



- 1 *Frameless bifacial PV module.*
- 2 *Bifacial PV modules installed on a white, highly reflecting flat roof.*
- 3 *Bifacial PV module.*

BIFACIAL PV MODULES – CHARACTERIZATION AND SIMULATION

Bifacial photovoltaic (PV) modules are able to utilize light from both sides and can therefore significantly increase the electric yield of PV power plants. The yield gain compared to monofacial modules is mainly determined by

- the conversion efficiency for solar irradiance incident on the rear side of a bifacial PV module, and
- the amount and quality of solar irradiance incident on the rear side.

Our comprehensive services for bifacial PV modules at Fraunhofer ISE include

- module calibration and characterization under mono- and bifacial irradiance
- accurate simulation of bifacial irradiance in field operation, including partial shading
- yield simulation and optimization
- power plant testing
- monitoring on module and system level to evaluate different technologies

- analysis and optimization of cell-to-module efficiency
- analysis and optimization of module-to-system efficiency including BIPV systems
- reliability assessment of module materials and design
- analysis of local climatic stress conditions.

Yield Assessment

We compile yield assessments for bifacial PV power plants. With our unique simulation algorithm, developed in-house and validated by monitoring data, we can accurately predict the irradiation not only on the front side, but also on the rear side of the module. The detailed analysis considers characteristics of the system and the site (such as the reflection of the underground, shading, mounting height and the inclination angle) and provides recommendations for optimizing system design and yield.

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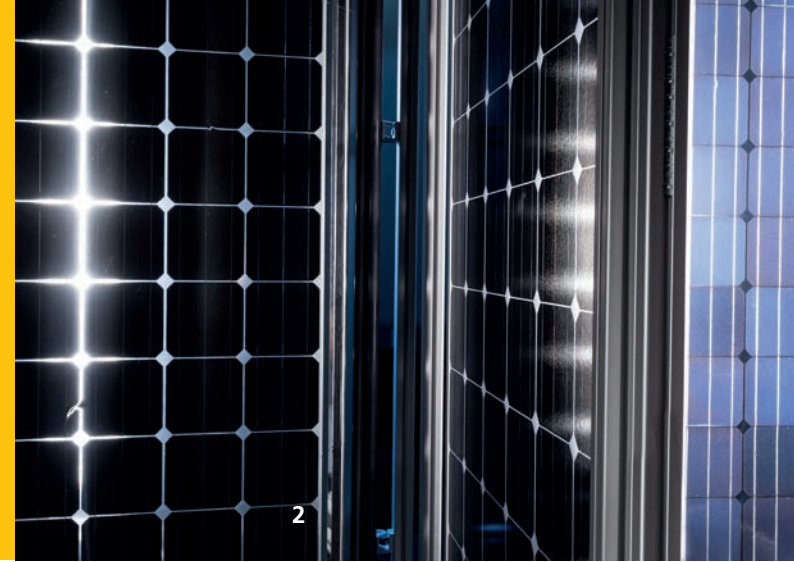
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Calibration and Characterization

The calibration and characterization of bifacial PV modules is conducted by our accredited calibration laboratory CalLab PV Modules, the world's leading laboratory regarding measurement precision.

For calibration of bifacial PV modules, we measure each side against a non-reflective ("black") background to guarantee highest reproducibility and measurement accuracy. Additionally, we are able to perform the measurements for frontside and backside simultaneously under different light intensities using a new test set-up developed by Fraunhofer ISE.

To characterize bifacial PV modules, we determine the most important yield-relevant properties, like low-light performance, the temperature coefficient and the rear side efficiency. According to our customers' special needs, we select the relevant properties for characterization. With the new test set-up, we are able to provide services beyond the proposal for new standard IECNP 60904-1-2-TS.

Monitoring

To verify the characteristics and yield of bifacial PV module technology, Fraunhofer ISE builds and monitors demonstration systems on module and system level. The mounting system and the underground can be specified by the customer. Simulations are used to verify the measured data.

Efficiency Analysis and Optimization

For optimal yield in bifacial operation, module design and bill of materials need to be carefully adjusted. Our electrical and optical simulation of module efficiency and performance supports both material and module manufacturers. In the Module Technology Center (Module-TEC) we apply innovative interconnection and encapsulation technology to manufacture samples from 1 to 60 cell format for characterization and testing purposes.

Reliability Assessment

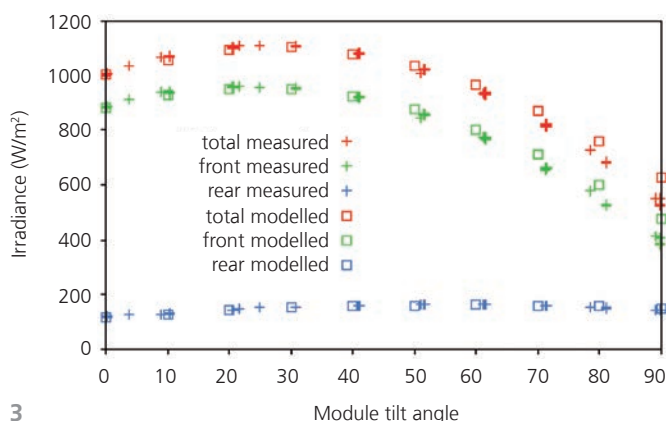
Independent reliability assessment is an essential milestone on the way to bankability for bifacial PV technology. Based on comprehensive experience in environmental monitoring and simulation, we qualify new materials such as transparent back sheets, encapsulants and sealants. In our ISO 17025 accredited TestLab PV Modules, we perform customized accelerated testing, precertification as well as certification testing.

We analyze the degradation behavior of bifacial PV modules under real weather conditions by exposing them at our outdoor test sites in different climates. An important aspect is the influence of different material combinations on long-term reliability.

Non-destructive monitoring of degradation indicators helps our customers to identify potential degradation paths at an early stage.

Customer-Specific Services

Our individual services can be combined in various ways according to our customers' specific needs.



- 1 New test set-up for calibration of bifacial PV modules developed by Fraunhofer ISE.
- 2 Bifacial module mounted in the test set-up.
- 3 Measured (+) and modelled (□) irradiance values for different tilt angle.