Recommended Practices for PV Module Outdoor Characterization and Power Rating

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Agenda

• Introduction
• Energy Rating standard
• Module benchmarking and uncertainties
• Module energy yield measurements
  - Reference documents
  - Presentation of best practice survey
  - Recommendations
• Conclusions
Some key questions

• Which module technology is the best for my system?
• What annual energy yield can I expect?
• What annual degradation do I have to assume?
• How long will the modules last before I have to replace them?
Module & system yield calculation

Need of accurate module input parameters!

Ref: C. Reise, Fraunhofer ISE
PV Module Energy Rating
According to IEC 61853

Photovoltaic (PV) module performance testing and energy rating

- Module measurements
  - IEC 61835-1: Irradiance and temperature performance measurements and **power rating**
  - IEC 61835-2: Spectral responsivity, incidence angle and module operating temperature measurements

- Meteorological data
  - IEC 61835-4: Standard reference climatic profiles

- Performance prediction:
  - IEC 61835-3: Energy Rating of PV Modules
PV Module Energy Rating
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• Module measurements
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• Meteorological data
  – MeteoNorm, SolarGIS, ...

• Performance prediction:
  – PVsyst, PV*SOL, Zenit, ...
Module Benchmarking and its Uncertainties
based on energy yield calculations

Typical module performance ratio uncertainties may be greater than the actual differences in module performance ratio. Any benchmarking has always to take into account the involved uncertainties.

Using the “z-score”: \( z = \frac{\text{MPR} - \text{MPR}_{\text{ref}}}{u_{\text{MPR}}} \)

Module Benchmarking and its Uncertainties based on energy yield measurements

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\[ \text{c-Si } \Delta \text{MPR } \pm 1.5\% \]

\[ \text{thin film } \Delta \text{MPR } \pm 10\% \]

Ref: G. Friesen et al., SUPSI
Module Outdoor Energy yield measurements

Energy yield measurements of PV modules in different climatic locations plays an important role:

- deeper understanding of module performance
- demonstration of technological differences (benchmarking)
- assessment of typical degradation rates
- validation of energy prediction models/energy rating

Need of standardized procedures and clear uncertainties!
Energy Yield Monitoring - Reference documents


![DERLAB Technical Guideline](image1)

Ref: Gantner – test facility

**IEC 61724-1 (2017) PV system performance Part 1: Monitoring**

![IEC 61724-1](image2)

**IEA Technical report on Photovoltaic Module Energy Yield Measurements: Existing Approaches and Best Practice.**

![IEA Technical report](image3)
Best Practice survey

- 15 test laboratories participated
- 33 test facilities distributed worldwide
- 7 out of 8 are ISO 17025 accredited laboratories

**Participants**

- CSIRO – Australia
- AIT - Austria
- GANTNER – Austria
- KU LEUVEN - Belgium
- LABORELEC - Belgium
- IEE.AC - Cina
- University of Cyprus - Cyprus
- INES – France
- Fraunhofer ISE – Germany
- TUV Rheinland - Germany
- University of Utrecht - Netherlands
- SUPSI - Switzerland
- NIST - USA
- NREL - USA
- SANDIA - USA
Typical configuration and testing scopes

Module benchmarking
- relative meas. accuracy
- comparability of modules

Degradation studies
- long term data reliability
- comparability of different sites

Model validations
- absolute measurement accuracy
- synchronization of data

Ref: SUPSI – test facility
Ref: TüV Rheinland – test facilities
Ref: NREL – test facility
Variations of typical configurations

Special modules

- different orientations and albedo
- additional sensors

Ref: SANDIA – bifacial modules

Special modules

- thermal insulation
- additional sensors

Ref: SUPSI – BIPV components

Specific losses

- 0-2000 bias voltage
- monitoring of leakage currents

Example: SERIS - PID testing
General test requirements

The measurement accuracy depends as much on the conditions around the measurement system as on the test equipment itself!

- **Test device**
  - reference power (kWh/Wp)
  - selection of modules

- **Test site**
  - irradiance uniformity
  - temperature uniformity
  - soiling
  - hardware exposure

- **Test equipment**
  - hardware definition
  - \( P_m \) measurement accuracy
  - \( E \) measurement accuracy
  - \( G, T_{mod} \) measurement accuracy

- **Test processing**
  - data quality
  - failure identification
  - reporting
Recommendations on sampling procedures

**Benchmarking**
- clear and same procedure for all modules for a fair rating
- consideration of manufacturer distribution and binning
- selection from flasher list values
- characterization and stabilization in accordance with IEC 61215

**Long-term measurements**
- min 2 modules/type for cross verification
- dark reference module for control measurements with solar simulator
- Sorting of damaged/not representative modules (VI, EL)
Recommendations on reference power

**Nominal STC power** $P_{nom}$ as stated by the manufacturer
- commercial approach (sensible to labeling strategies)

**Stabilized real STC power** $P_{stab}$ as measured accord. IEC 61215
- most suitable approach for benchmarking, lowest measurement uncertainty, degradation has to be controlled

**Actual STC power** $P_{out}$ as measured during outdoor exposure
- most suitable for the study of meta-stabilities or degradation effects, higher measurement uncertainty, requires additional measurement of correction parameters, requires IV-tracer system
Recommendations for test facilities and module mounting

- **Mounting rack layout**
  optimal and controlled tilt and orientation, co-planar racks, no back side obstructions, consideration of wind conditions

- **Module mounting**
  minimum height from ground and spacing between modules, dummies on the sides, single module rows

- **Shading**
  Maximize and equal time window, shadow free mounting/clamping

- **Albedo radiation**
  uniform ground, minimum high from ground, sufficient row distance, avoid high-reflective surfaces
Recommendations on current voltage measurement

Maximum power point tracker (MPPT)  IV-tracer (IV)  IV-tracer with MPPT

- e.g. micro-inverters or high precision laboratory equipment
- e.g. programmable bidirectional power supplies or capacitive loads
- e.g. all-in-one solutions or assembled instruments.

- Measurement accuracy has to fulfil the standard requirements (IEC 60904-1, IEC 61724-1).
- Static and dynamic tracking accuracy of MPPT’s has to be known when using the MPPT for power integration.
- Synchronization errors has to be avoided or minimized.
- Load conditions different from $P_{\text{max}}$ between IV curves has to be avoided.
- IV tracer and MPPT has to be configured in accord. to the technology.
Recommendations for irradiance measurement

- The installation of irradiance sensors should follow the recommendations of the standard IEC 61853-2 and IEC 61724-1.
- Multiple irradiance sensors shall be monitored to detect any drifts.
- The scatter of solar irradiance measured at different locations in the array shall not exceed ±1%.
- Pyranometers should be used for the calculation of MPR.
- Reference cell values and spectral data are used for scientific analysis.

**Pyranometers**
- e.g. fast responding broadband thermopile pyranometers

**Reference cells**
- e.g. filtered and unfiltered cells for different spectral response

**Spectrumradiometer**
- e.g. spectrum radiometer
# Recommendations for temperature measurement

<table>
<thead>
<tr>
<th>Contact methods</th>
<th>Voc methods</th>
<th>Infrared methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>e.g. Pt100 RTD or thermocouples</td>
<td>ECT method accord. IEC 60904-5</td>
<td>e.g. spectrum radiometer</td>
</tr>
</tbody>
</table>

- The installation of temperature sensors should follow the recommendations given in the standard IEC 61853-2 and IEC 61724-1.
- To ensure the best results, it is recommended to cross check the contact method with at least another method.
- Number and positioning of sensors should be adapted to the scope and type of device under test.
Recommendations for maintenance

Survey results: implementation of different maintenance measures within the 15 interviewed parties.

All system maintenance, including cleaning of sensors and modules, or soiling state of modules, shall be documented.
### Recommendations for data pre-processing

<table>
<thead>
<tr>
<th>Error Marker</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>out of range</td>
<td>12</td>
</tr>
<tr>
<td>missing data</td>
<td>11</td>
</tr>
<tr>
<td>disconnected module</td>
<td>11</td>
</tr>
<tr>
<td>detachment of temp. sensor</td>
<td>9</td>
</tr>
<tr>
<td>irradiance drift</td>
<td>9</td>
</tr>
<tr>
<td>anomalous peaks</td>
<td>8</td>
</tr>
<tr>
<td>bad I-V curve</td>
<td>8</td>
</tr>
<tr>
<td>module drift</td>
<td>7</td>
</tr>
<tr>
<td>noisy signal</td>
<td>6</td>
</tr>
<tr>
<td>shadowed module</td>
<td>3</td>
</tr>
<tr>
<td>snow detection</td>
<td>3</td>
</tr>
</tbody>
</table>

**Survey results:** implementation of data quality control within the 15 interviewed parties.

Data availability = \( 1 - \frac{\text{useful nr. of data}}{\text{theoretical nr. of data}} \) * 100%

**Recommended** > 90%
Recommendations for data post-processing

Module benchmarking

Degradation studies

Model validations

Ref: SUPSI – test facility

Ref: TüV Rheinland – test facilities

Ref: NREL – test facility

Any data reporting has to include a description of the uncertainties, sampling and testing procedure.
Recommendations for uncertainty declarations

- measurement accord. best practice guidelines (minimize uncertainties).
- there exist no unique reference conditions for the module energy measurements → calculation of uncertainties specific to time, location and test facility.
- reporting of integration time (year, month, day, hour or minute).

Ref: A. Driesse; PVSENSOR project, Daily and annual profile of the measurement error (minute and weekly resolution) caused by angle-of-incidence, spectrum and temperature for a reference cell located in Golden Colorado, tilted 40° South.
Conclusions

Best practice on module energy yield measurements have been collected and reported with general recommendations. The survey revealed:

- good measurement practice (high precision equipment + prevention of major measurement errors)

- good quality control (e.g. use of quality markers, e-mail alerts) and maintenance practice spectral data monitoring

Comparability of outdoor data and validation of models could be further improved in future.

- harmonization of uncertainty calculations and declarations of performance indicators.
Thank you for your attention

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