Quo vadis bifacial PV?

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ABSTRACT

This paper presents a summary of the status of bifacial PV in respect of the technology in mass production, the installed PV systems, and the costs relating both to module production (cost of ownership – COO) and to electricity (levelized cost of energy – LCOE). Since the first bifacial workshop, organized by ISC Konstanz and the University of Konstanz, in 2012, many things have changed. Bifacial cells and modules have become cost effective, with installed systems now adding up to more than 120MWp and the technology becoming bankable. Large electricity providers have recognized the beauty of bifacial installations, as the lowest costs per kWh are attainable with these systems. The authors are sure that by the end of 2017, bifacial PV systems amounting to around 500MWp will have been installed, and that by 2025 this type of system will become the major technology in large ground-mounted installations.

Introduction

In a previous paper about bifacial PV by Kopecek, Shoukry & Libal [1], published in February 2016, the focus was on simulations of bifacial gain and on comparisons of real data from bifacial systems. A minimum bifacial gain of 10% was observed in every system, which reached almost 30% in systems in perfect conditions with regard to module properties, mounting system geometry, and reflection of the ground and surroundings (albedo). A bright future for the application of bifacial technology is forecast, as PV technology is becoming bifacial regardless: more and more module manufacturers are switching to glass–glass, cell manufacturers are switching to passivated rear-side devices (PERC, PERT, HJ), and more manufacturers are printing a grid on the rear in order to save material. In early 2016 the largest bifacial installation at the time (also reported in the above-mentioned paper) was nearing completion in Chile – the 2.5MWp 'BiSoN farm', named 'La Hormiga', which uses bifacial cells produced by MegaCell.

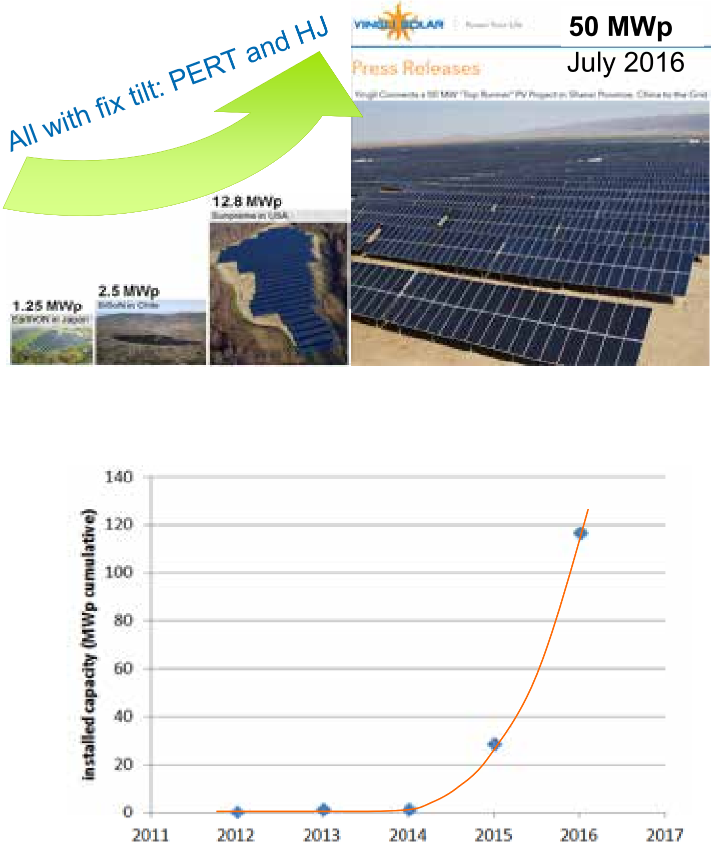

Figure 1. The largest bifacial installations at the moment (top), and the cumulated power for bifacial systems since 2012 (bottom).

Since that article in 2016, there has been a rapid 'explosion' in the number of installations of bifacial PV systems, so much so that the Chilean BiSoN farm is now quite a small bifacial installation, relatively speaking. The four largest bifacial systems at the moment (to the best of the authors' knowledge) are shown in Fig. 1.

The bifacial system from PVGS was for a long time the largest, with 1.25MWp very often quoted; it has now been surpassed in terms of size, but is still the one with the best reported data, with regard to the bifacial gains and duration of monitoring. The numbers can be found in the report by Nishiyama Sakata Electric Co., Ltd. [2]. The 2.5MWp system in Chile, which uses MegaCell-produced bifacial devices, is now up and running, and the owners are carrying out experiments regarding conditioning of the ground; for example, white pebbles are being placed below the modules in order to increase the albedo of the ground.

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The largest installation at the moment is a 50MWp from Yingli in China, followed by, in second place, the 13MWp system from Sunpreme in the USA. All these large installations are based on n-type technologies – nPERT (PVGS, MegaCell, Yingli) and heterojunction (Sunpreme). However, PERC+ (bifacial PERC) technology will also become important in bifacial systems, as will be seen in a later section.

The bottom graph in Fig. 1 depicts the cumulated installed bifacial MWp capacity in recent years; the current total bifacial power is estimated to be at least 120MWp. There are plans for large systems in 2017 from many electricity producers, such as the EDF project to install a 90MWp bifacial system in Mexico [3]. In addition, 8minutenergy is planning to install a 50MWp bifacial system in the USA. To the authors' knowledge both systems will be based on n-type technology in order to benefit from the better bifaciality of the modules. In 2017 it is expected that the number of bifacial installations will be at least triple that in 2016.

As illustrated in the cartoon in Fig. 2, serious discussions about bifaciality were first raised in 2000. At the moment, in 2017, there are still two split groups with two different views on bifaciality: one group says that bifaciality does not make sense, while the other claims that this technology will be the future. People from the second group are mostly from companies selling electricity and interested in costs per kWh, rather than from companies selling modules and more concerned with costs per Wp. The authors are convinced that, because in the end what matters is how high the system-generated electricity costs will be, bifacial technology will become the most important technology in the future; by 2025 this technology will be used in most of the newly installed ground-mounted systems, which will then produce electricity for less than US$ct1/kWh.

www. bifiPV-workshop.com

Since its foundation in 2005 ISC Konstanz has been working on bifacial technology. As the need to promote the information regarding this promising technology became evident, it was decided to begin organizing bifacial workshops (Fig. 3). The goal was to bring together the bifacial community and to start to work together on the most important topics in order to increase bifaciality's position in the market with regard to standardization, qualification, simulation and bankability. Three bifacial workshops have taken place so far, starting with the one in Konstanz in 2012 [4]. All the presentations of the bifiPV workshops are available for downloading, courtesy of SANDIA, from the PVPerformance Modeling Collaborative (PVPMC) website [5].

In 2015 an intermediate bifacial workshop in Chile was also organized in order to promote bifacial technology in that country, where the PV conditions are optimal. Bifaciality is now an important factor in Chile's roadmap for cost-effective solar technologies. Its government is planning large technology districts where bifacial systems will play an important role in the energy mix.

With many companies having introduced their bifacial products to the market and, as already mentioned, the number of installed bifacial PV systems having dramatically increased, the mood at the latest bifiPV in Miyazaki in 2016 was extremely positive. Fig. 4 summarizes the companies that currently produce bifacial solar cells.

There are basically three different bifacial solar cell concepts, namely pPERC, nPERT and nHJ; in addition to these, Luan is also involved in bifacial multicrystalline pPERCT production. Up until now, most bifacial cells have been based on n-type Cz-Si technology; however, as PERC technology has a total installed capacity of around 15GWp in Asia [6], 'PERC+' (bifacial PERC) technology is making a strong entrance into the market. The most prominent PERC+ manufacturers at the moment are SolarWorld, NSP and Sunrise. The bifacial factor, however, is much lower for PERC+ (60–75%) than for PERT (85–95%), although Al-paste development and improved

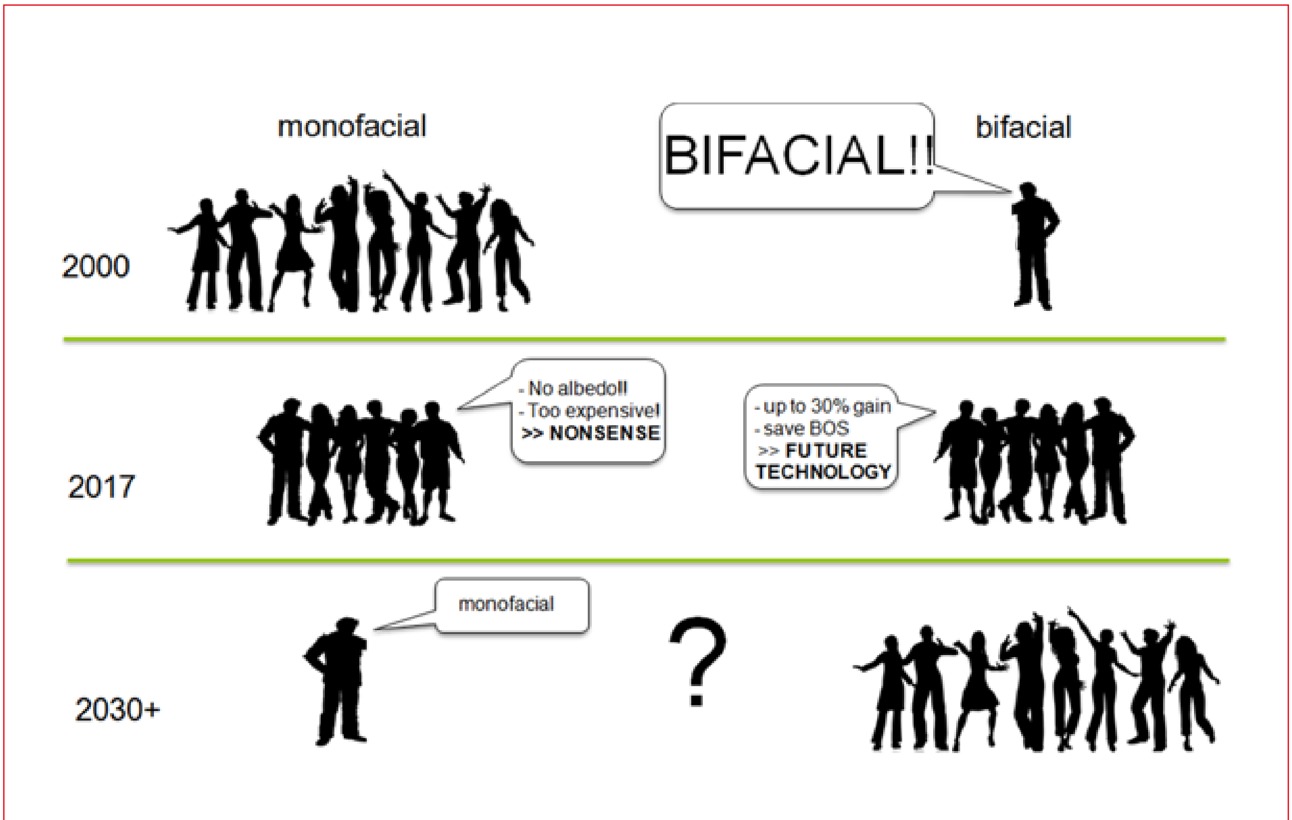

Figure 2. History of bifacial technology.

alignment of the Al-grid on the rear side are gradually improving this ratio. Nevertheless, the big advantage of PERT remains the totally diffused rear side, which means that high resistivity and high-lifetime wafers can be used; moreover, the surface passivation of the diffused rear side of the PERT cells is more stable over time.

“The total capacity for bifacial solar cell production is currently estimated to be circa 2GWp.”

MegaCell, Mission Solar and First Solar have now discontinued the production of bifacial devices. However, there are more new companies (e.g. Adani) entering the market, there are companies (e.g. LG electronics) expanding their bifacial capacities, and there are companies (e.g. NSP) bringing new products, such as PERC+, on the market. The total capacity for bifacial solar cell production is currently estimated to be circa 2GWp.

COO and LCOE

When an investor has to decide which cell and module technology to implement in a PV system, there are two main criteria that will guide this decision:

1. **Bankability:** the track record of the technology and of the module manufacturers offering modules based on the considered technologies.

2. **LCOE:** the levelized cost of energy (US$/kWh).

The first criterion poses a challenge for any technology that is entering the market. In the case of bifacial PV technology – apart from the track record of the existing bifacial cell and module manufacturers, and from the specific technology to be evaluated – the most important issue is how much bifacial gain can be reasonably expected for a given installation. As pointed out above and in Kopecek, Shoukry & Libal [1], for ground-mounted and flat-rooftop PV systems, between 10 and 30% bifacial gain can be expected for nPERT and HJ technologies that feature a bifaciality higher than 90%. More than 30% bifacial gain is possible in the presence of very high (artificially increased) ground albedo, whereas less than 10% might be achievable in configurations that are not favourable for the application of bifacial PV (e.g. a dark ground surface with very low albedo, or installations where the modules are mounted very close to the ground or rooftop).

The quantitative analysis of the second criterion – the LCOE – requires, first, a reliable forecast of the total amount of electricity produced during the useful lifetime of the PV system when assuming the implementation of the various technologies under consideration. Second, complete information about

Figure 3. Pictures taken at bifacial workshops: the bifacial community in Chambery 2014 (top), and the conference and bifacial workshop organizers in Miyazaki 2016 (bottom).

In production

1) **PVGS: PERT** (EarthON)
2) **Panasonic: HJ**
3) **NSP: PERT** and now **"PERC+"** (bifiPERC)
4) **Yingli: PERT** (Panda)
5) Mission Solar: PERT – Ended
6) MegaCell: PERT (BiSoN) - Ended
7) **Solarworld: PERC+** (Bisun)
8) **LG: PERT** (NeON/CELLO)
9) **Sunpreme: HJ**
10) **HT-SAAE: PERT**
11) **Jolywood: PERT**
12) **QXPV: PERT**
13) **Shanxi Lu´an: mcPERCT+**
14) **Sunrise: "PERC+"**
15) + others

In pilot

a) **Motech: PERT**
b) **TRINA: PERT**
c) **Tesla/Panasonic: HJ**
d) **REC: PERT**
e) First Solar/Tetra Sun: "HJ" - Ended
f) + many others

Figure 4. Companies with bifacial solar cells in production or in pilot production.

the module and balance of system (BOS) cost is required, together with the data about the cost of financing and of operation and maintenance. While, for each specific case, taxes and potential feed-in tariffs would have to be included, in the present analysis these are omitted, as the situation varies significantly from one country to another and is also in continuous evolution.

Fig. 5 summarizes the results of the calculations for the cost of ownership (COO) for various module technologies currently in mass production, as well as the respective module efficiencies (expressed as the Pmpp of 60-cell modules) that have been used as input for the subsequent LCOE calculations. These COO calculations are based on an integrated 500MWp/year cell and module factory located in a low-cost country in Asia.

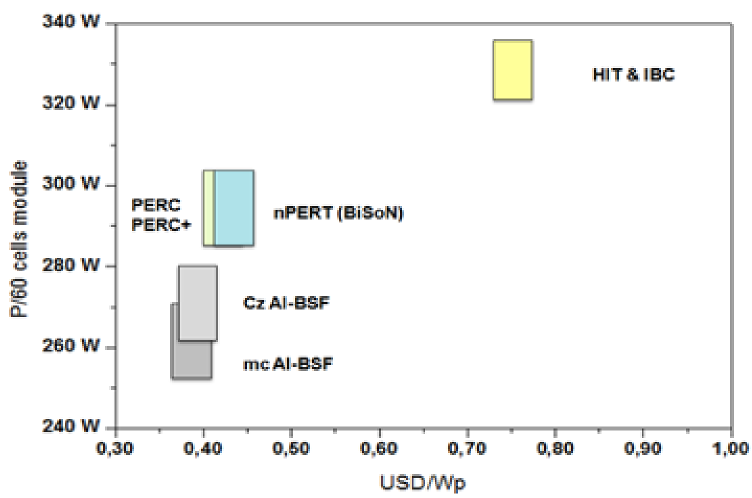

Figure 5. Summary of the results of COO calculations for monofacial and bifacial technologies currently in mass production (as of January 2017).

As regards electricity generation, a utility-scale ground-mounted solar farm located in an area with a yearly global horizontal irradiance (GHI) of 1,800kWh/m^2 was considered. Such a solar irradiation level is representative of, for example, the south of Spain, the USA and large regions of India.

The module lifetime is assumed to be mainly dependent on the module technology, and, as glass–backsheet is applicable to all module technologies, the useful system lifetime has been set to 25 years for all of them. In the case of bifacial technologies, glass–glass modules, with a useful lifetime that can be assumed to be around 35 years [7] and a lower yearly degradation rate (0.2% instead of 0.4%), have also been included in the comparison.

In order to evaluate the LCOE of various bifacial technologies under comparable conditions, the present considerations and calculations of the LCOE are based on a bifacial gain of 20% for PERT and HJ (90% bifaciality), while for PERC – because of its lower bifaciality of around 70% – a bifacial gain of 15% has been assumed.

The results of the LCOE calculations based on the above-mentioned assumptions are summarized in Fig 6. The outcome of this analysis indicates that high-efficiency but high-cost monofacial technologies, such as HIT and interdigitated back contact (IBC), currently in mass production at large manufacturers, are not competitive in terms of LCOE in the case of utility-scale system application. The results

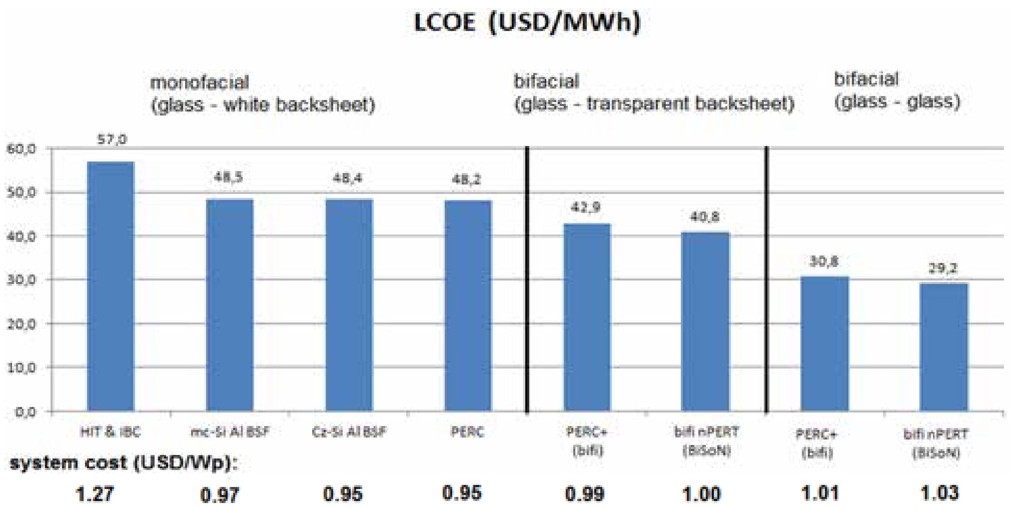

Figure 6. Summary of the results of LCOE calculations and system costs for the various technologies, based on the module COO shown in Fig 5.

Figure 7. The BiSoN farm 'La Hormiga' in Chile.

also show clearly that the mainstream monofacial technologies (mc-Si and Cz-Si Al-BSF, and Cz-Si PERC) can be considered equivalent with respect to LCOE. Bifaciality, with its reasonable module and system cost, achievable with PERC+ and nPERT, is the technological factor that results in a significant (around 14%) reduction in LCOE compared with monofacial standard technology. A further substantial reduction in LCOE of an extra 25% can be achieved by the use of glass–glass modules; this is due to the huge increase in cumulated electricity, produced during the 10 years of additional system lifetime.

Regarding heterojunction (HJ) and IBC solar cells, innovative cell concepts with lower-cost manufacturing processes are currently entering the market. With cell efficiencies of 22.5 to 23%, a module power of 320 to 330W can be achieved, while the module COO is expected to be significantly lower than that of today's HIT and IBC technologies. Both HJ and IBC are bifacially adaptable technologies; accordingly, the respective LCOEs of their modernized versions are expected to be significantly lower than for today's HIT and IBC, and slightly higher than for PERC+ and BiSoN (nPERT). In addition, there are other possibilities: for example, the company Solaround is developing a bifacial PERT solar cell technology [8] based on Cz-Si wafers, with an anticipated lower manufacturing cost than for PERC+ while featuring a bifaciality of 95% or higher.

An example of a large bifacial PV system is the previously mentioned 2.5MWp solar BiSoN farm 'La Hormiga' in Chile, which has been installed using bifacial glass–glass BiSoN (nPERT) modules produced by MegaCell (Fig. 7). The module design has also been optimized in order to guarantee a module lifetime of 35 years under the harsh desert climate conditions. The use of these modules, combined with a yearly GHI of around 2,500kWh/m^2, yields an LCOE of around US$23/MWh.

Summary and outlook

The time is ripe for new technologies to enter the conservative PV market. PERC technology has already pronouncedly penetrated the market, with a production capacity of around 15GWp in 2016 and an expected capacity of 25GWp in 2017 [6]. Fig. 8 shows the predicted PV market shares for cell technologies in future years (taken from the technology roadmap [9]).

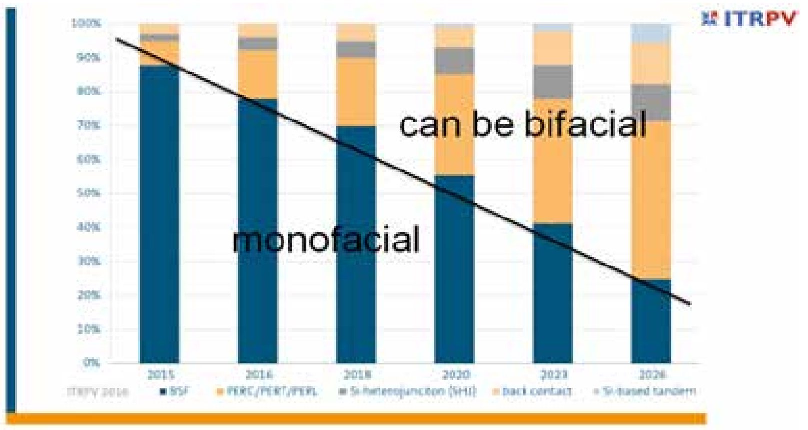

Figure 8. Projected shares in the PV market for different solar cell technologies [9].

> "By 2026 the market will be dominated by solar cells that will be made bifacial and therefore result in the lowest LCOEs."

The standard Al-BSF solar cell, which has been dominant for decades, is being replaced to an increasing extent by technologies which feature rear-side passivation and can be made bifacial. PERC+ is now the latest trend for PERC producers to save material and to gain power by rear-side illumination. By 2026 the market will be dominated by solar cells – such as PERC, PERT, HJ and IBC cells – that will be made bifacial and will therefore result in the lowest LCOEs. In addition, a small contribution of tandem solar cells is predicted with a front-side efficiency exceeding 30%, for example by using perovskites in IBC cells.

A book on the topic of bifaciality is currently in preparation (due to be published at the end of 2017). The past, present and future of bifacial solar cell technology will be covered, and all the existing bifacial technologies on the market and in R&D will be discussed. In addition, the status of bifacial simulations will be reported, as well as standardizations with regard to bifacial cell and module measurements. Finally, bifacial PV systems, bankability and costs will be examined. Parameters collected from running bifacial systems will be available on the bifacial website, www.bifiPV-workshop.com.

Last, but not least, as it has been common practice to assign large-scale PV projects through a bidding process on the basis of who can achieve the lowest possible LCOE, the authors are convinced that, for utility-scale PV, bifacial technology will experience a marked increase in its market share in the next few years.

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About the 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.

Dr. Joris Libal works at ISC Konstanz as a project manager, focusing on business development and technology transfer in the areas of high-efficiency n-type solar cells and innovative module technology. He received a diploma in physics from the University of Tübingen and a Ph.D. in the field of n-type crystalline silicon solar cells from the University of Konstanz. Dr. Libal has been involved in R&D along the entire value chain of crystalline silicon PV for more than 10 years.

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