152 - Bifalo
Bifacial PV modules for lowest levelized cost of energy

Project duration: from 10.2016 to 03.2020
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Publishable Summary

After several years of dynamic reductions of PV module production cost and prices, module prices are now stabilizing and further reductions of LCOE (Levelized Cost of Energy in €/kWh) will now be driven by reduction of the Balance Of System (BOS) cost. A main driver for reduction of the BOS cost is the enhancement of the energy yield (kWh/m^2 of module area) of the PV modules. On the one hand, this can be achieved by increasing the energy conversion efficiency of the solar cells - with the risk of increased production cost for cells and modules (see e.g. back-contact module technology by Sunpower and hetero-junction technology by Sony/Panasonic and REC). A more cost effective way for increasing the energy yield of PV modules is the implementation of bifacial cells and modules: under favorable installation conditions (e.g. high albedo of the ground at the installation site), the rear side contribution to the total energy production of a bifacial module can reach 30% or more, while 10-15% gain can be easily achieved even with bifacial PV systems installed over grassland. Taking the example of a bifacial module with 19% front side efficiency, its total energy yield will be the same as the energy yield of a monofacial module with 24.7% (= 19.0% x 1.3) - accordingly, the bifacial module has an equivalent efficiency of 24.7%, outperforming any non-concentrating PV module based on c-Si and, first and foremost, in the same price and cost range as standard modules with around 18% efficiency. In addition, contrary to e.g. back-contact technologies, bifacial cells are suitable to be processed in standard module manufacturing lines that are currently available for more than 100 GW/year capacities worldwide. Bifacial PV is becoming even more relevant due to the fact that many new advanced cell concepts (as e.g. n-type and p-type PERT: refered to as pPERT) are inherently bifacial. Accordingly, very recently, bifacial PV is gaining more and more interest, both from manufacturers and from PV system operators. Therefore ISC Konstanz started organizing bifacial workshops bifiPV from 2012 on: www.bifiPV-workshop.com. During the virtual bifiPV2020 in July 2020 we had 1035 registrations from more than 50 countries. Most companies that are currently implementing high efficiency bifacial cells on industrial scale are working on n-type wafer based cell-technology. The same is valid for the research activities at the main R&D institutes worldwide. In addition, during the project period, industrial manufacturing of bifacial PERC cells and of bifacial modules based on such cells, has gained significant importance. However, even if the p-type based PERC concept in its bifacial variant is a cost effective alternative to bifacial n-type PERT cells (which where state of the art at the beginning of the project), still the development of cost-effective pPERT-cells and modules is very relevant due to their significantly higher bifaciality factors (> 0.9 vs around 0.7 in case of PERC) which allow for higher energy yields (bifacial gains) in a given system configuration and location. In the case of vertically installed bifacial systems – which are currently gaining more and more attention by system developpers – a high bifacial factor is even mandatory for the economical viability of such systems. From the technological point of view, working with n-type c-Si wafers is

more straightforward with respect to achieve high front side efficiencies and, in addition, bifaciality comes automatically with n-type cell production (P-diffused BSF instead of Al-alloyed BSF in p-type). However, current market prices for n-type Cz-Si wafers are around 10% to 20% higher compared to p-type Cz-Si. The reason for this is mainly the better economy of scale of the p-type wafer production that today represents around 80% of the overall monocrystalline production capacity for PV. Accordingly, the situation is not expected to change in the short term. The latest achievements in fabrication technology of high efficiency p-Si based bifacial solar cells allow starting development of high efficiency bifacial modules using such cells. Cheaper starting Cz p-type c-Si, readiness of the industry to produce material with high quality recombination parameters and existing cell fabrication technology able to retain the bulk lifetime are making this cell type very promising for production of high efficiency bifacial modules enabling a low LCOE. The working conditions of a bifacial module are different compared to the conditions of a regular monofacial module: higher current density due to the both sides contribution to the current generation, time and weather dependence of the gain due to back side contribution, effect of the back shading on the power generation. These differences affect the test set-up, power classification, design and safety requirements. These topics that – before the start of this project - were practically not investigated up to now. One of the main achievements of the Bifalo project is the fabrication of pPERT cells and respective full size (60 cells modules) with a bifacial factor of 0.9. Accordingly, in an outdoor PV test system at the partner Fraunhofer CSP where the electrical output of a monofacial module, an nPERT module (bifacial state of the art at project start) and pPERT modules fabricated within the project have been monitored during the same time period of 4 months, a relative increase of bifacial gain by 28% and 44% has been demonstrated for two different Bifalo module designs. Thereby the bifacial gain has been increased from 4.6% (state of the art) to 5.9% and 6.6% respectively. Furthermore, a mathematical model for energy yield prediction has been developed and its accuracy been validated based on field data collected within the project. For one of the test systems, a very low deviation between simulated and measured energy yield (accumulated during 4 months) of -0.95% has been demonstrated.

Project consortium

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Participating countries and financing:

Country	**Number of organisations involved**	**Project costs in EUR**	**Public funding in EUR**
Germany	3	919’729	735’775
France	1	96‘416	42‘358
Israel	2	128’000	128’000
Total	*6*	*1’144’145*	*9066’133*

Funding agencies involved and contracts

Funding Agency	**Contract N° and Title**
Projektträger Jülich (PtJ)	Förderkennzeichen 0324088A: "Verbundvorhaben: BiFaLo- Bifaziale PV Module für minimale Stromgestehungs-kosten; Teilvorhaben: Entwicklung einer bifazialen Solarzelle und Modul sowie Entwicklung eines Modells für die Ertragssimulation und Berechnung der Produktions- und Stromgestehungskosten" Föderkennzeichen: 0324088B: (Kassenzeichen: 810303466044) Verbundvorhaben: BiFaLo- Bifaziale PV Module für minimale Stromgestehungskosten; Teilvorhaben: Entwicklung von Herstellungsprozessen und Moduldesigns für Bifacialsolarzellmodule Förderkennzeichen 0324088C: BiFaLo – Bifaziale PV Module für minimale Stromgestehungs-kosten
ADEME	1605C0018: “Projet BiFaLo”
Ministry of National Infrastructures, Energy and Water	215-11-039 Development of simulation tool for predicting energy generation and of methods for field testing, for new high efficiency bifacial modules