Bifacial PV: comparing apples with apples sometimes does not make sense

Bifacial | Bifaciality is a complex area of PV technology and currently there is some confusion over what bifacial gains can be expected and how these transfer to system cost reductions. Radovan Kopecek and Joris Libal describe how bifacial gains are defined, what bifacial gains can be expected and what this means for real applications

Bifacial systems offer a very promising possibility to reduce the levelised cost of energy (LCOE) for many PV system applications. There is a huge application field for this new upcoming technology – such as large ground-mounted systems, flat reflective rooftops, sound blocking systems, floating systems or even in utility-scale systems using trackers. The last application is very interesting, these days achieving the lowest LCOE for many cases. The lowest bid ever for a PV system was announced recently in Saudi Arabia, offered by EDF and Masdar for first time below US$0.02/kWh and most likely using bifacial technology in conjunction with trackers [1].

Not only are there many potential application fields, there are also various mounting geometry possibilities: from standard slanted systems, to horizontal to even vertical bifacial installations with almost zero ground coverage. Three prominent examples are depicted in Figure 1.

Definition of bifacial gain

An obvious way to visualise the benefits of bifaciality is to analyse the "bifacial gain", which means the difference in the energy yield if bifacial and monofacial devices with identical installation configurations are compared. The comparison can either include single modules or larger units of one or both device types, because typically the energy yield in kWh/kWp ratio is analysed. The kWp data usually reflects the STC front-side measurement of the bifacial module(s). In the most direct form, devices of similar type and with the same front-side efficiency are compared, for example if bifacial modules with covered rear sides are used as reference.

The bifacial gain is usually defined as:

$$g_{bifacial}\ [\%] = \left(\frac{(e_{bifacial} - e_{monofacial})}{e_{monofacial}}\right) \times 100$$

With

- $e_{bifacial}$: specific energy yield (kWh/kWp) of the PV system with bifacial modules
- $e_{monofacial}$: specific energy yield (kWh/kWp) of the PV system with monofacial modules on the same site, with the same configuration and during the same time period.

As the bifacial gain is another way to indicate the energy yield, it is the metric that determines – together with the total cost of installing and operating the bifacial PV system – the LCOE (€/kWh) and therefore the economic viability of bifacial PV.

The above mathematical definition of bifacial gain is quite simple – however there are different possibilities in terms of what module type can be chosen for the monofacial reference. Therefore sometimes the reported bifacial gains already differ there – even if at a first glance identical conditions are applied. Figure 2 depicts in (a) the bifacial module and three different monofacial references (b) to (d) which are very often used.

Many groups use standard white backsheet modules with monofacial cells for reference (Figure 2 (d)), some use monofacial white backsheet modules

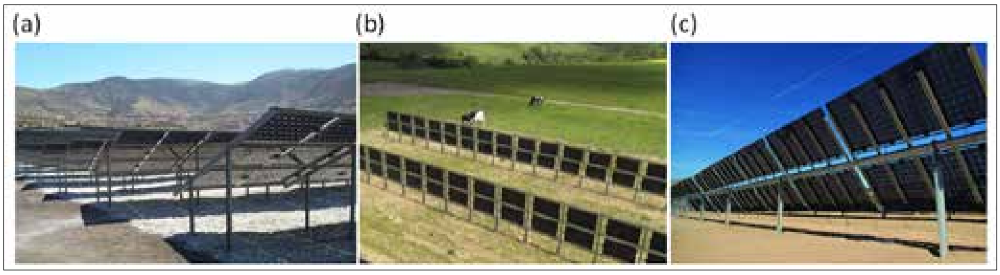

Figure 1. (a) La Hormiga fixed tilt bifacial PV plant in St Felipe, Chile (b): vertical bifacial PV plant by Next2sun in Germany and (c) a tracked bifacial PV plant in La Silla, Chile

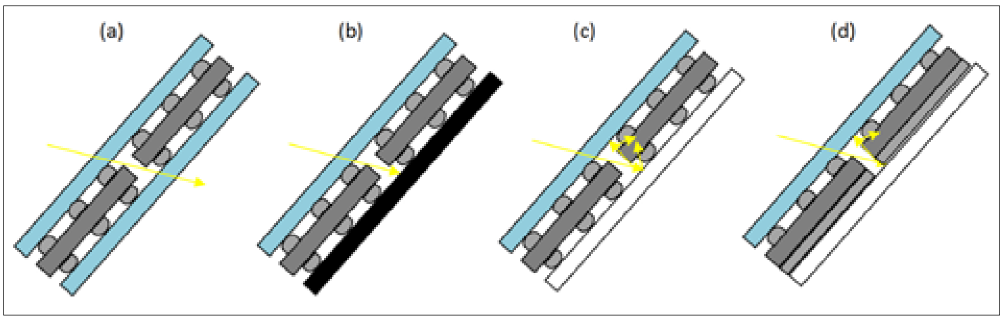

Figure 2. Schematic cross section of a (a) bifacial module and three possible monofacial reference modules with (b) bifacial cells and black backsheet, (c) bifacial cells and white backsheet and (d) monofacial cells and white backsheet

with the same bifacial cells (Figure 2 (c)) and some monofacial black backsheet modules with the same bifacial cells (Figure 2 (b)). All three references will lead to different results, as the white backsheet is causing additional reflection of the front-incoming light into the solar cells. Even if the monofacial solar cell has similar properties as the bifacial (e.g. front-side power, voltage and temperature coefficient) the front side power of the module is increased by ca. 2% at STC (standard test conditions: 25°C, 1,000 W/m^2, AM 1.5 spectra) because of the additional reflection of light to the front side and during field measurements the energy harvest is increased more. An increased level of power can also be seen in the case of the bifacial cell and white backsheet: the total additional energy yield (kWh/kWp), also due to the scattering of the light into the solar cell rear side, can be up to 5%, as observed, for example, in LG NeON modules.

Therefore: if you want to observe bifacial gain only, as a reference the same bifacial cell in a module with a black rear cover or black backsheet is required.

This comparison reveals precisely what additional energy is provided by the rear side only. If you take for example a monofacial module with a bifacial solar cell and white backsheet as a reference, you will underestimate the bifacial gain by ca. 5%, as the rear side is already contributing in field measurements. Therefore the choice of different references leads already to different results reported in various publications.

Another important point is that the temperature coefficient of the monofacial reference module should be in the same range as for the bifacial ones. Otherwise, for example when comparing bifacial heterojunction modules (temperature coefficient for Pmpp around 0.30%/°C) with standard monofacial aluminium back surface field (Al-BSF) c-Si modules (temp coeff around 0.45%/°C), a significant part of the gain attributed to bifaciality will be due to the reduced temperature losses of the HJT module. Here, as a reference, the same HJT module with a black back cover would be the best choice leading to an "apple to apple" comparison.

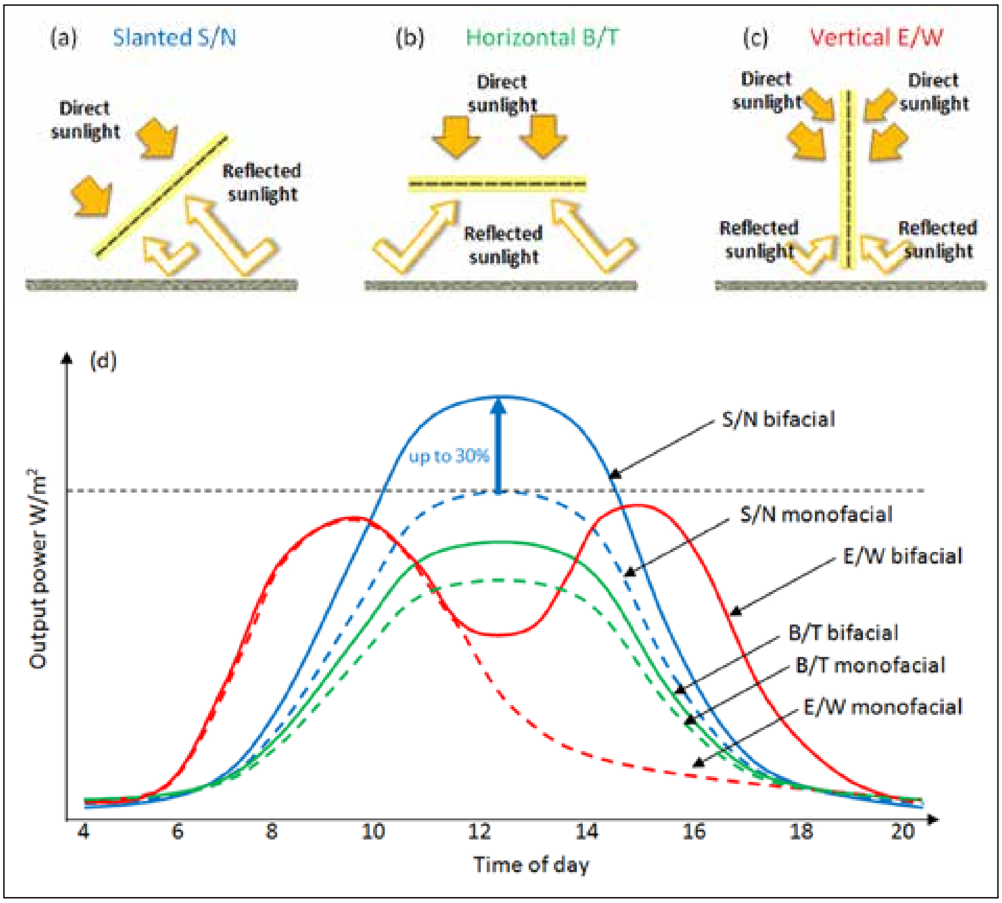

Figure 3. (a)-(c) Possible applications for bifacial modules and (d) resulting daily power generation curves compared to monofacial ones in the same configuration.

Examples of bifacial gains: comparison of apples with apples

Not only the choice of different references, but also different mounting geometries will lead to different bifacial gains – and as we will show, these can be even more than 100% in some cases. Figure 3 depicts different mounting geometries: (a) slanted S/N (south/north) oriented mounting, (b) horizontal B/T (bottom/top) and (c) vertical E/W (east/west) oriented mounting.

The slanted S/N-oriented mounting leads to the highest powers of the applied bifacial modules as the front side produces the highest possible power and the rear, depending on the albedo of the ground, can contribute up to 30% additional electricity. Here, a 300Wp module can behave as a module with an effective power of close to 400Wpe ('peak efficiency'). This relationship can be seen in Figure 3 (d) between the dotted and solid blue curve.

Horizontal B/T-oriented installations, used in car ports, for example, demonstrate very similar behaviour, only that the absolute energy production is reduced, as the module is – apart for sites located nearby the equator – not oriented at an optimal angle towards the sun. The monofacial and bifacial generation curve is demonstrated by the green dotted and solid lines respectively. The shape for all installations so far discussed is very similar, having a peak intensity around noon.

A completely different form (camel and dromedary curve) is generated by a vertical E/W-oriented installation. When you install a bifacial module with a high bifacial factor (b: rear power/front power >0.9, for example an nPERT BiSoN (Bifacial Solar Cells on N-type) or "HJT module" from Sunpreme) you end up with the solid red line. Much more electricity is generated during morning and evening as compared with the S/N-oriented case. During midday there is a generation dip, as the direct sunlight is shining on the frame and only diffuse light is hitting the module front and rear side. However, due to the ground coverage ratio close to zero and due to the broader generation peak this installation geometry is very interesting. Now: if you install a monofacial module in such a mounting geometry the generation peak moves to a dromedary-like (red dotted line) shape with generation energy less than 50% compared to the bifacial one. Here the bifacial gain is therefore higher than 100%. However such a comparison does not make much sense as installing a monofacial module vertically with an E/W orientation is highly improbable. In this case the vertical bifacial modules have to be compared with a slanted monofacial equator-oriented module. Depending on the installation latitude the bifacial gain can be even negative – in this case, if modules are installed vertically in sun-belt regions. However this might make also sense in some cases, if the soiling can be reduced by the vertical installation.

Table I summarises several examples of various installation geometries and resulting 'bifacial gains' for BiSoN nPERT modules. Because in the large bifacial systems in Chile standard monofacial modules with white backsheet are used as a reference by developers MegaCell and Enel, the real physical bifacial gains would differ from there slightly.

In the case of the fixed-tilt S/N module system there are already many cases reported all around the world with different albedi. Depending on the ground albedi (25% for natural sand and 75% for white stones) bifacial gains from 15-30% can be achieved.

When it comes to vertical E/W systems things become more complex and also not so many reference systems exist. In these cases, not only are the module type and albedo of importance but so are the mounting geometry of the reference module and the installation latitude. If you compare with a vertical installed monofacial module, a bifacial gain of more than 100% can be observed. This comparison makes only little sense – here a comparison with a slanted equator-oriented monofacial module is more interesting as well. If you install such systems at high latitudes, where the amount of diffuse sunlight is higher and where the vertical mounting is less far away from the optimum slanted angle, an electrical gain of 10% is observable – however at low latitudes even an electrical loss of -5% was observed. Still this application remains interesting because of several reasons: the ground coverage is close to zero, the generation peak is broader and vertical installations have less soiling problems. However also some challenges have to be solved as the wind loads are high using this mounting configuration.

Within the last few months bifacial systems using single-axis tracking have gained more and more attention, as experimental results in large systems showed that the bifacial gain in those cases is also very high. This is because many tracking mounting systems are almost ideal for bifacial modules as they are mounted high from the ground with high row spacing. Therefore the bifacial gains – in this case, the gains compared to monofacial single-axis tracking – are very similar as for the fixed-tilt systems. The first one to report this behaviour was Enel in la Silla [7].

A combination of single-axis tracking with bifacial modules in systems with high albedo result in electrical gains of over 40% compared to fixed-tilt monofacial modules [8].

More and more large companies have realised this incredible increase and the companies building single-axis trackers are optimising their systems for bifaciality.

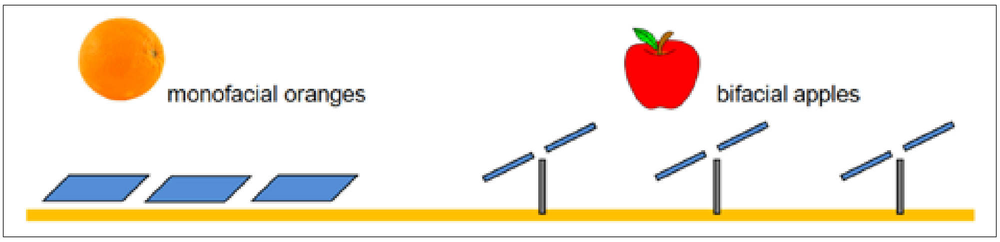

Figure 4. Schematic drawing of (a) a monofacial S/N oriented system and (b) an E/W-oriented bifacial single-axis tracked system

Bifacial module	Bifacial installation geometry and latitude	Installation geometry of monofacial reference	Albedo	"Bifacial gain" (rounded to 5% steps)
nPERT, BiSoN (b>0.9)	Slanted fixed tilt in San Felipe, Chile (32° south)	Slanted fixed tilt	25%	15% [2]
nPERT, BiSoN (b>0.9)	Slanted fixed tilt in San Felipe, Chile (32° south)	Slanted fixed tilt	65-75%	30% [2]
nPERT (b>0.9)	Vertical installation, USA	Vertical installation	Unknown	100+% [3]
nPERT, BiSoN (b>0.9)	Vertical installation in Winterthur, Switzerland (47° north)	Slanted fixed tilt	25%	10% [4]
nPERT (b>0.9)	Vertical installation in Saar, Germany (49° north)	Slanted fixed tilt	25%	10% [5]
nPERT, BiSoN (b>0.9)	Vertical installation in el Gouna, Egypt (27° north)	Slanted fixed tilt	25%	-5% [6]
nPERT, BiSoN (b>0.9)	Single-axis tracked in La Silla, Chile (29° south)	Single-axis tracked	25%	15% [7]

Table 1. Bifacial gains for nPERT modules (mostly BiSoN) with various installation geometries

Bifacial applications in reality: comparison of apples with oranges

We have learned that bifacial gains, as they are defined, can reach values of more than 100%. However, this information is not very practical for system designers. The only interesting question for them is: how can a PV system with the lowest LCOEs be designed? Then the best possible monofacial installation has to be compared with the best bifacial one, as depicted, for example, in Figure 4.

Many PV system designers are using PVsyst for this purpose which is a simulation software generating bankable results. With all the necessary import parameters such as module properties, system geometry and data for specific local conditions, the energy output can be calculated which at the end leads to values for LCOE. PVsyst is also since September 2017 capable of running reliable bifacial simulations – however for systems with fixed-tilt mounting only. At ISC Konstanz we have developed a simulation program (MoBiDiG: Modeling of Bifacial Distributed Gain) which is capable of conducting reliable simulations for bifacial tracked systems

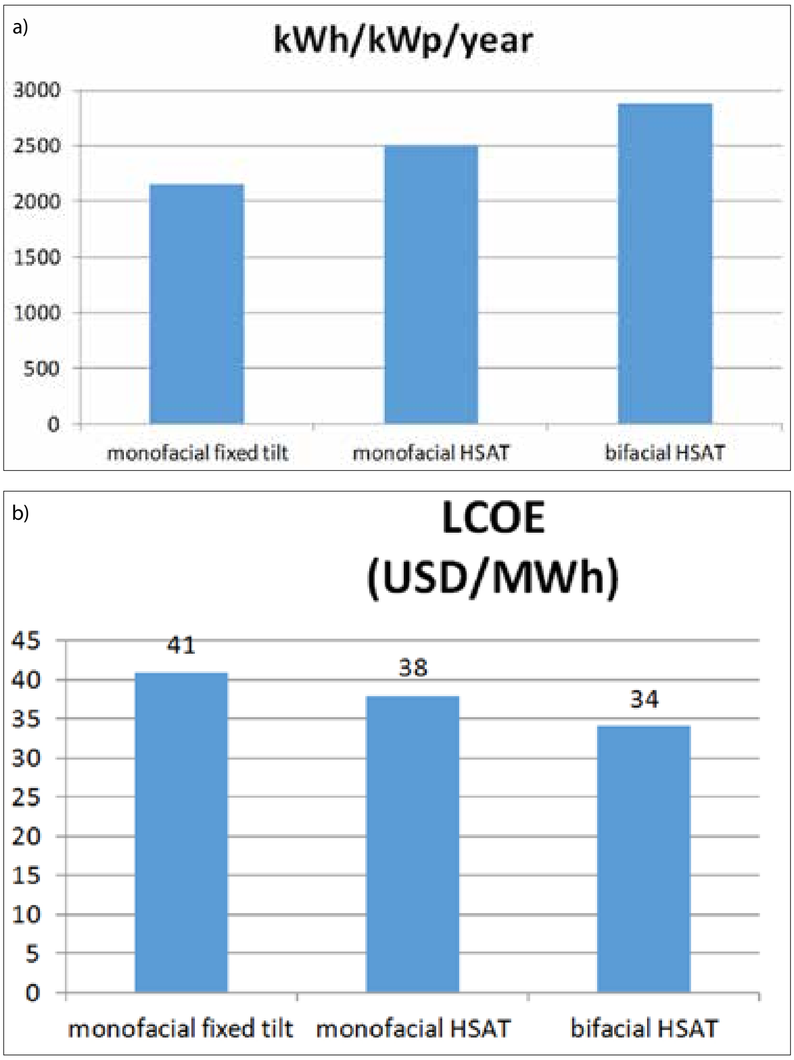

Figure 5. Examples of a) calculated energy yield and b) resulting LCOE for different module and system technologies when installed in Chile (assumption for monofacial installed fixed-tilt system cost: US$0.92/Wp and US$1.00/Wp for monofacial and bifacial horizontal single-axis tracker) with a ground albedo of 25%. In this case the tracking gain (monofacial horizontal axis tracking compared with monofacial fixed tilt) is 17%. Using bifacial instead of monofacial modules on the HSAT system results in an additional 14.7% (rel.) gain, leading to a combined gain (tracking + HSAT) of 34%

as well. Figure 5 depicts the result of three different systems at the same location in Chile.

Summary

Bifacial gains show how bifacial modules increase the electrical performance of a system when bifacial modules instead of reference monofacial modules are mounted. Depending on the choice of reference modules these values can differ by more than 5% (rel.), even when choosing the same installation configuration for the bifacial and the monofacial system. If you want to know the real bifacial gain – the additional power that the rear side is generating – then the easiest way is to use the bifacial module covered by a black sheet for reference. Bifacial gains are also dependent on module bifacial factor, b. Bifacial PERC modules at the moment have b<80%, nPERT and HJT b>90%. Therefore it has to be also stated which modules with which b were used in corresponding modelling or experiment.

In special configurations, bifacial gains of more than 100% can be measured, when e.g. bifacial vertical installations are compared with monofacial vertical installations. However in practice, for the optimal design of PV systems, it makes only sense to compare the energy output for an optimised monofacial versus an optimised bifacial system and at the end compare the resulting LCOEs. The meaning of "optimised" can be influenced by restrictions imposed by the specific application and by the available installation site.

In the bifacial area more standards and more advanced simulations programs are needed. Therefore we organise yearly bifacial workshops where the newest results are presented - this year 10-11 September in Denver, Colorado. Details on BifiPV2018 are at www.bifiPV-workshop.com ■

Authors

Dr. Radovan Kopecek is one of the founders of ISC Konstanz. He has been working at the institute as a full-time manager and researcher since January 2007 and is currently the leader of the advanced solar cells department. Dr. Kopecek received his M.S. from Portland State University, USA, in 1995, followed by his diploma in physics from the University of Stuttgart in 1998. The dissertation topic for his Ph.D., which he completed in 2002 in Konstanz, was thin-film silicon solar cells.

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