Webinar: Uncertainty Estimations of PV Outdoor Measurements

Topic 3: PV Energy Yield Uncertainty Estimation using the Propagation of Uncertainty Method

Vincent Helmbrecht

Organisation: Franco Roca; Vincent Helmbrecht
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Contact: vincent.helmbrecht@der-lab.net

Speaker: Vincent Helmbrecht (DERlab)
Long-term PV Module Outdoor Measurements for Energy Yield Estimations

Data from long-term PV Outdoor Measurements contain unintended and intended environmental effects in the measurement results. Unintended effects during the testing period have to be described and reduced as far as possible. Because of environmental effects, long-term outdoor measurements are site specifically not repeatable.

Examples for unintended environmental effects:

a) A birds’ relieve

b) Flora on a modules’ frame

Photos: Peter Funtan
Different practices for PV Module Maintenance

1. “Clean” Module practice: Regular cleaning of the modules’ surface; back heating/reverse current to prevent shading from snow.

→ Result: Higher energy yield compared to not cleaned modules

2. “Dirty” Module practice: Leave modules without cleaning during the testing period, including soiling and snow.

→ Result: Self-cleaning mechanisms of the module affect the energy yield (Frame/Frameless; Surface Structure)

→ Test conditions have to be described in detail for the test reports!
Sources for Uncertainties in PV Module Outdoor Yield Measurements:

- Maintenance of the test site
- Environmental effects
- MPP Tracking
- Calibration
- Measurement equipment
- Further sources …
Types of Measurement Uncertainty according to GUM¹:

- **Type A**: “Method of evaluation of uncertainty by the statistical analysis of series of observations”

- **Type B**: “Type B evaluation of an uncertainty component is usually based on a pool of comparatively reliable information”

→ **Required information for PV Outdoor Energy Yield Measurements Type B analysis:**

- Measurement device uncertainties (Calibration protocol)
- Data Acquisition Resolution (A/D-converter)
- Module Temperature (Temperature homogeneity, surface-to-cell temperature correction, e.g. 2.5K ± 1K @ SIT → ASU)
- Spectral response (if using reference cells)
- Time Step (e.g. Annual deviation comparing 1 min and 1s measurement intervals: 0,02%  □
  Uncertainty increases with short measurement periods!)
- Uncertainty of the applied calculation models

Three steps to analyze Type B Measurement Uncertainty for PV Module Performance:

1. Collection of information on all uncertainty components $u_x$.

2. Assumption of uncertainty probability distribution based on manufacturer‘s specifications, calibration history, etc.

3. Calculation of combined standard uncertainty, $u_c$, combining the components’ uncertainties by using propagation of uncertainty method (also: root-sum-of-squares)$^2$

Propagation of Uncertainty according to GUM:

\[ u_c(Y) = \sqrt{\sum_{k=1}^{m} \left( \frac{\partial Y}{\partial X_k} \right)^2 \cdot u(X_k)^2} \]

- \( u_c(Y) \): Combined Standard Uncertainty
- \( Y \): Measurand
- \( u(X_k) \): Standard Uncertainty of each parameter

Each \( u(X_k) \) is already the combined uncertainty including uncertainties of the parameter,
\[ \Rightarrow \text{e.g. For voltage measurements: voltage range DAQ, resolution A/D, accuracy of the instrument in the range of operation, tolerance.} \]

Calculating Annual Energy Yield Normalized to P\(_{\text{STC}}\):

\[
E_{\text{yield}/a} = \frac{\sum_{k=1}^{n} P_{\text{mpp}} \cdot \Delta t_k}{P_{\text{STC}} \cdot a} = \frac{\sum_{k=1}^{n} U_{\text{mpp}} \cdot I_{\text{mpp}} \cdot \Delta t_k}{P_{\text{STC}} \cdot a} \left[ \frac{kWh}{kW_{\text{STC}} \cdot a} \right]
\]

- \(P_{\text{mpp}}\): Power at Maximum Power Point
- \(U_{\text{mpp}}\): Voltage at Maximum Power Point
- \(I_{\text{mpp}}\): Current at Maximum Power Point
- \(P_{\text{STC}}\): Power at Standard Test Conditions
- \(a\): Year
- \(\Delta t_k\): Time Step / Resolution
1. Uncertainty of $P_{\text{MPP}}$ Measurements:

$$P_{\text{mpp}} = U_{\text{mpp}} \cdot I_{\text{mpp}}$$

**Absolute Uncertainty of $P_{\text{mpp}}$:**

$$u(P_{\text{mpp}}) = \sqrt{ \left( \frac{\partial P_{\text{mpp}}}{\partial U_{\text{mpp}}} \right)^2 \cdot u(U_{\text{mpp}})^2 + \left( \frac{\partial P_{\text{mpp}}}{\partial I_{\text{mpp}}} \right)^2 \cdot u(I_{\text{mpp}})^2}$$

$$u(E_{\text{yield}}) = \sqrt{ (I_{\text{mpp}})^2 \cdot u(U_{\text{mpp}})^2 + (U_{\text{mpp}} \cdot I_{\text{mpp}})^2 \cdot u(I_{\text{mpp}})^2}$$

**Relative Uncertainty of $P_{\text{mpp}}$:**

$$\frac{u(P_{\text{mpp}})}{P_{\text{mpp}}} = \sqrt{ \frac{u(U_{\text{mpp}} \cdot I_{\text{mpp}})^2}{U_{\text{mpp}}^2} + \frac{u(I_{\text{mpp}})^2}{I_{\text{mpp}}^2}}$$
2. Example for Uncertainty of \(P_{STC}\) Measurements:

\[
P_{STC} = \frac{U_{mpp} \cdot I_{mpp} \cdot F \cdot (1 + \alpha \cdot (25 - T_{mod}))}{G_{tmod} \cdot (1 + \beta \cdot \ln(G_{tmod}))}
\]

\[
u_c(P_{STC}) = \sqrt{\left(\left(\frac{\partial P_{STC}}{\partial G_{tmod}}\right) \cdot \left(\frac{G_{tmod}}{P_{STC}}\right)\right)^2 \cdot (u_{G_{tmod}})^2 + \left(\frac{\partial P_{STC}}{\partial I_{mpp}}\right) \cdot \left(\frac{I_{mpp}}{P_{STC}}\right)^2 \cdot (u_{I_{mpp}})^2 + \left(\frac{\partial P_{STC}}{\partial U_{mpp}}\right) \cdot \left(\frac{U_{mpp}}{P_{STC}}\right)^2 \cdot (u_{U_{mpp}})^2 + \left(\frac{\partial P_{STC}}{\partial T_{mod}}\right) \cdot \left(\frac{T_{mod}}{P_{STC}}\right)^2 \cdot (u_{T_{mod}})^2}
\]

\[
= \sqrt{(-1 - (\beta/(1 + \beta \cdot (\ln(G_{tmod}))))^2 \cdot (u_{G_{tmod}})^2 + 1^2 \cdot (u_{I_{mpp}})^2 + 1^2 \cdot (u_{U_{mpp}})^2 + (-\alpha \cdot T_{mod}/(1 + \alpha \cdot (25 - T_{mod}))^2 \cdot (u_{T_{mod}})^2}
\]

Open Questions:

→ Uncertainty of applied models?

→ Quantification of unintended environmental effects?

→ Best practices for inconsistent Measurement Data?
Sources:


Guidelines on PV Outdoor Measurements:

• Common Activities with JRA 2 /NA 2,3 (further comments for 2nd Edition)

• Enlargement of the scope (Measurement Uncertainties)

• Publication of the 2nd Edition fall 2013
Thank you very much for your attention!