Tackling inconsistencies in bifacial PV technology

Bifacial technology | A comprehensive understanding of the global performance and extra gain offered by a bifacial module remains an elusive goal for PV owners and EPCs due to variations arising from different design, manufacturing and testing methods. Vicente Parra, Ruperto J. Gómez, José C. Vázquez and Francisco Álvarez of Enertis review the main sources of variability and outstanding uncertainties that must be addressed as the industry seeks to define standard rules for reliably selecting, purchasing and deploying bifacial PV modules

Credit: Enertis

Nowadays, considering bifacial modules as a first option for a new solar plant is becoming mainstream in the PV market, thanks to their rapidly growing trend as a standard PV device worldwide.

In September 2018, the 9th edition of the International Technology Roadmap for Photovoltaic (ITRPV) report forecasted a market share for bifacial cells close to 15% by 2020 [1]. In fact, bifacial module deliveries exceeded 25% in 2019 and are expected to reach 40% this year and 60% in 2021, with no indications of a market slowdown in the short term.

Not long ago, the idea of using higher performance, double-faced PV modules was still considered a sort of double edge-sword versus the traditional monofacial-based PV technology. The main reasons behind this were its higher price and the somewhat limited project bankability, due to the additional uncertainties to deal with, subsequently guaranteeing the theoretical energy gain from the modelling of many new site and PV system variables [2, 3].

Notwithstanding this, it was implicitly understood – and, today, better modelled – that increased energy yield per module area was beneficial. The development was also favoured by the rapidly narrowing price gap versus traditional monofacial devices (basically the same, as of today), eventually leading to a remarkably minimised levelised cost of electricity (LCOE), as the key economic metric of a solar PV plant [4]. However, despite the fact that optimisation of the front side power output of a solar panel will prevail as a key factor to consider in a project development, the race for a comprehensive understanding of the performance gain offered by the back side of a bifacial module continues to be a test for any PV asset owner and EPC player. Therefore, a close and multidisciplinary cooperation framework with PV equipment manufacturers, technical advisors, modelling software developers, etc. is needed to rise to the challenge.

Testing and factory inspections are key measures in controlling the uncertainties and variabilities in bifacial PV technology

Even so, these uncertainties associated with the design of a bifacial PV system in turn take for granted that the

Tier-1 Supplier	Nameplate Power/W	Cell type	BOM's key parameters
A	380/385	Half-cell 9BB	POE/Dual glass 2.5mm, transparent rear side glass. Wire cell connector Φ 0.35 mm Aluminium frame 30x28 mm[a]
B	400/405	Half-cell 9BB	POE and EVA+POE/Dual glass 2.0mm white ceramic glaze on rear side glass Wire cell connector Φ 0.35mm Aluminium frame 30x35 mm
C	370/375	Full cell 5BB/12BB	POE/Dual glass 2.5 mm white ceramic glaze on rear side glass. Cell connector 0.23x1 mm (5BB) and wire Φ 0.40mm (12BB) Aluminium frame 30x28 mm
D	400	Half-cell 9BB	POE/Dual glass 2.0 mm white ceramic glaze on rear side glass Wire cell connector Φ 0.35mm Aluminium frame 30x28mm
E	370/375	Full cell 5BB	POE/dual glass 2.5mm, white ceramic glaze on rear side glass Cell connector 0.25x0.9mm Frameless

Table 1. Manufacturing cases, suppliers, PV modules and related features cited in the present article; [a] *BxC* sides (C: coplanar to glass substrate, potentially leading to cell shading)

bifacial module's datasheet and international standards are perfectly determined, understood and experimentally validated when facing the purchase of thousands of panels for a utility-scale PV project; nothing could be further from the truth as of yet.

Therefore, and specifically concerning the design and power performance of a bifacial PV module, this article reviews some of the main sources of variability and outstanding uncertainties that need to be addressed by the industry to grasp and define a series of standard rules for a reliable selection, purchase and use of bifacial panels in high-performance PV projects, as a new technological paradigm in the solar market worldwide.

For this purpose, examples of real cases devoted to the advisory, manufacturing inspection and testing activities performed in the last year by Enertis in several Asia-based module factories are reviewed (Table 1). All of them refer to bifacial modules' manufacturing for large-scale projects worldwide, which in turn were dictated by specific Module Supply Agreements (MSA), designs and Bill of Materials features, many of which are barely known in detail by the buyers prior to and even after production completion. It is here that the role of independent third-party inspectors as Enertis monitoring the processes is key.

The present article will cover four key subjects, as follows:

- Lack of international standards adopted by the industry;
- Inhomogeneous bifaciality values, within and amongst manufacturers;
- Effect of module design and Bill of Materials (BOM) on bifaciality;
- Front versus rear-side performance asymmetries.

To conclude, a quick overview vis-à-vis the influence of bifaciality on the PV plant's economics will be reported, so that the interest in controlling the bifacial properties of the modules at the early stages of development of a PV project is highlighted.

As a matter of fact, guaranteeing the bifacial values during the production of hundreds of thousands of PV modules for a large-scale plant is certainly not a straightforward task. Thus, this article is not a criticism of the activities currently performed by the module manufacturing industry, but a review of the actual picture that a module purchaser should consider when dealing with bifacial devices.

Lack of standardisation

The purchase of a bifacial PV module is currently equivalent to that of monofacial. In a bifacial module, despite the inherent two active faces, the purchased power output is delimited by the front side, which is suitably stated in the corresponding nameplate label. Nonetheless, flashing the front side of a bifacial module with the solar simulator setup typically used for monofacial technology leads to potential imprecisions in the panel's maximum power values (*Pmax*), owing to the residual light absorption by the rear side during the measuring process.

Also, a quick review of the commercial datasheets available in the market evidences that the definition of the extra power gain coming from the rear side is somewhat conservative and imprecise, hitherto based on diverse concepts such as 'integrated power', 'synthetic power' or just 'bifacial gain', depending on the supplier. The bifacial performance is basically defined by a series of simplistic power additions (5%, 10%, 20%, etc.) to the front-side, Standard Test Conditions (STC) Pmax value, including general disclaimers regarding the dependency on the eventual site conditions. A similar situation occurs with the PV performance files characterising the module, e.g. the acquainted, but usually not experimentally validated .pan files used by PVSyst modelling software, despite its direct influence on energy yield and derived financial metrics. In terms of warranties, tentative attempts related to bifacial performance are currently being proposed, even though there is still work to be done in this sense as well.

Therefore, the implementation of internationally accepted standards ruling the reliable and accurate description and determination of both power output and bifacial performance of a PV module now becomes a requirement.

In early 2019, the *IEC TS 60904-1-2:2019 - Photovoltaic devices - Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices* draft document was launched [5], as a first official trial to describe the best practices and protocols to measure the current-voltage (I-V) characteristics of bifacial photovoltaic cells and modules, using either natural or simulated sunlight. Unfortunately, to date, this technical specification (TS) still seems far from being adopted as a mainstream guideline by, principally, module manufacturers. This means that PV modules are not being rated in a consistent and standardised manner.

In short, this IEC guideline addresses the two main aspects indicated previously or namely i) the use of well-controlled and consistent flash testing setup and measurement procedures and ii) the determination of a series of parameters characterising the bifacial properties of a PV module, such as the so-called $Pmax_{bifi100}$ and $Pmax_{bifi200}$, which stand for the Pmax values at rear side irradiances of 100W/m^2 and 200W/m^2, respectively, based on module's bifaciality or bifacial coefficient (expressed, for Pmax, as $\varphi_{Pmax} = Pmax_{rear}/Pmax_{front}$). This document also introduces concepts such as equivalent irradiance (G_E) and BIFI coefficient, this one based on Wp/Wm^{-2} units, being quite conveni-

Supplier	Sun simulator	Pulse length	Calibration method	Calibration frequency	Control of rear-side irradiance during flash	Rear-side measurement frequency	Rear-side calibrated values	Pmax Bifacial Coefficient (inline)
A	Tower simulator/ Xenon lamp	10ms	**Isc and Pmax** Front side reference values @ STC for both front and rear side maximum power	Every 2h	[a]DL: 5.95m [b]GD: 1m [c]Full dark conditions: No Baffles: No. [d]Non-reflective back material: Yes	10 pcs/day	No	[e]73.15 ± 1.23 *(75.64, 68.26)* *N = 1,000*
B	[f]**Wks 1** Flatbed Simulator/LED Flatbed Simulator/Xenon lamp	**Wks 1** 100ms 100ms	**Pmax** Front and rear side reference values @ STC for front and rear side maximum power respectively.	**Wks 1** Every 6h Every 4h	**Wks 1** DL: 50 cm GD: N/A. Full dark conditions: No Baffles: No. Non-reflective back material: No	0.5% of daily Wks production (minimum 10 pcs/day).	Yes	67.11 ± 1.24 *(70.50, 65.02)* *N = 1,120*
	Wks 2 Tower simulator/ Xenon lamp	**Wks 2** 10ms		**Wks 2** Every 6h	**Wks 2** DL: 5.80m D: 1m Testing area is covered simulating a dark room. Full dark conditions: No Baffles: No. Non-reflective back material: No			
C	Flatbed simulator/Xenon lamp	10ms	**Pmax** Front side reference values @ STC for both front and rear side maximum power	Every 2h	DL: 50cm GD: N/A. Full dark conditions: No Baffles: No. Non-reflective back material: No	10 pcs/day	No	76.40 ± 2.52 *(82.41, 71.07)* *N = 110*
	Tower simulator/ Xenon lamp	100ms			**Wks 2** DL: 5.50m GD: 1m D: 1m Full dark conditions: No Baffles: No. Non-reflective back material: No			
D	**Wks 1** Tower simulator/ Xenon lamp	**Wks 1** 50ms	**Isc** Front side reference values @ STC for both front and rear side maximum power	Every 4h	DL: 5.95m GD: 1m Full dark conditions: No Baffles: No. Non-reflective back material: Yes	10 pcs/day	No	71.59 ± 1.33 *(77.29, 70.00)* *N = 155*
	Wks 2 Tower simulator/ Xenon lamp	**Wks 2** 50ms						
E	**Wks 1** Tower simulator/ Xenon lamp	10ms	**Isc and Pmax** Front side reference values @ STC for both front and rear side maximum power	Every 2h	DL: 5.50m GD: 0.97m Full dark conditions: No Baffles: No. Non-reflective back material: Yes	3 pcs/4h	No	71.54 ± 0.91 *(74.82, 68.43)* *N = 4,120*
	Wks 2 Tower simulator/ Xenon lamp							

[a] DL: Distance between module and light source; [b] GD: Ground-to-rear side distance; [c] in general, testing area was covered by curtains simulating a dark room. Still, open areas or windows to allow staff operation were evidenced; [d] If included, it did not comply with IEC TS 60904-1-2 recommendations; [e] Mean ± Std. Dev. (maximum value; minimum value), N: number of samples; [f] Wks: Production Workshop

Table 2. Experimental variables regarding flash test setups and protocols used by the suppliers herein reported, including Pmax bifacial coefficients

ent to correlate bifacial extra power with rear irradiance conditions. The $Pmax_{bifi100}$/ $Pmax_{bifi200}$ parameters could be included in a module's datasheet, as a prelude for the implementation of a standard bifacial power value ($Pmax_{bifi\text{-}STC}$). In this way, the acknowledged game rules historically used for monofacial panels could also be applied to bifacial.

As empirical proof of this, quite a few aspects revealing a lack of standardisation and subsequent heterogeneity when performing flash tests during inline manufacturing were noticed (Table 2), from daily inspection works conducted by Enertis in the workshops. As a result of it, and despite the equivalent datasheet's bifacial coefficients declared by the suppliers, significant differences were found in the average Pmax bifacial coefficients recorded during inline production (e.g. six points variation between Supplier A and B). Further comments to this outcome will be mentioned in sections below. Besides, unlike the 100% measurement of front side Pmax values performed in the workshops, those from the rear are limited to just a few units per production day.

For instance, the use of optical baffles around the module sample, plus non-reflective surfaces behind the module are highly recommended [5] to limit the rear side irradiance absorption during the flash tests, as it is also proposed in the abovementioned IEC specification. However, there was no clear harmony among suppliers in this regard, exemplified by the use of different solar simulator systems and setups, such as LED-based flatbed or Xenon lamp-based tower simulators, even by the same supplier in different workshops. Likewise, divergencies related to a flash tester's calibration procedure were found, namely the use of Isc, Pmax or both Isc and Pmax values of the reference modules to set the correct parameters of the solar simulator for the inline Pmax module rating. Also, there was a tendency to consider front's side I-V values during flash testing calibration to determine the rear side Pmax values, and thus bifaciality, introducing additional uncertainties in the measurement. In this sense, internal studies showed a ca. 1% absolute overestimation of Pmax bifaciality could be observed when testing rear side Pmax using rear side calibrated values, instead of front side parameters for both front and rear values.

It has been also reported that high-efficiency PV modules, such as bifacial ones, may have a significant internal capacitance, resulting in I-V measurement artefacts due to transient effects when measured with short pulse durations using common pulsed flash testers [7], leading to inaccurate output power values. Also, as indicated in Table 2, no uniformity among suppliers was found, not even within workshops from a same brand, in some cases.

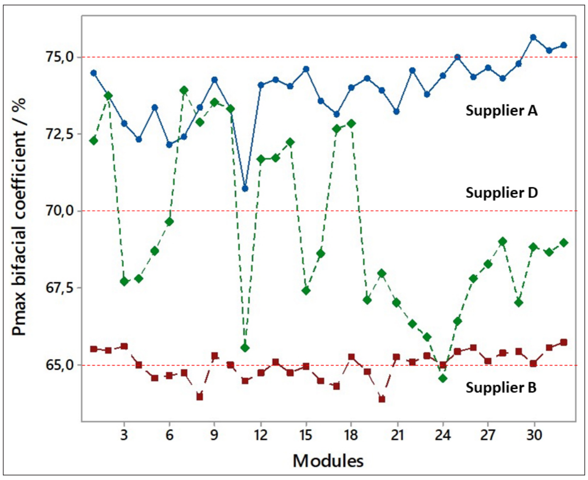

Figure 1. Pmax bifaciality values registered by Enertis laboratory from random samples taken during manufacturing of the first batch of modules. The dashed lines represent bifaciality thresholds from the 70±5% market standard

In summary, all these inconsistencies involve further sources of uncertainty, potentially leading to non-negligible power rating deviations from basic metrology issues reasonably easy to standardize and control during inline processing. In this regard, special care will need to be taken with the incoming era of large size, high performing solar panels [8], expected to beat the barrier of 600W shortly.

Regarding the quality and reliability of bifacial panels, it is not usual that a purchaser receives commercial proposals including extended certification tests for bifacial modules. These devices have higher current values outdoors, on account of the extra rear irradiance gain onsite. Therefore, BOM certifications should be adjusted to this new experimental reality. For instance, the common IEC 61215-based bypass diode and thermal cycling tests should now be performed at no less than 20% additional maximum currents versus a module's datasheet short circuit values.

Bifacial inhomogeneity during inline production. Module design and BOM

The bifaciality of an e.g. 144-half-cells, >2.0m² area PV module is a macroscopic variable difficult to be set in a fully consistent and replicable way even by the most sophisticated module manufacturer today. Proof of this is the declared, somewhat tolerant, industry standard in this regard: 70±5% bifacial coefficient. Consequently, up to 10 points' variation is virtually accepted by the PV market at present.

So, in this section, the patent non-uniformity of bifacial properties of the modules witnessed by Enertis during in-factory inspection activities for different large-scale module supplies, is reported.

As plotted in Figure 1, and, again, despite the use of equivalent datasheet bifacial coefficients, Enertis laboratory data revealed noticeable differences amongst manufacturers, in terms of absolute Pmax bifaciality (e.g. Supplier A vs. Supplier B) and large fluctuations during production, as occurred with the first production batches of Supplier D, with more than eight points deviation in several samples.

In case of Supplier B, several values below the minimum accepted 65% threshold were also reported. This was considered a major non-conformity, and so an investigation process was triggered, aiming at improving this low bifaciality value in real time during production, without incurring delays with deliveries. For this purpose, several BOM/design features were analysed: module frame, ceramic glazed glass pattern and the solar cells, particularly their metallisation grid.

Regarding the impact of a module's frame, Table 3 collects I-V flash data for the same module serial number, with and without frame. In the framed module, the rear side's current values were markedly influenced by shading effects, resulting in more than 7% lower rear side power output and then a ca. five-point loss of bifaciality. This outcome should not lead per se to conclusions about the preference of bifacial frameless modules, but to understand the effect of frame dimensions – especially the C side – on the rear-side performance. In this case, the 30x35 mm aluminium frame could not

	Front side						Rear side						
PV Module	**Pmax/ Wp**	**Voc/V**	**Isc/A**	**Vmpp/V**	**Impp/A**	**FF/%**	**Pmax/ Wp**	**Voc/V**	**Isc/A**	**Vmpp/V**	**Impp/A**	**FF/%**	**Bifacial coefficient (%)**
Frameless	406.62	48.98	10.49	40.49	10.04	79.13	285.29	48.29	7.24	41.11	6.94	81.64	70.16
Framed	406.18	48.99	10.43	40.63	9.99	79.51	264.71	48.44	6.94	42.28	6.26	78.76	65.17

Table 3. Effect of frame on the bifacial I-V flash characteristics for a same PV module

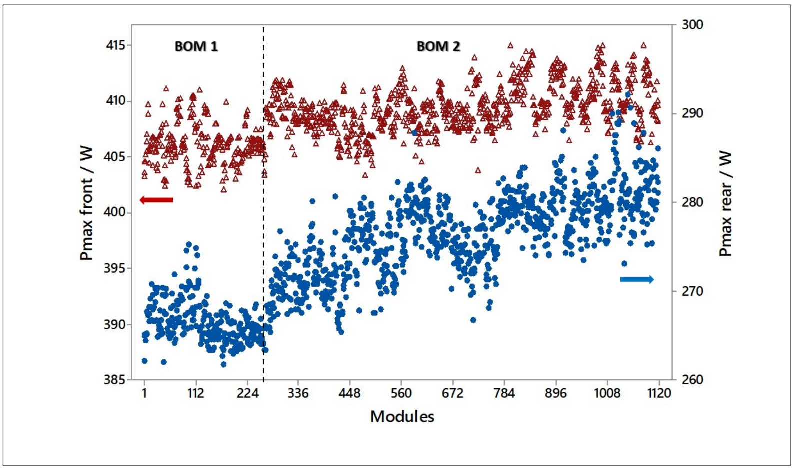

Figure 2. Pmax bifacial coefficients registered during inline production by Supplier B (400/405W modules are random and equivalently plotted). The dashed lines represent change of module's BOM/design, leading to bifaciality and frontal Pmax enhancement

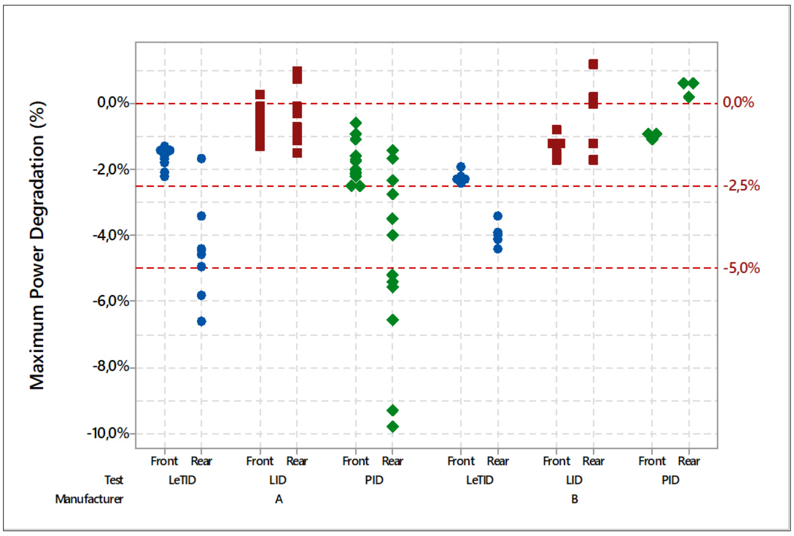

Figure 3. Pmax degradation results of modules' front and rear sides after LeTID (168h, 75° at Isc-Impp current injection), LID (outdoor, 25KWh/m² at Impp conditions) and PID (-1,500V, 85%RH, 85°C) controlled stresses for Supplier A and B

Location	Bifaciality (%)	Yield (MWh/MWp)	Bifacial gain (%)	LCOE (%)
Chile, North (Albedo: 0.30) 150MWp	Monofacial	*3.058*	N/A	N/A
	65	*3.154*	*+3.15*	*-2.54*
	70	*3.160*	*+3.36*	*-2.78*
	75	*3.167*	*+3.56*	*-3.02*
USA, Arizona (Albedo: 0.30) 150 MWp	Monofacial	*2.375*	N/A	N/A
	65	*2.487*	*+4.73*	*-3.43*
	70	*2.496*	*+5.10*	*-3.76*
	75	*2.504*	*+5.46*	*-4.09*
Spain, South (Albedo: 0.20) 150MWp	Monofacial	*2.028*	N/A	N/A
	65	*2.108*	*+3.95*	*-2.70*
	70	*2.114*	*+4.25*	*-2.98*
	75	*2.120*	*+4.56*	*-3.26*
UK, South (Albedo: 0.25) 50MWp	Monofacial	*1.124*	N/A	N/A
	65	*1.197*	*+6.45*	*-4.98*
	70	*1.202*	*+6.94*	*-5.42*
	75	*1.208*	*+7.44*	*-5.86*

Table 4. Yield, bifacial gain and LCOE analysis of the effect of bifaciality over three PV plants in various locations worldwide. General assumptions: 400W module; 2V-tracking; 2.2m height; 35% GCR; central inverter 4MW; CAPEX, OPEX and discount rate as per Enertis internal data

be eventually modified, even though it was considered a key factor reducing the global Pmax bifaciality of the module.

In collaboration with the supplier, further modifications related to BOM were implemented. The first one involved a minor reduction of the ceramic glazed pattern of the rear glass (3mm adjustment; 'BOM 2' in Figure 2), plus the use of narrow rear-side soldering pads in the PV cells was carried out. These material-based tunings led to a manifest rise (up to three points) of bifacial coefficient through the increase of rear-side Pmax power output. In parallel, the front side's Pmax was, in turn, improved, at no extra cost for the buyer.

From this descriptive example, it can be concluded that there is room for optimisations of bifacial modules, just considering relatively affordable PV device design and BOM adjustment actions.

Bifacial asymmetries: performance

Any stakeholder involved in the development of a PV project is aware of power degradation phenomena such as light-induced degradation (LID), potential-induced degradation (PID) and the last guest at the PV party, light and elevated temperature-induced degradation (LeTID), characteristic of modules using the currently mainstream Passivated Emitter Rear Cells (PERC).

The bifacial coefficients of the I-V parameters are not the only variables featuring the non-symmetrical behaviour of a bifacial panel. Figure 3 illustrates this in a revealing way.

The graph evidences how the asymmetrical nature of a bifacial PV module can lead to significatively different degradation rates towards LeTID and PID-induced stresses. For instance, in the case of Supplier A, Pmax rear-side values after just 168 hours of LeTID processing reached an outstanding 7% absolute degradation. For PID, this effect was even more pronounced, surpassing 9% rear-side degradation in the case of Supplier A. Discussing these exciting effects in detail goes beyond the scope of the present article. However, in a few words, it is known that both LeTID and PID phenomena are ascribed to solar cells' architecture and manufacturing processing. Regarding PID, additional influences at module level, specifically from the encapsulant's volume resistivity and glass chemical composition [9] are also expectable. So, PID is a markedly BOM-related effect, so that additional materials requirements are to be considered in advance to mitigate PID-based risks in the modules. Therefore, from these results, it can be claimed that that PID and LeTID are understood as surface-like degradation phenomena, whereas LID, typically associated to wafer substrate's Boron-doping and oxygen contamination, is rather considered a bulk-like degradation mechanism. In agreement with this statement, Figure 3 shows how front- and rear-side LID-based underperformances were nearly equivalent.

PV plant performance and economics

As mentioned before, optimising the modules' front-side power output remains a key task to address for the design of a high-performance bifacial PV plant. Therefore, to this end, ensuring the accurate measurement of the Pmax value of a bifacial panel, including bifaciality, is mandatory.

Table 4 includes a quick sensibility analysis of the influence of module bifaciality in significant PV project metrics as energy yield, bifacial gain and LCOE. Three PV project cases are considered, namely Chile (Atacama zone, 150MWp), USA (Arizona, 150MWp), Spain (Andalusia region, 150MWp) and the southern UK (50MWp). For a global comparison purpose, the monofacial case is set as reference for bifacial gains and LCOE reductions. A properly measured 400W front-side power output module was considered.

It is well known that bifacial gain will depend mostly on geographical location (direct/diffuse irradiances), ground albedo conditions and system configuration. These variables will impact directly on the irradiance reaching the modules from the rear side.

Nonetheless, non-negligible differences associated to the intrinsic module bifaciality will also be expected. As observed in the table, increasing a module's bifaciality from the formally accepted 65% to 75% values would result in an increase of annual yield of 0.4-1.0% depending on project location. Likewise, LCOE can be reduced by 0.5-0.9%. Such reduction in the cost of the energy, even if apparently minor, could fairly determine the feasibility of a solar PV project in current competitive markets such as those based on energy auctions. It should not be forgotten that, in all these cases, the PV modules being purchased would be based on equal price, regardless the resulting bifacial coefficients eventually delivered, from the rough, but virtually official 70±5% standard thresholds. Thus, it seems more than reasonable for a project developer to pay attention to the Pmax rating and bifaciality determination of a bifacial PV module during its manufacturing.

In conclusion, bifacial technology is here to stay. At present, there are no major technical or economic reasons not to consider bifacial modules when starting a new PV project development. Although the front-side power output will keep ruling the performance of a solar panel, several sources of variation and vis-à-vis the right rating of a module's front output and the extra power and energy potentially harvested by the rear side remain unresolved. This happens not only at the PV site, but also from the device design or BOM used, and throughout the inline I-V testing activities.

These uncertainties, summarised as follows, still need further assessment and an improved control, so that reliable PV plant energy yields and LCOE figures can be optimised and warranted at early phases of the project development:

- Even after the appearance of the IEC TS 60904-1-2 document early in 2019, the adoption of international standards for an appropriate measurement of the electrical parameters of both the front and rear side of bifacial modules is yet to come. This applies to both the I-V curve testing method and solar simulator setups. Improving this is a question of time and market education, so that the best controlled and standard practices can be assumed by the industry in short order.
- Patent inhomogeneity of the bifacial coefficients during production, in part associated with non-optimised module designs and BOM, but also the still non-uniform flash test procedures already mentioned.
- Asymmetric rear versus front-side degradation behaviour of modules towards well-known effects as PID, LID or LeTID, potentially leading to unexpected performance losses in the first years of operation.

Hence, and probably more than ever, with prices per watt-peak reaching historical minimum values with big sized and high output modules arriving, the investment in technical revisions of bifacial modules specifications and performance control activities during production would be rationally encouraged [10]. ■

Turn to p.58 for insights into the latest developments in bifacial yield modelling

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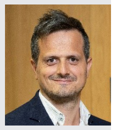

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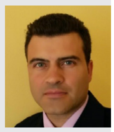

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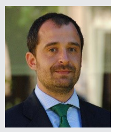

Francisco Álvarez, as a senior consultant of eight years' experience, is specialised in the evaluation of the solar resource and energy production for PV plants worldwide. Since 2016, his experience has focused on Latin America market. Currently, Francisco is the consultancy manager at Enertis Chile Spa, focusing on technical due diligence activities of solar PV projects for developers and financial entities.