dr. Lars Podlowski is an executive board member of PI Photovoltaik-Institut Berlin AG and *Director Global Technical Services*. In his previous roles as a technical executive at various solar manufacturers he has worked on bifacial PV technology since 2006.

Lars began working in the PV industry in 1996 when he started his first PV module manufacturing enterprise. Since then he has become a technical specialist in PV modules and manufacturing.

Lars holds a PhD in semiconductor physics from the Technical University Berlin, and is co-author of various publications and PV-related patents and patent applications.

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Contact

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