

Systematic Approaches to Ensure Correct Representation of Measured Multi-Irradiance Module Performance in PV System Energy Production Forecasting Software Programs



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Presented at the 2013 PV Performance Modeling Workshop

Santa Clara, CA | May 1-2, 2013

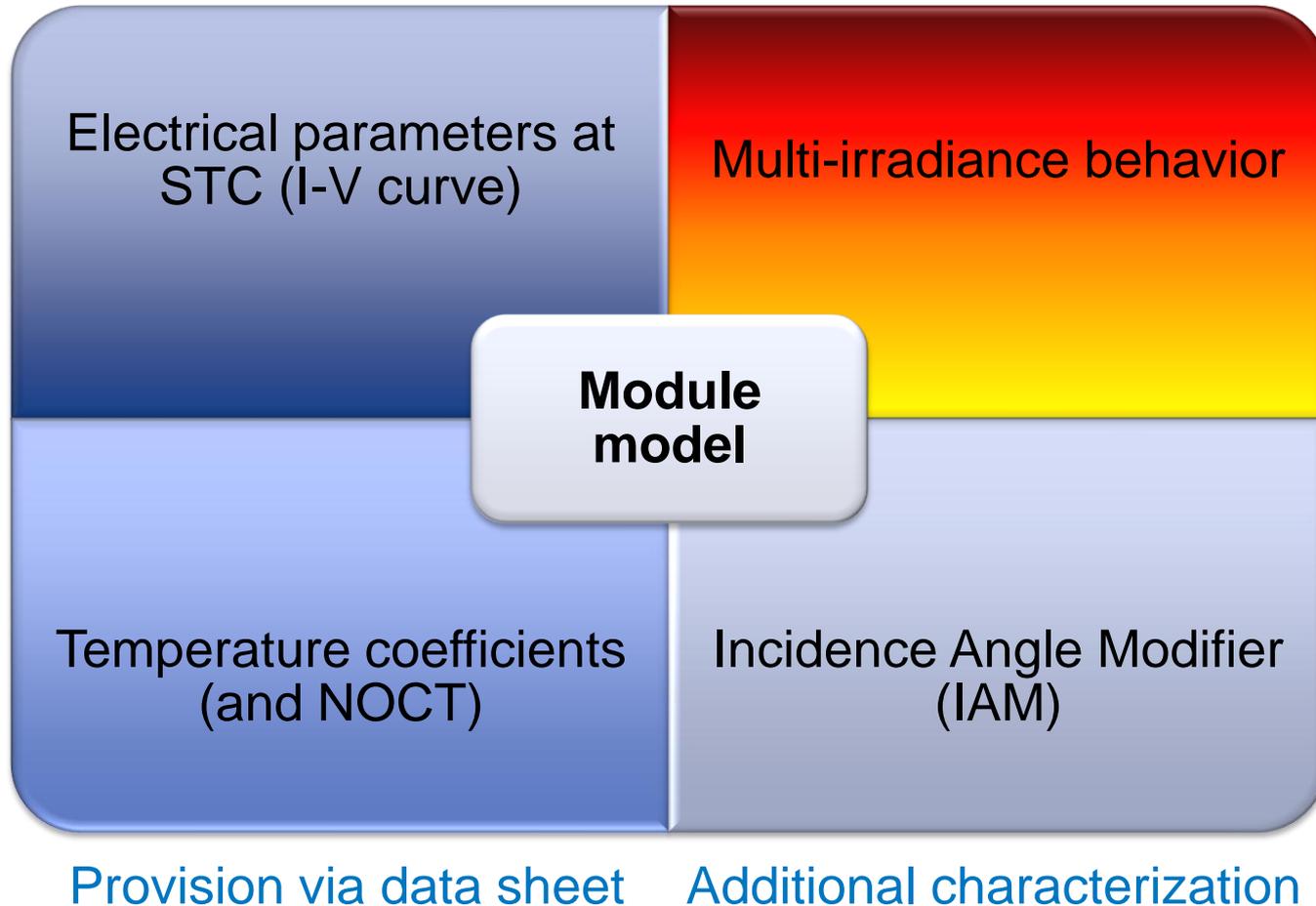


Outline

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Basics: Main components of PV module models



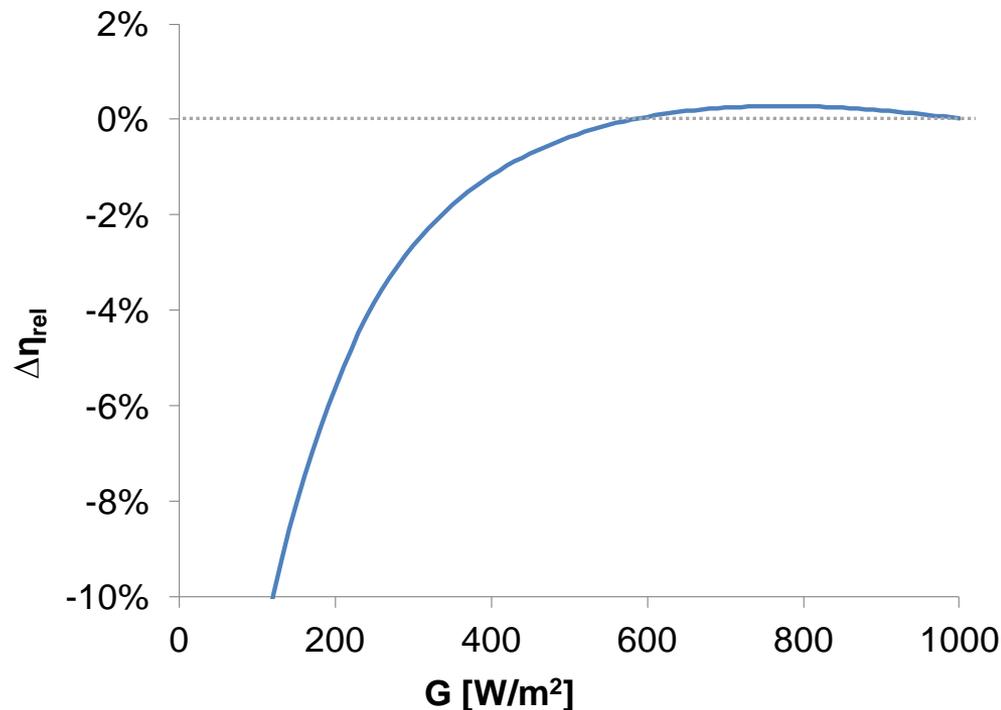
Basics: Multi-irradiance behavior of PV modules

- Characterized via “relative efficiency deviation” $\Delta\eta_{\text{rel}}$ [%] as function of irradiance G [W/m^2]:

$$\Delta\eta_{\text{rel}}(G) = \left(\frac{P_{\text{max}}(G)}{P_{\text{max,ref}}} \times \frac{G_{\text{ref}}}{G} \right) - 1$$

Subscript “ref” means reference conditions; usually STC (where $G_{\text{ref}}=1,000\text{W}/\text{m}^2$).

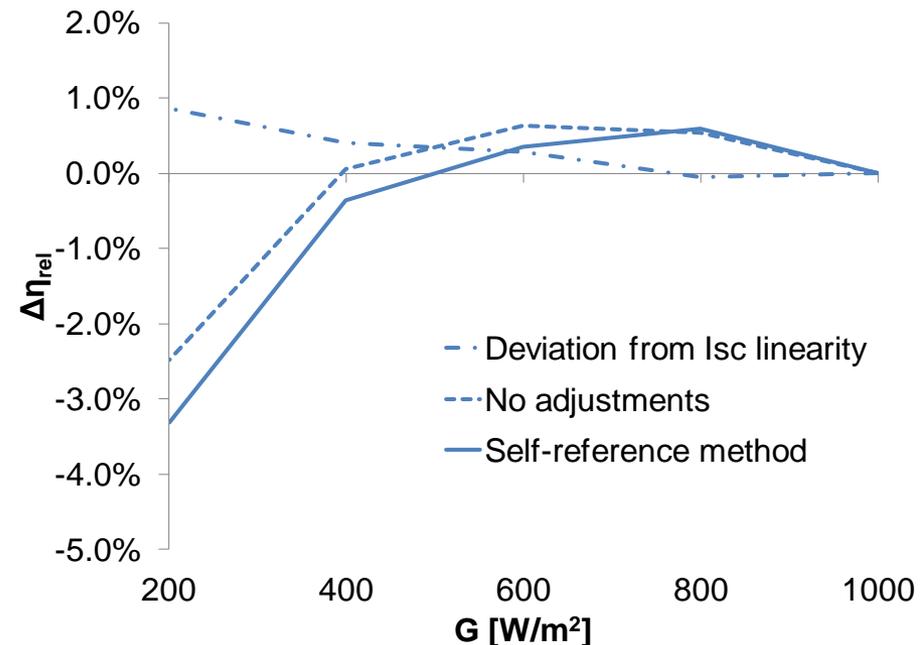
- Typical behavior:



Basics: Self-reference method

- For linear devices, if data are obtained from indoor flash testers, check that deviations from I_{sc} linearity are $<1\%$ (see IEC 61853-1 Section 8)
- Possible causes of I_{sc} non-linearity include but are not limited to:
 - Spectral mismatch between the irradiance sensor and sample under test if the spectrum changes over the irradiance range
 - Spatial non-uniformity caused by filter placement during calibration or test
- Obtain effective irradiance G used to calculate $\Delta\eta_{rel}$ following the self-reference method (IEC 61853-1 Section 8):

$$G = G_{ref} * (I_{sc} / I_{sc,ref}).$$



Multi-irradiance behavior in PV*SOL® and PVsyst

PV*SOL® (v4.0)

- Multi-irradiance behavior via one value of irradiance below reference conditions ($G_{\text{partial_load}}$), at which I-V curve parameters must be provided

The screenshot shows the 'Module Characteristic Values' window in PV*SOL v4.0. It has four tabs: 'Basic Data', 'U/I Char. - STC', 'U/I Char. - Part Load', and 'Other Data'. The 'U/I Char. - Part Load' tab is active. It displays two sections: 'Working Point under STC' and 'Working Point during Part Load Operation'. The 'Working Point during Part Load Operation' section is highlighted with a red box. It includes a checkbox for 'Standard Part Load Operation' which is checked. A red arrow points from the label $G_{\text{partial_load}}$ to the 'Irradiation [W/m²]' field, which is set to 300. Other parameters shown include MPP Voltage [V] (28.2951), MPP Current [A] (2.5650), Open Circuit Voltage [V] (33.9019), Short Circuit Current [A] (2.6790), Fill Factor (79.9), and Rel. Efficiency [%] (91.3).

PVsyst (V5.56)

- Multi-irradiance behavior via 5 parameters of one-diode model (series and shunt resistance, photo current, saturation current and diode quality factor), where 2 additional parameters are used to describe $R_{\text{Sh}}(G)$

The top screenshot shows the 'Definition of a PV module' window in PVsyst V5.56, 'Model parameters' tab. It lists 'Basic model parameters' for a Yingli Green Energy YL235P-29b module. A red box highlights the 'Shunt resistance' section where R_{sh} is set to 250 Ohm and R_{s} is set to 0.220 Ohm. A red arrow points to these values with the label $R_{\text{Sh}}, R_{\text{s}}$. A graph on the right shows the I-V curve for Incident Irrad. = 1000 W/m², Cells temp. = 25 °C, with a horizontal line at $R_{\text{sh}} = 250$ Ohm.

The bottom screenshot shows the same window but with the 'Exponential behaviour of R_{sh} as function of incident irradiance' section active. A red box highlights the 'Rshunt exponential' section where 'Rshunt at $G_{\text{inc}} = 0$ ' is set to 1000 Ohm and the 'Exponential parameter' is set to 5.5. A red arrow points to these values with the label $R_{\text{Sh},0}, R_{\text{Sh}}^{\text{Exp}}$. A graph on the right shows 'Rshunt as f(Irradiance)' with 'Effective Rshunt' (blue line) and 'Rsh ref = 250 ohm at 1000 W/m²' (black dots).



Motivation: Example data and default models

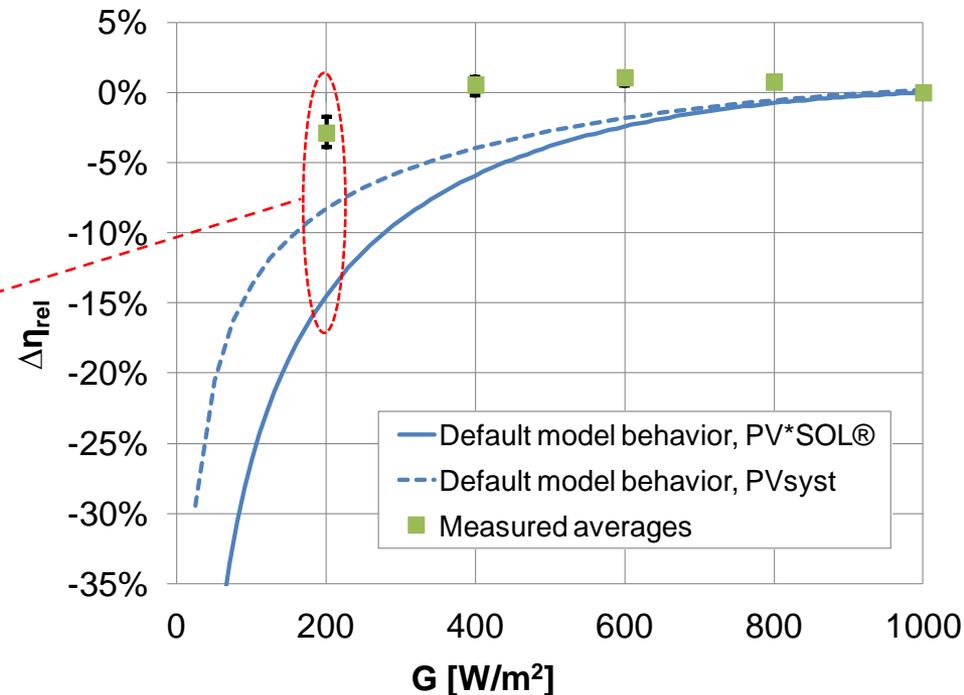
- (22) 235W Yingli Solar mc-Si PV modules
- Reputable 3rd party laboratory in USA
- Class AAA pulsed solar simulator
- I-V curve at STC
- 4 additional I-V curves (25°C and AM 1.5g)

- 800W/m²
- 600W/m²
- 400W/m²
- 200W/m²

IEC 61853-1
Section 8.5

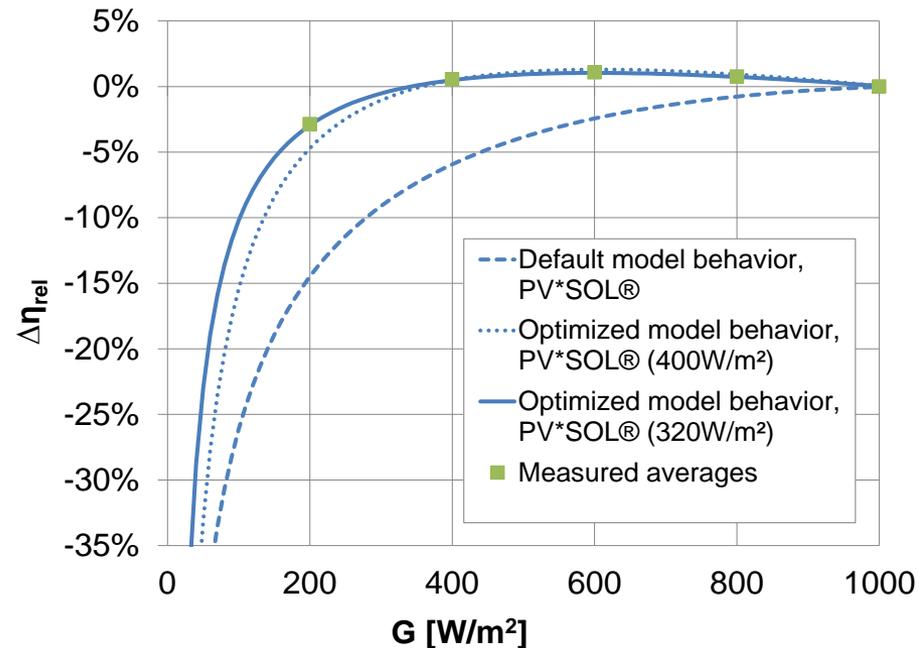
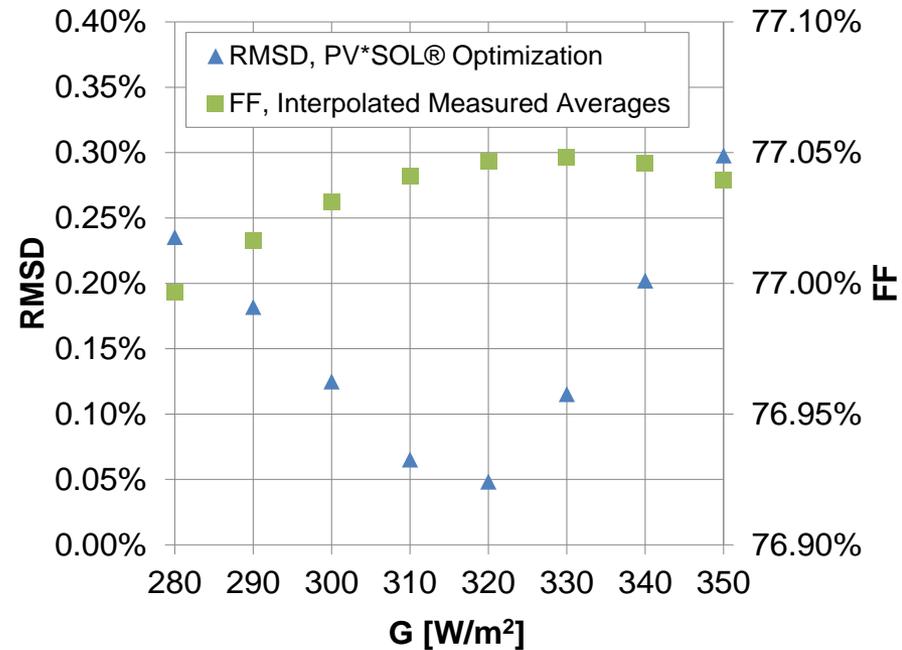
- $\Delta\eta_{rel}(200W/m^2)$:

- Measured averages = -2.9%
- Default PVsyst (V5.56) = -8.3%
- Default PV*SOL® (v4.0) = -14.5%



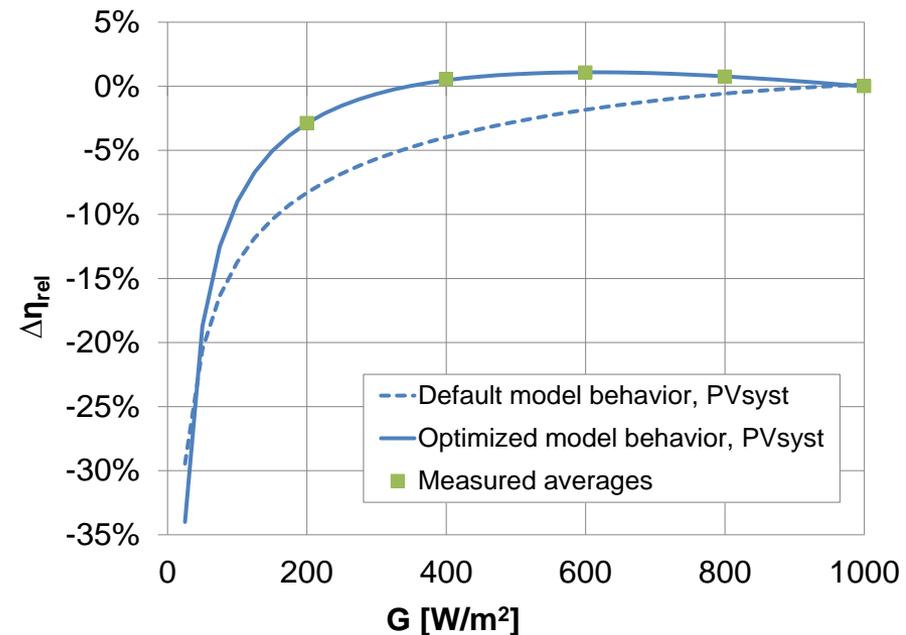
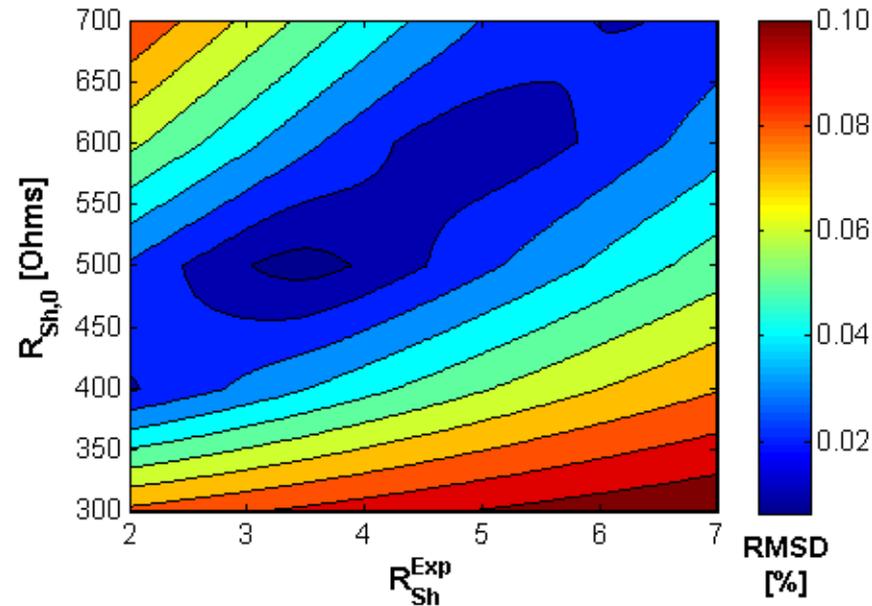
Systematic approach for PV*SOL®

- One user-modifiable variable ($G_{\text{partial_load}}$), thus manual optimization possible
- Limitations of coarse-grained grid of tested G
- Interpolation of measured data (IEC 61853-1 Section 9)
- RMSD: 6.19% (default) \rightarrow 0.05% (optimized)



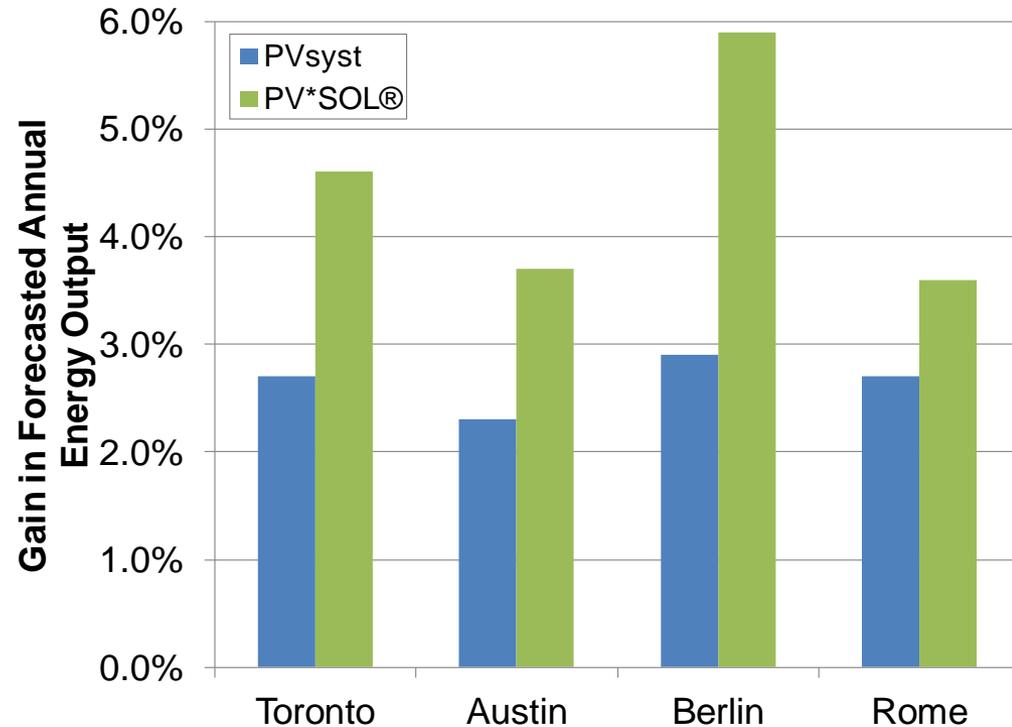
Systematic approach for PVsyst

- Optimization over a 4-dimensional space of parameters describing parasitic series and shunt resistances
 - Numerical optimization procedures are required
- RMSD: 3.46% (default) → 0.07% (optimized)



Impact on energy forecasts

- Annual energy production simulated over four geographically distributed locations
- Reported as gains in forecasted outputs using optimized models over forecasted outputs using default models
 - PV*SOL®: 3-6% gains
 - PVsyst: 2-3% gains



Summary and outlook

- Risk of relying on default settings that prescribe irradiance behavior in PV*SOL® and PVsyst module models
- Importance of characterizing PV modules following, e.g., IEC 61853-1
 - Plus fine-grained measurements close to $\max[FF(G)]$
- Systematic optimization procedures reported for fitting PV module models to measured data
- Next step: field validation of optimized models



Appendix: New software versions

