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Performance Modeling and Testing of Bifacial PV Systems

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Main Takeaways

1. The bifacial gain depends on three major factors: the system geometry, the ground albedo, and the module bifaciality.

   First-order approximation:
   Bifacial gain = geometrical factor x albedo x bifaciality

2. PV modeling software takes care of (most of) the system-geometry effects.

3. The albedo should be measured at the project site.

4. Module manufacturers are on a learning curve. Sample testing per IEC 60904-1-2 is recommended.

# Popular PV Modeling Softwares Now Support Bifacial Systems

- In PVsyst, NREL SAM, PlantPredict, and many others, you can now declare a module type to be bifacial, and define its "bifaciality factor".

- In some softwares (NREL SAM and PlantPredict), you can additionally define a "transmission factor" for modules with clear cell-to-cell gaps, and loss terms related to structure shading and backside mismatch.

- The modeling software takes care of the effect of system geometry.
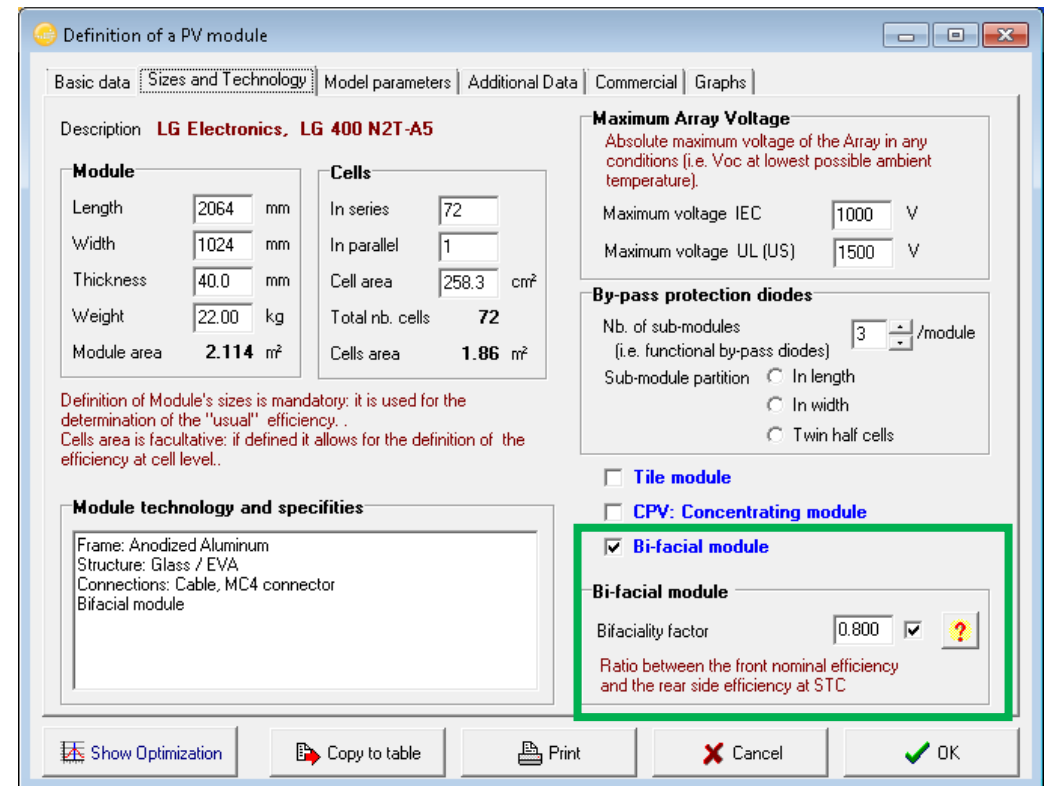
Two-Dimensional View-Factor Model

PVsyst, NREL SAM, PlantPredict, and many other softwares use an extended 2D view-factor model to capture the effect of system geometry.

1. Identify the incident irradiance on the ground. Which part is shaded and which part is not?

2. Integrate the ground view factors along the backside of the array

Beam on Ground

Diffuse on Ground

View Factor
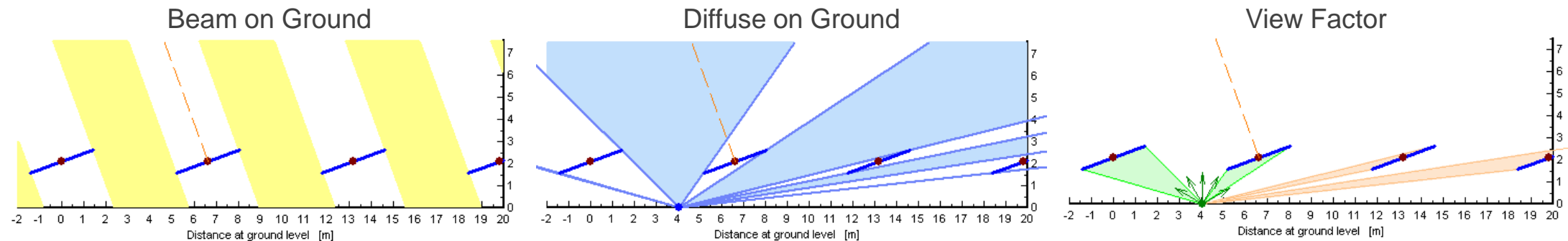
All graphics from PVsyst 6.7.5 "Bi-facial system definition" dialog

B. Marion et al., "A practical irradiance model for bifacial PV modules", NREL/CP-5J00-67847
A. Mermoud and B. Wittmer, "Horizontal axis trackers with bifacial modules in PVsyst", PVSS 2018

Nontrivial Effects: Ray Tracing

- Nontrivial effects such as edge brightening and partial soft shading due to underlying structures can be studied via ray tracing (PV Lighthouse SunSolve, NREL Bifacial Radiance).

- Ray-tracing studies can provide guidance on what value to put as additional loss factors for the bifacial PV systems (structure shading, backside mismatch, etc.)

K. McIntosh et al., "The effect of non-uniform illumination on bifacial tracking modules: a simulation study", PVSS 2019

Mismatch within a module

$\theta_{sun} = 48.2°$ $\phi_{sun} = 156°$

$\theta_{mod} = 24.7°$ $\theta_{inc} = 42.7°$

South
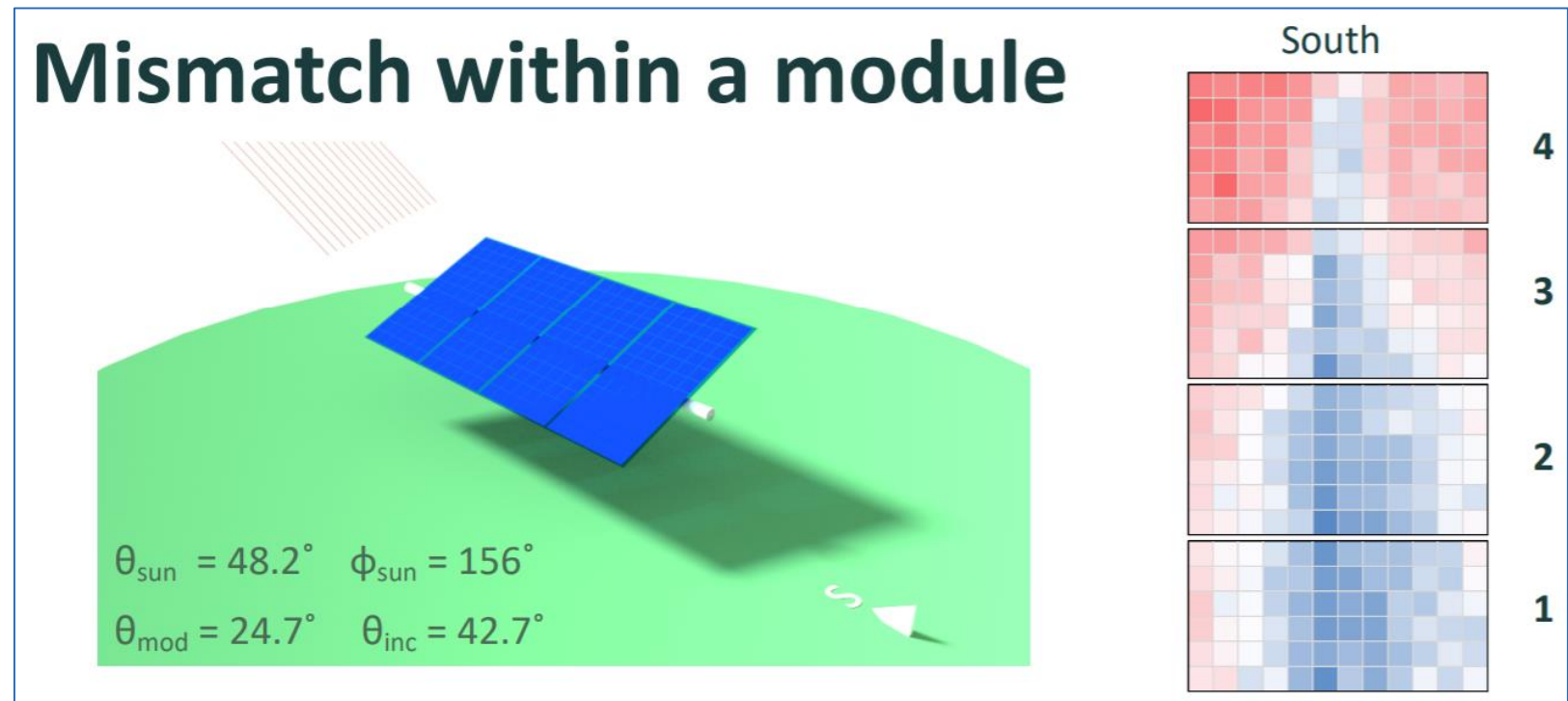
Ground Albedo: Measurements Recommended

- Albedo is the biggest source of uncertainty for bifacial gain.

- Albedo can vary with the time of the year and also the time of the day. Published data show large ranges of values even for a single type of ground cover (dirt: 15-30%).
  B. Bourne, "Ground Albedo Field Measurements", Bifacial PV Workshop 2018

- Satellite-derived albedo data are now becoming available, but there are ongoing discussions on which satellite data is the best source to use and what the best algorithm is.
  C.A. Gueymard et al., Solar Energy 182, pp. 194-212, 2019
  R. Bailey, "Investigations of site-specific long term average albedo determination for accurate bifacial system energy modeling", IEEE PVSC 2019.

- For a large project, 1-year-long albedometer measurement at the project site is recommended.
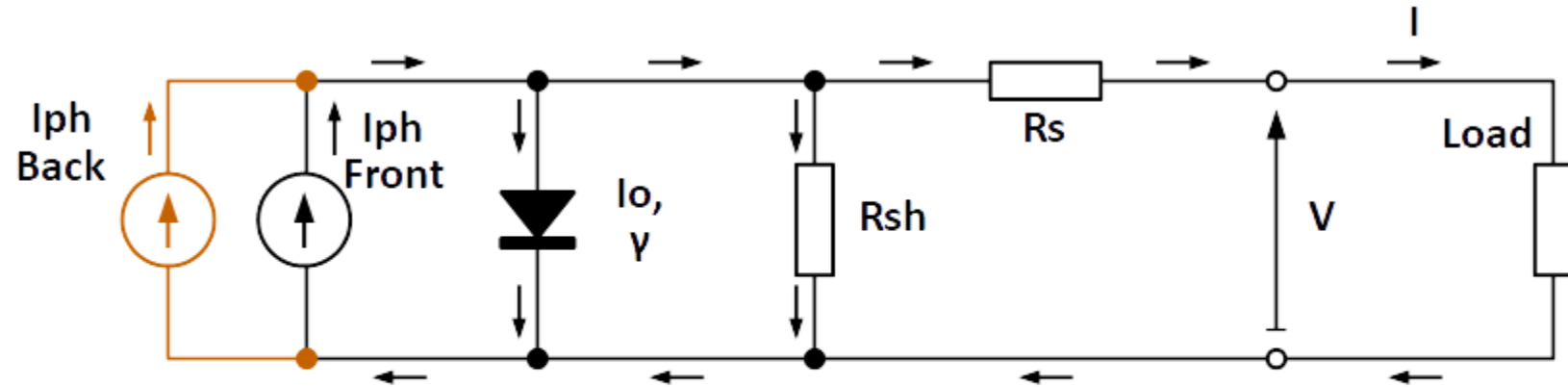
GroundWork Rey MET System with Albedo Measurement
(http:/grndwork.com)

Bifacial PV Module Equivalent Circuit

- The single-diode model is a popular and accurate equivalent circuit for a PV module.

- The backside of a bifacial PV module just acts as an additional current source.

Iph: Photo-generated current   Rs: Series resistance   I: Terminal Current
Io: Dark saturation current   Rsh: Shunt resistance   V: Terminal Voltage
γ: Ideality factor

- The current sources are in parallel $\rightarrow$ They act as a single current source at $Iph_{Back} + Iph_{Front}$.

Characterizing a Bifacial PV Module per IEC 60904-1-2

- IEC TS 60904-1-2:2019 defines how a bifacial PV module shall be characterized.
  Main idea: flash the front and the back separately, **taking care to minimize stray light effects**

Problem: Light rays outside the module boundaries or passing through clear gaps can reflect off surfaces behind the module and enter the non-irradiated face.

Solution: Cover the non-irradiated side with non-reflective material to minimize the stray light entry.
When flashing the frontside, cover the backside.
When flashing the backside, cover the frontside.
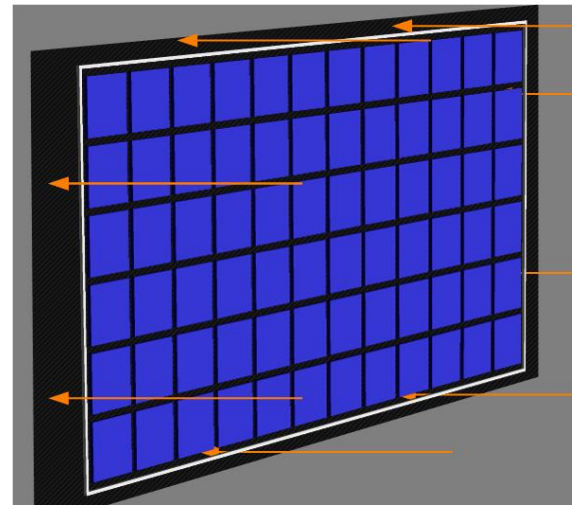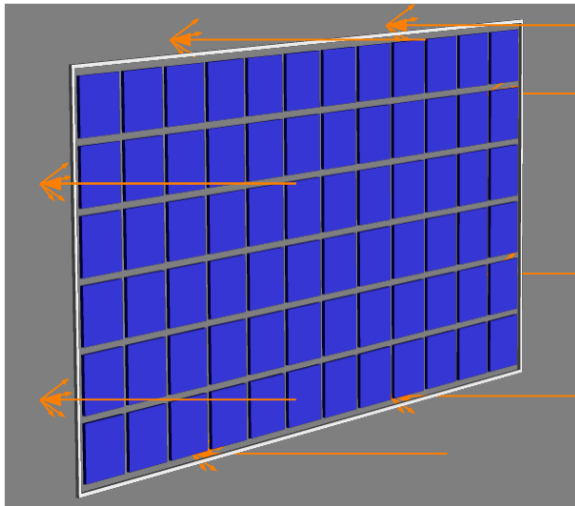
Flashing the frontside,
$Isc \sim Iph_{Front}$
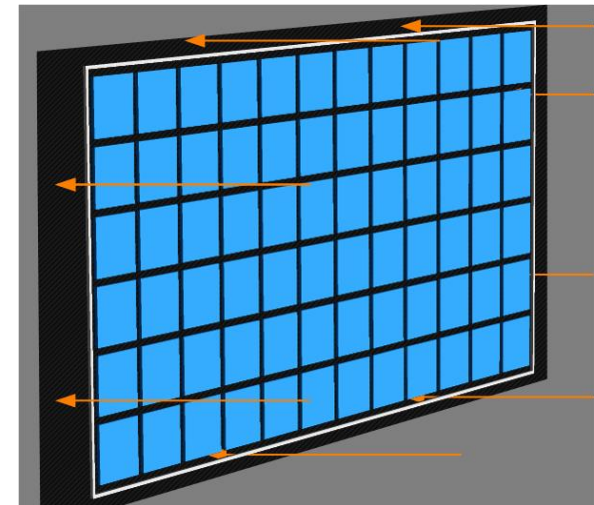
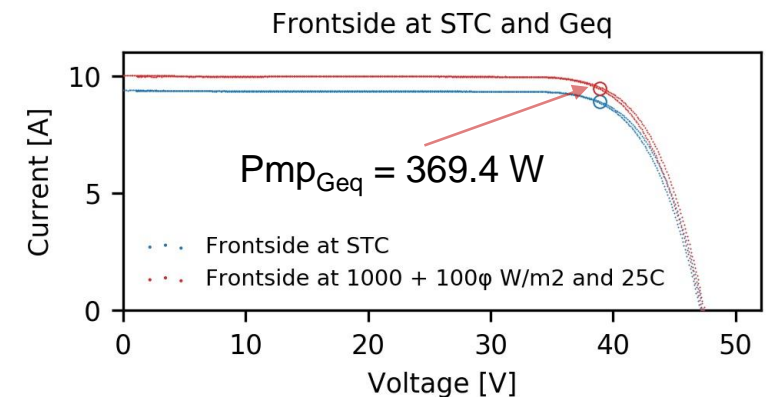Flashing the backside,
$Isc \sim Iph_{Back}$

Module Bifaciality

- The first international round-robin testing of bifacial modules per IEC 60904-1-2 was organized by SERIS of Singapore in 2018 and is due to complete this year (BifiPV 2018 presentation). NREL and CFV participated from the USA.

- Module bifaciality φ is Pmp_{Back} / Pmp_{Front} at STC.
  - Strictly per IEC 60904-1-2, φ is the smaller of Pmp_{Back} / Pmp_{Front} and Isc_{Back} / Isc_{Front} at STC, but those values tend to be very close except on modules with gross design errors (J/B or nameplate shading of the backside).

- Module performance in a bifacial scenario (irradiances on front and back) can be simulated by flashing just the frontside at a higher irradiance *equivalent* to the scenario.
  - Equivalent frontside irradiance for 1000 W/m² front + 100 W/m² back = 1000 W/m² + φ x 100 W/m²
  - 2016 presentation by IEC 60904-1-2 project leader Vahid Fakhfouri (then at Pasan)

Frontside and Backside STC I-V

Pmp_{Front} = 346.3 W

Pmp_{Back} = 232.2 W
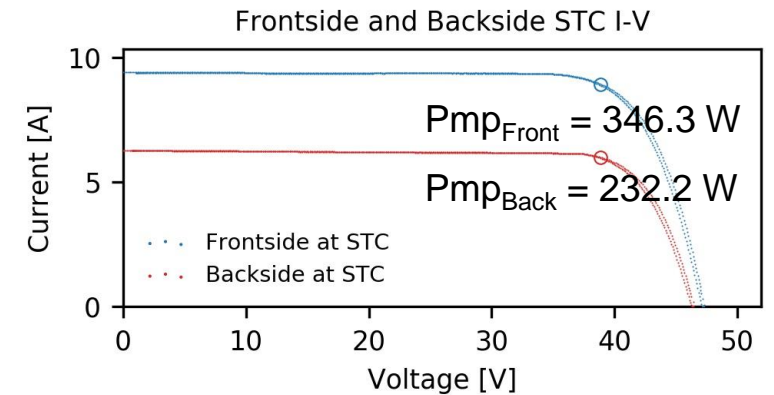
PERC, φ = 67%

G_{eq} for G_{Back}=100 W/m² = 1067 W/m²

Frontside at STC and Geq

Pmp_{Geq} = 369.4 W

Open Issues on Bifacial Modules that Customers Should Be Aware of

- **Does the rated power already include some bifacial gain?**
  - Current versions of certification standards do not provide guidelines on how a bifacial module should be rated. The drafts of the next versions refer to IEC 60904-1-2, but the drafts cannot be enforced on certifications to the current or legacy versions of the standards.
  - Modeling softwares assume that the rated power reflects only the frontside performance.

- **How accurate is the module bifaciality factor on the datasheet?**
  - Current trends: PERC - 60-70%, n-type - 70-90%
  - The bifaciality factor tends to change over time (we've seen ± 10 p.p. changes), corresponding to design changes. The bifaciality factor is coupled with the frontside performance.
  - As with many datasheet values, the bifaciality factor may have been characterized on just one power class and only once during the initial module certification.

- The industry as a whole, including manufacturers and certification bodies, is on a learning curve. **Due-diligence IEC 60904-1-2 testing on samples is strongly recommended.**

Some Pitfalls for Project Developers to Avoid

1. **Do not confuse "bifacial gain" with "albedo".**

    First-order approximation of bifacial gain for SATs = (0.2 to 0.5) x albedo x bifaciality
    For albedo = 30%, bifaciality = 65%, and SAT, the realistic range of bifacial gain is 4-10%.
    Module manufacturers tend to include electrical data at up to 30% bifacial gain in datasheets.

2. **When presented with field data showing high bifacial gains, pay attention to the details.**

    Early studies carried out at research labs and universities often used small setups that are not representative of actual field installations, and also unrealistic ground covers (white-painted ground). Pay attention to these details.

    Over time, more data will become available from real-world-like test facilities.

Summary

1. Popular PV modeling softwares can now handle bifacial systems, via the 2D view-factor approach.

2. There is a lot of ongoing discussion on the satellite albedo data. The best approach now is to measure it.

3. When selecting bifacial modules, we strongly recommend due-diligence testing (IEC 60904-1-2) on production samples.

CFV's bifacial tracker test yard goes into service in July 2019.

• **Five rows of industrial single-axis trackers; Each row is 30 modules long in portrait.**

• **All arrays are installed per IEC 62738:2018; Monitoring equipment satisfies IEC 61724-1:2018 Class A**

Thank you.

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