The Outdoor Bifacial PV Testing Facility at Technical University of Denmark

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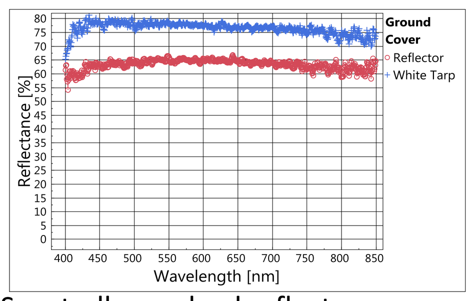
Background: Since summer 2018, European Energy A/S and DTU have measured the performance of bifacial PV strings mounted on trackers and fixed tilt systems located in Northern Europe (55.6° N, 12.1° E). A new publically funded project is underway with the intent to evaluate in-house and commercially available bifacial PV performance models. The facility includes several sub-systems where the conditions known to affect bifacial performance are varied including tracker spacing (GCR), albedo (ρ) and module tilt (β).

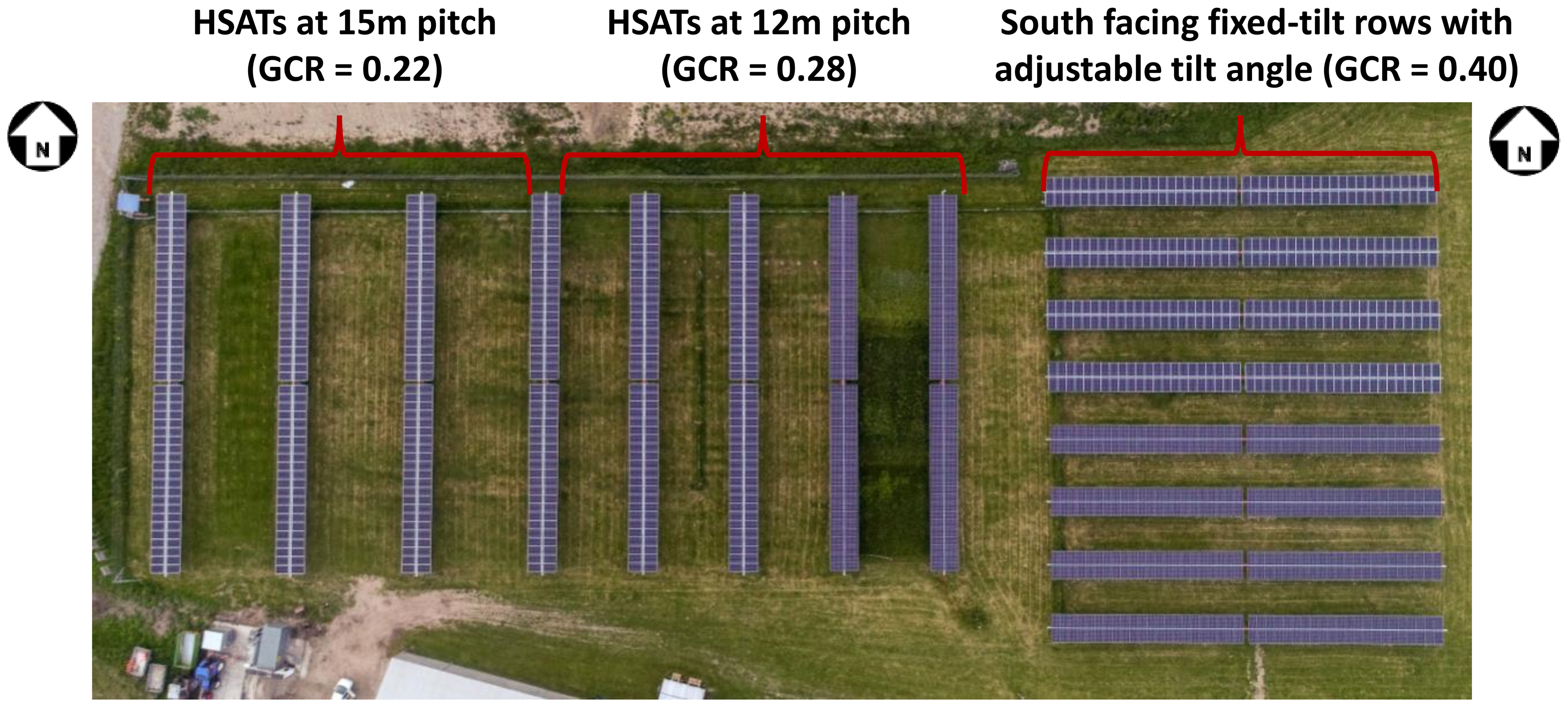
Equipment and Layout

- Monofacial and bifacial strings of similar front side power mounted side-by-side.
- Horizontal East-West (HSAT) trackers (x8) and south facing 2V racks with adjustable tilt angle (x8).
- Tilted single axis trackers (x2) and dual axis tracker (x1).
- Multiple ground covers under test:
  - Seasonal grass ρ ≈ 20%
  - Coarse sand ρ ≈ 28%
  - Medium-size gravel ρ ≈ 26%
  - White polymeric tarp ρ ≈ 76%
  - μ-structured reflector ρ ≈ 63%

Broadband albedo data from the unshaded measurement zones are used as input to bifacial PV performance models.



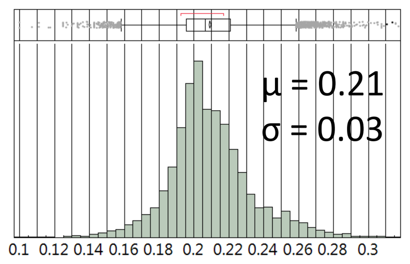
Spectrally resolved reflectance can be measured in the DTU Fotonik laboratories.



White tarp and gravel ± 3m under tracker rows

Micro-reflector under fixed tilt string (β = 25°)

Moveable pyranometer albedometer (class A)



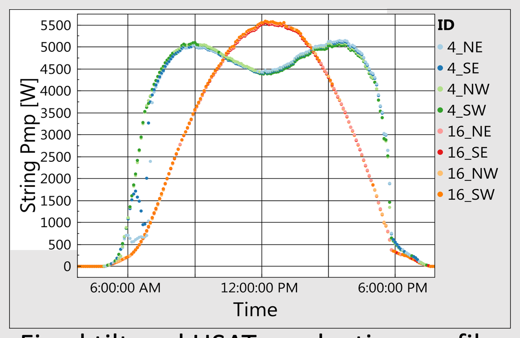
Five month distribution of albedo measurements on grass (θ_{Zenith} > 85°)

Sensors and Detailed Monitoring

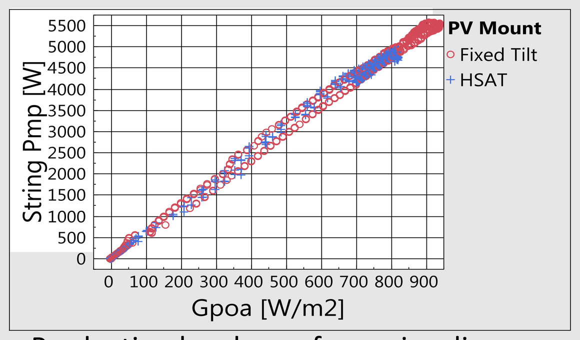
Max-power current (I_{MP}) and voltage (V_{MP}) measurements on 64 individual strings.

Monitoring independent of inverter measurements

DC Power meters with isolated surface mount resistors and digital filtering

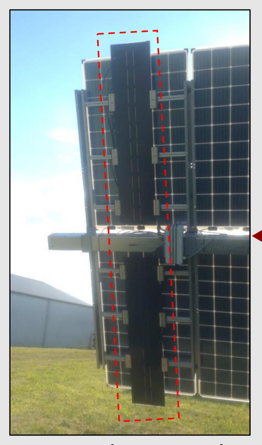


Fixed tilt and HSAT production profiles



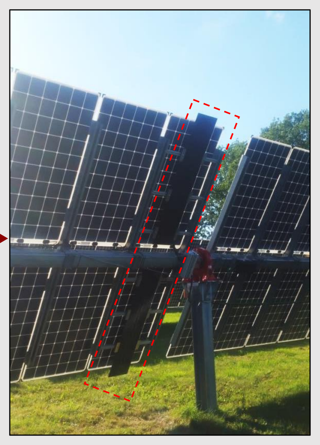
Production by plane of array irradiance

Four panels with 10 individually measured 5" mono-Si cells for studying distribution of rear side irradiance.

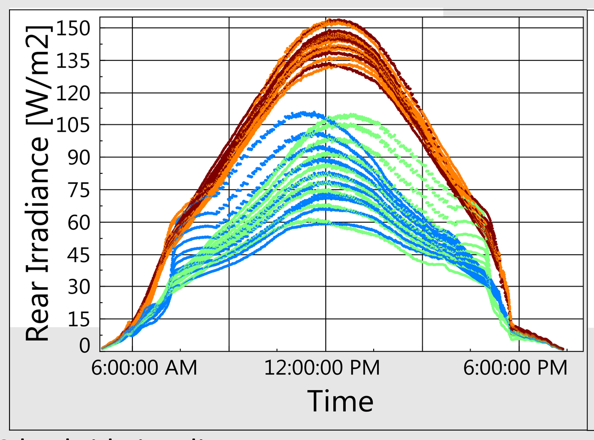


Two edge panels (20 measurements)

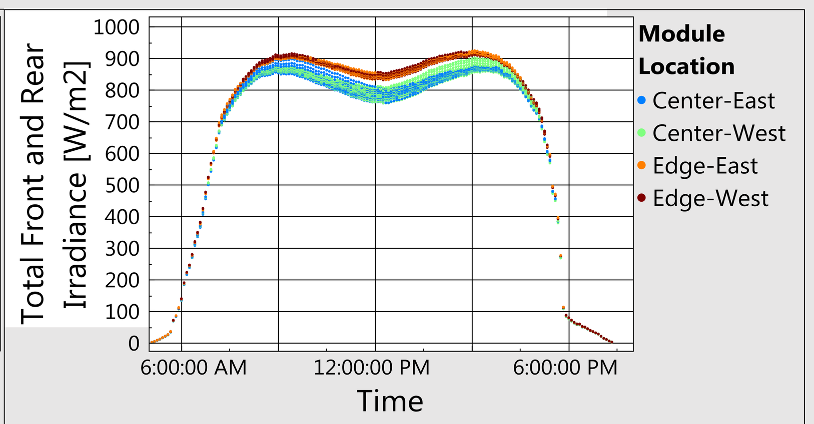
22 panel (~22m) long tracker sub-array.



Two center panels (20 measurements)



40 backside irradiance measurements as measured by 5" mono-Si cells on a clear sky day. Cells closest to the torque tube are always lower in output.

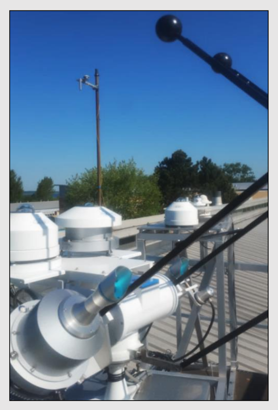


Backside irradiance measurements summed with front side global POA irradiance.

Spectroradiometers for diffuse and beam measurements (300-1100 nm) for investigation of spectral effects.

Solar radiation Measurements include:

- DNI (spectral)
- DNI (broadband)
- DHI (spectral)
- DHI (broadband)
- GHI (broadband)

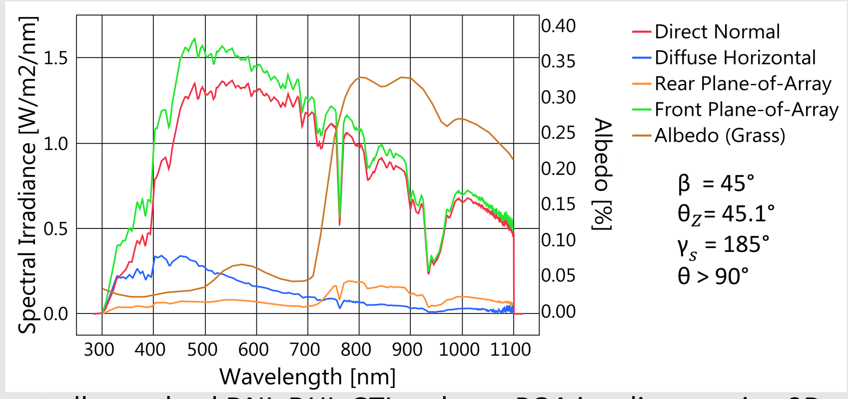


$$GHI(\lambda) = DHI(\lambda) + DNI(\lambda) * \cos(\theta_Z)$$

$$G_{Rear}(\lambda) = DNI(\lambda) * \cos\theta + \ldots$$

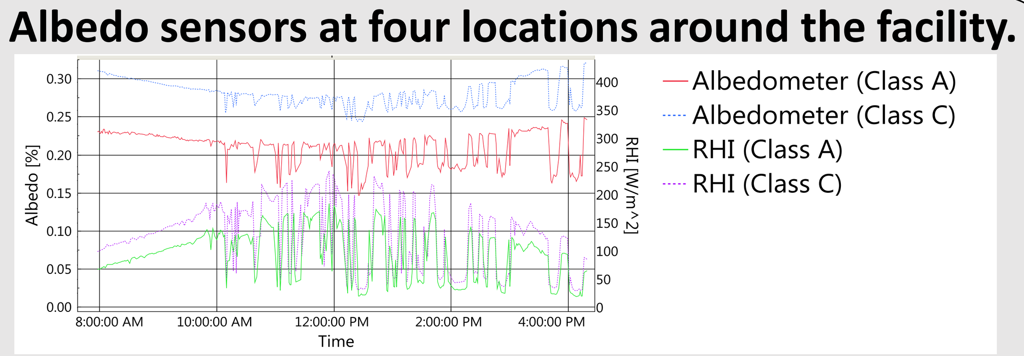
$$\sum_{i=1°}^{180°} VF_{nsh\rightarrow PV,i} * GHI(\lambda) * \rho(\lambda) + VF_{sh\rightarrow PV,i} * \rho(\lambda) * DHI(\lambda)$$

Where:
i = ith 1° segment of PV rear side
$VF_{nsh\rightarrow PV}$ = view factor from unshaded ground to PV
$VF_{sh\rightarrow PV}$ = view factor from shaded ground to PV
θ = Angle of incidence to PV rear side



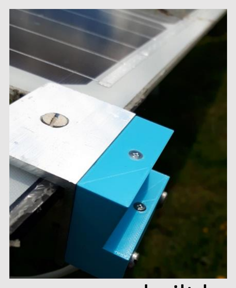
Spectrally resolved DNI, DHI, GTI and rear POA irradiance using 2D VF model and assumptions for albedo (SMARTS database).

Albedo sensors at four locations around the facility.

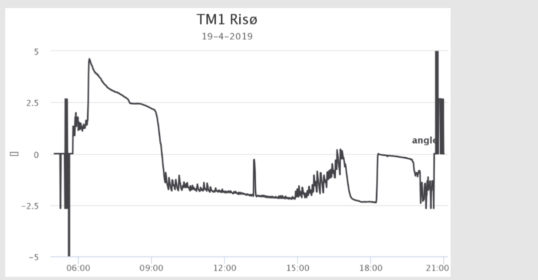


Albedo of grass as measured by Class A pyranometers vs. Class C photodiodes.

Tracker error monitor for single axis trackers.



Tracker error sensor built by Startak.



HSAT Tracking error measured by Startak Sensor.

Performance Modeling

We are using the onsite meteorological data as inputSs to bifacial PV models. The model's output is then compared to our electrical measurements. View factor models under consideration currently include MoBiDiG (ISC Konstanz), PVsyst, and SAM. Ray trace models currently being tested include Zemax and Radiance.

Measured Model Inputs
- DHI, DNI, Albedo, GHI, Tamb and Windspeed
- PV electrical parameters
- Shade Scene, tracker features

Model Assumptions

→ **Simulation** →

Obtain Model Outputs
- DC+AC power
- Transposed irradiance
- Cell temperature (Tcell)

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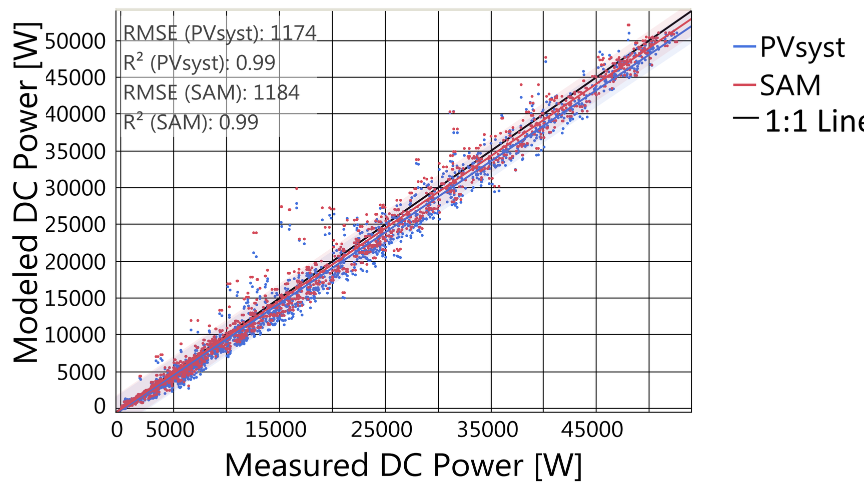
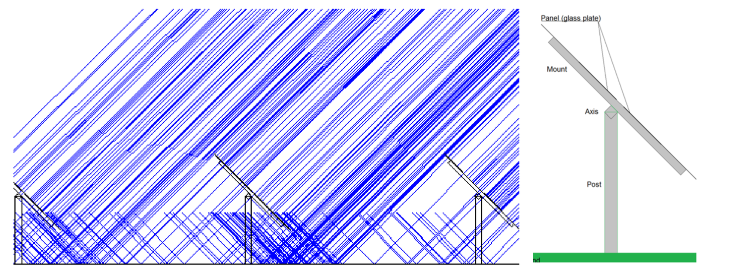
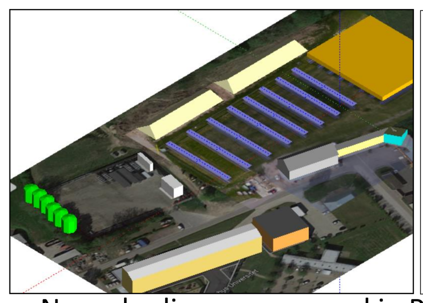
Compare to Field Measurements
- DC+AC power
- Plane of array irradiance (front and rear)
- Tcell (currently only mono-fi)

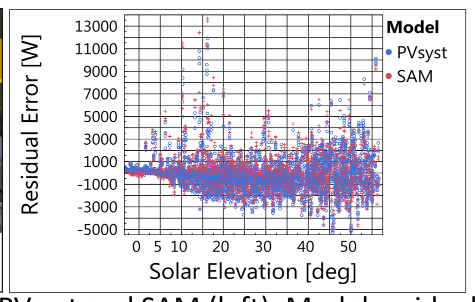


Modeled vs. Measured power of four rows of 25° fixed tilt bifacial systems mounted on seasonal grass over 6 months (Jan. – Jul. '19).

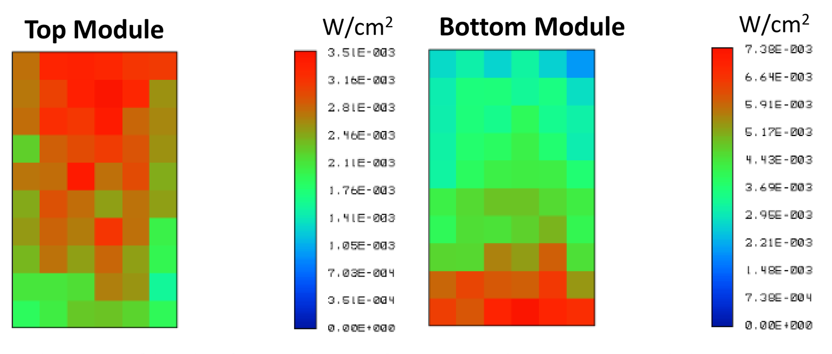


Non-sequential ray tracing in Zemax (left). Simulated structural geometry (right).





Near shadings scene used in PVsyst and SAM (left). Model residuals plotted as a function of sun height (right).



Distribution of back of module irradiance on the center modules within the '2V' module string during a clear sky conditions (ρ= 20%, β = 25°). Both the top (left) and bottom (right) modules in the 2V configuration are shown.

Acknowledgements

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Partners

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www.solartrackercontroller.com