Overview of the PV Module Model in PVWatts

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Model Used in PVWatts

Model based on PVFORM Version 3.3 (1988)

- Provides estimate of maximum power, P_m
- For irradiance > 125 W/m^2

$$P_m = \frac{E_e}{E_0} \cdot P_{m_0} \cdot \left[1 + \gamma \cdot \left(T - T_0\right)\right]$$

where,

E = POA irradiance, W/m^2

T = PV cell temperature, ºC

γ = P_m correction factor for temperature, ºC^{-1}

Zero subscripts denote performance at SRC, the e subscript denotes an “effective” irradiance, which in the case of PVWatts means corrected for AOI but not spectrum.

Model Used in PVWatts (cont.)

A different formula is used at low irradiances to account for reductions in output observed by Sandia for crystalline silicon PV modules.

- For irradiance <= 125 W/m^2

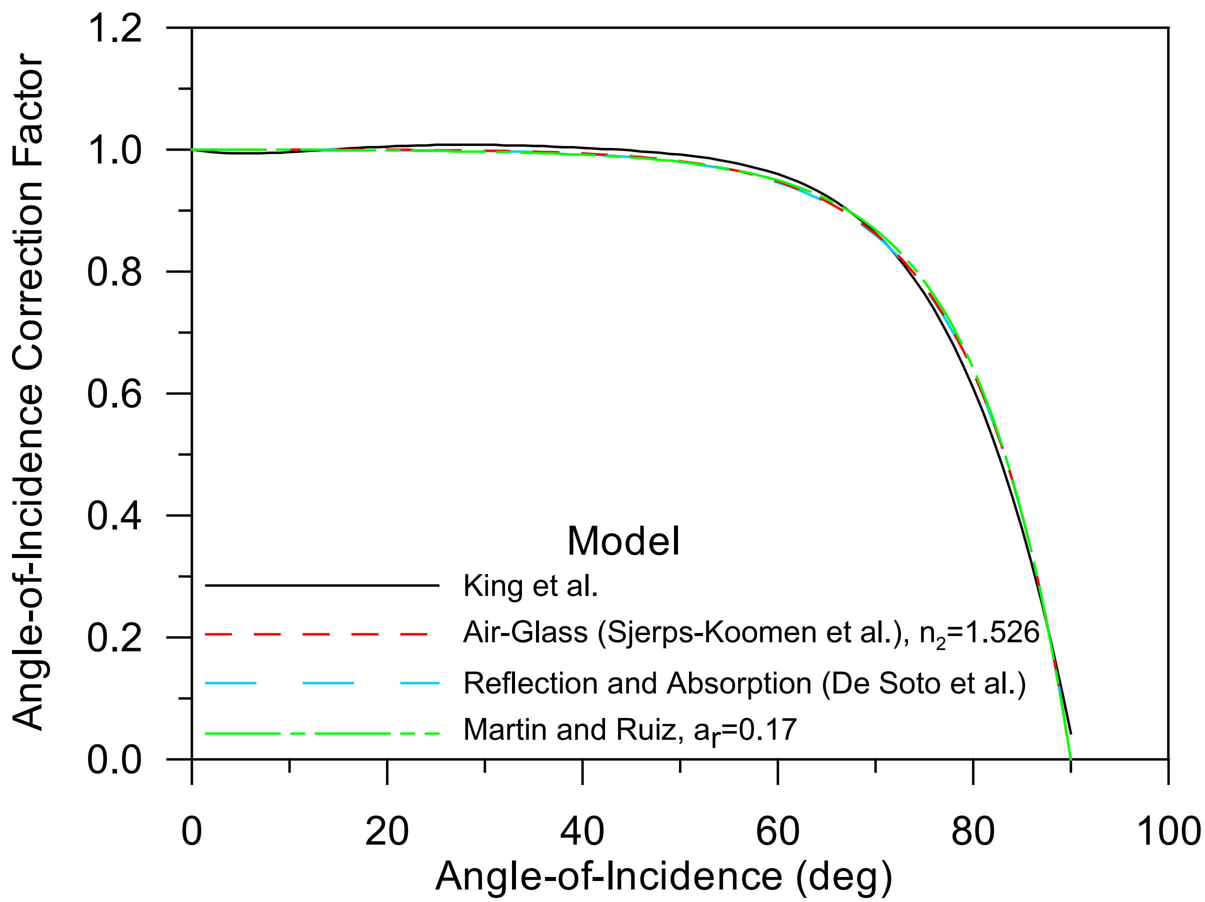
$$P_m = \frac{0.008 \cdot E_e^{\,2}}{E_0} \cdot P_{m_0} \cdot \left[1 + \gamma \cdot \left(T - T_0\right)\right]$$

- PVWatts also applies an AOI correction.

AOI Correction

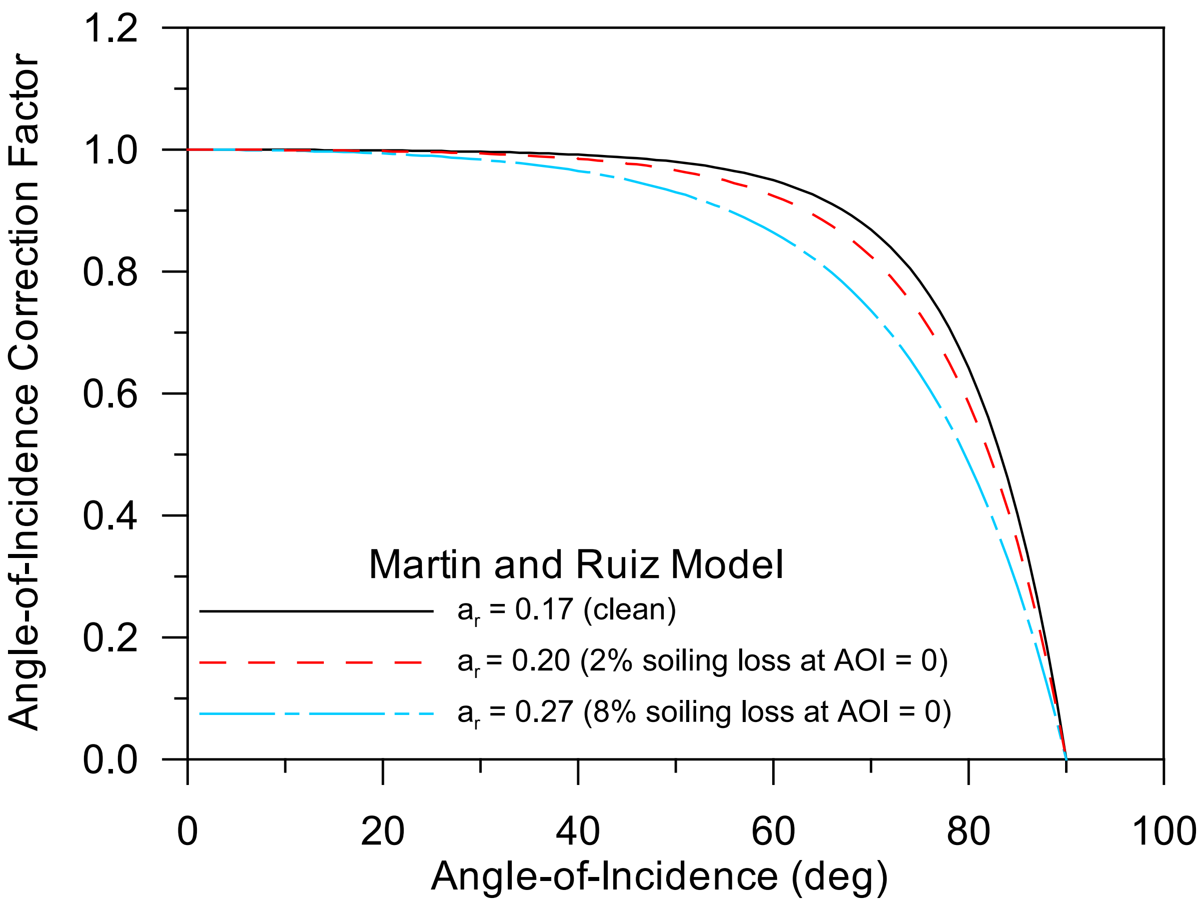
The King-Sandia AOI function is used to correct direct beam radiation for incident angles greater than 50 degrees.

Other equivalent methods are shown in the figure.



AOI Correction for Soiled PV Modules

Not used in PVWatts, but the method of Martin and Ruiz may allow for better predictions if the soiling amount is known. (Progress in PV, 2005; **13**:75-84)

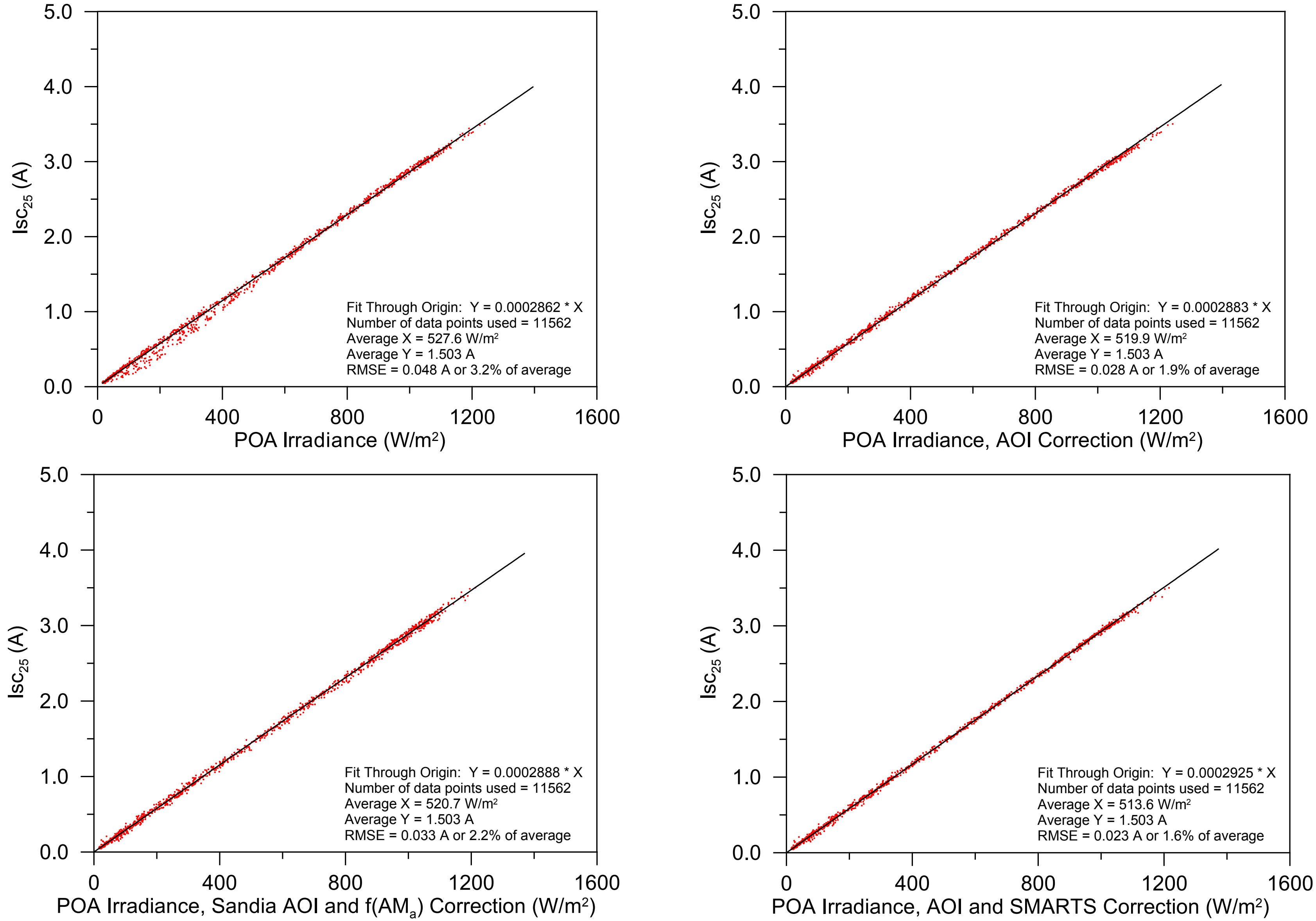


No Correction for Variations in Spectrum

Analysis of data collected at NREL and FSEC indicates no benefit for applying spectral corrections in PVWatts for x-Si and m-Si PV modules.

- For a group of 5 x-Si and m-Si PV modules at NREL, use of a spectral model and spectral response data reduced the RMSE in I_{sc} by only 0.1%, use of the Sandia AM_a function increased the RMSE by 0.3%.
- For amorphous silicon PV modules, both methods reduced errors in estimating I_{sc}, and the most favorable results were for the CREST air-mass function.

AOI and Spectral Correction Results



Historical Perspective

The traditional linear expression for PV power using irradiance, temperature, and a power correction factor for temperature was published by Evans and Florschuetz in 1977 (Solar Energy 19, 255-262).

- Is it appropriate for today's PV modules?
- How do it's predictions compare with later models when using the same inputs of irradiance and temperature?

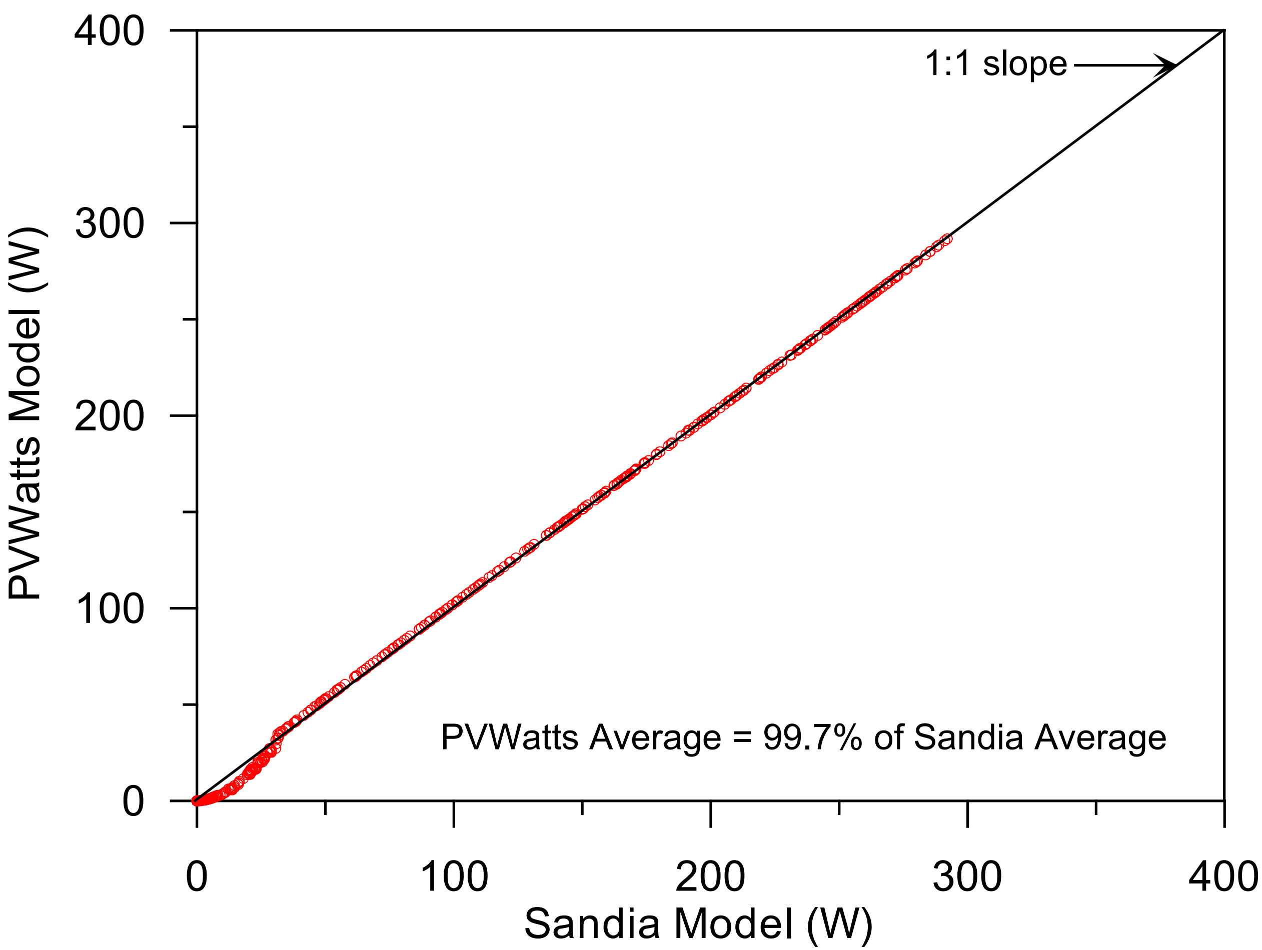
Comparison with Sandia Model

For the three modules and data sets for this workshop study, PVWatts module power estimates were compared with those using the Sandia model.

For PVWatts:

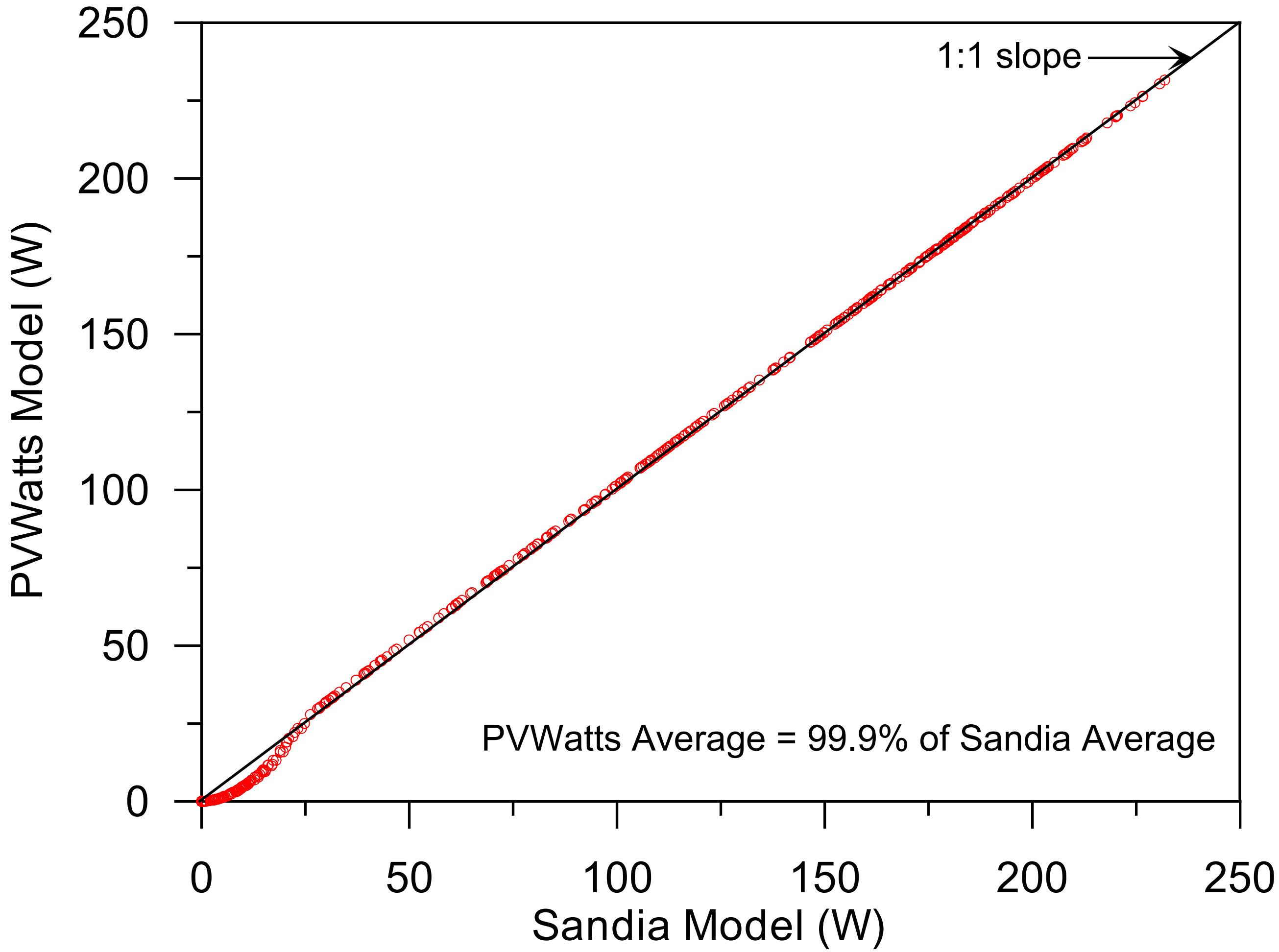
- P_{m_0} determined using the Sandia model for SRC.
- P_m correction factor for temperature determined using the Sandia model for SRC and for 1000 W/m^2 and 55 C
- This ensured agreement at 1000 W/m^2 and allowed differences at other irradiances to be more readily observed.

PVWatts versus Sandia for the Mobil Module

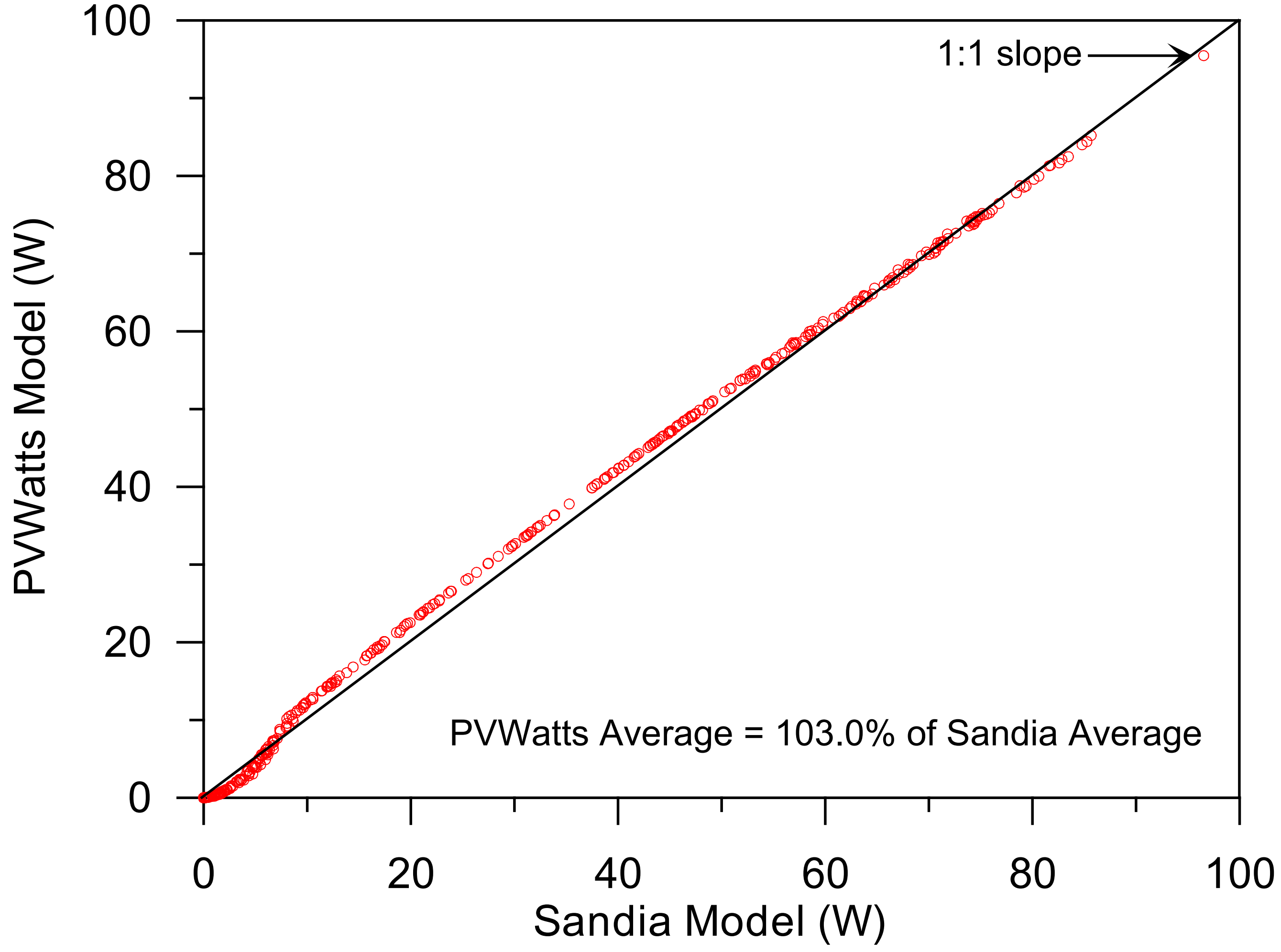


Differences at low irradiances from PVWatts using a different algorithm below 125 W/m^2.

PVWatts versus Sandia for SunPower

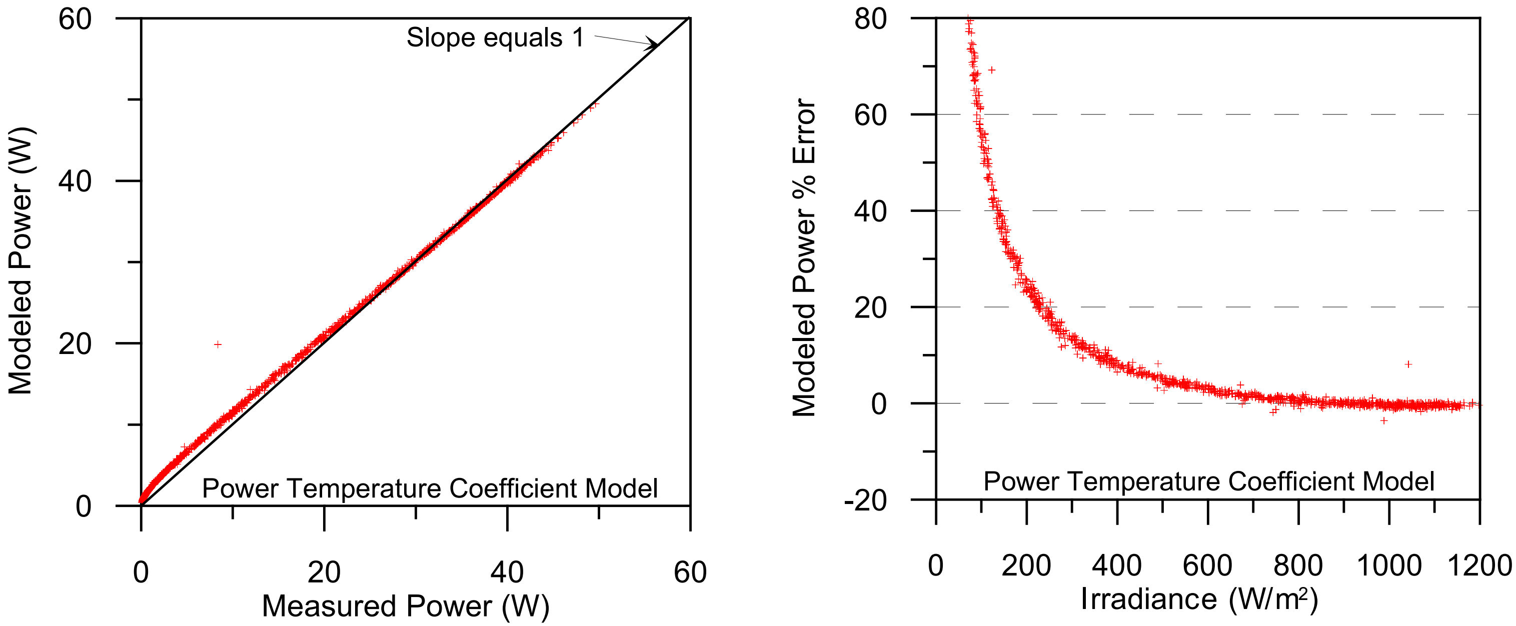


PVWatts versus Sandia for Shell



Correction for Irradiance Nonlinearity

Previous work (Marion, 2008 PVSC) presented a method for correcting for irradiance nonlinearity.



Scatter plot and percent error graph showing nonlinearity with respect to Irradiance for a multi-crystalline PV module.

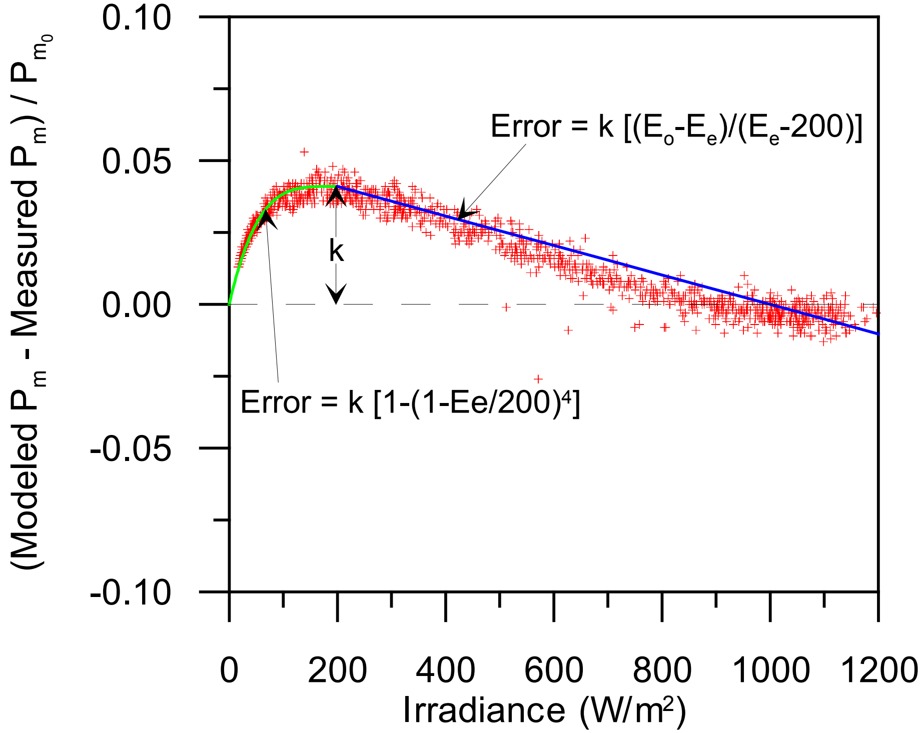
Correction for Irradiance Nonlinearity

Error function applies a non-linear correction below 200 W/m^2 and a linear correction above 200 W/m^2

- k is determined using a power measurement at 200 W/m^2 (now required by IEC 61215 and 61646)

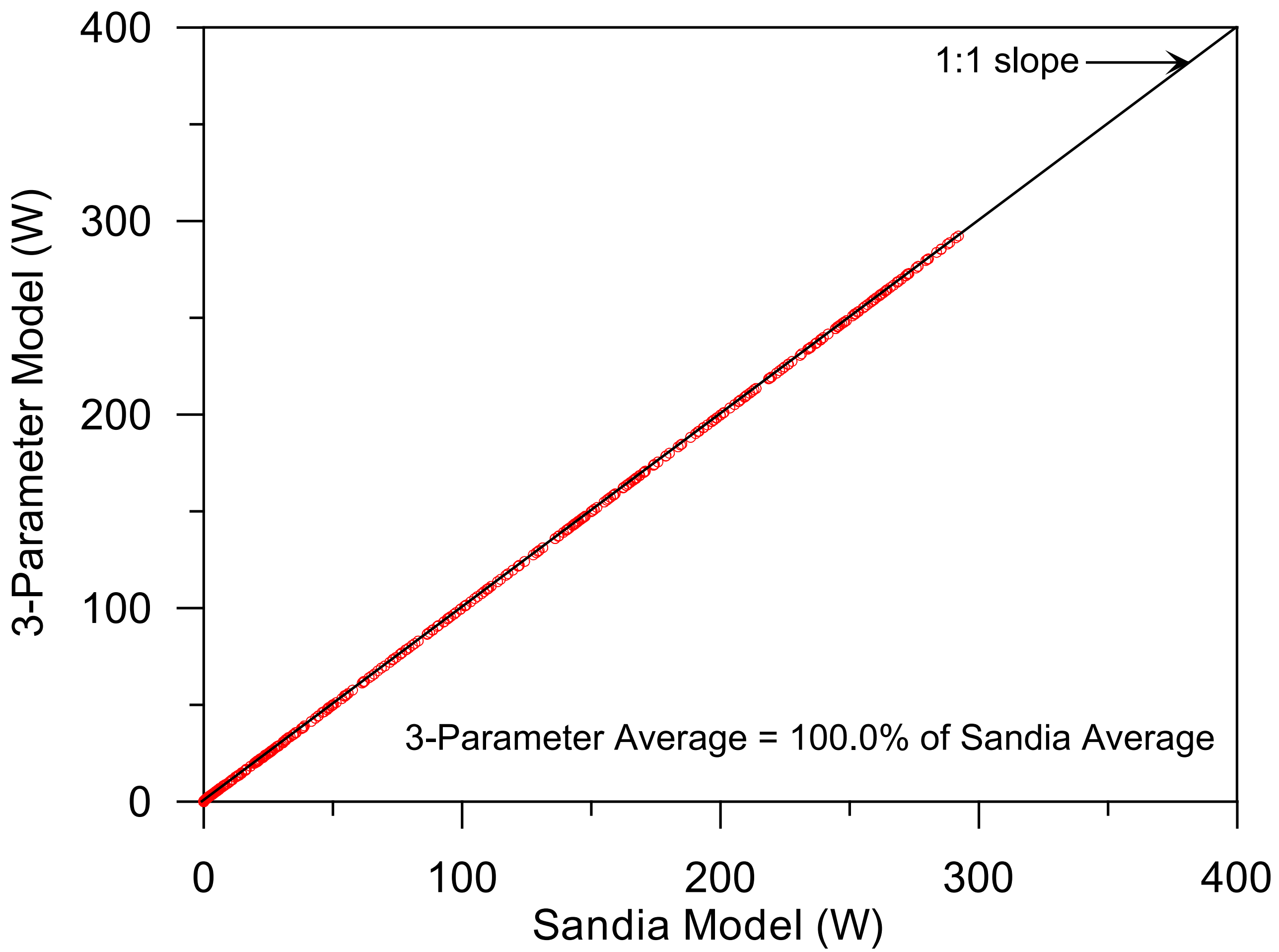
$$k = \frac{0.2 \cdot P_{m_0} - P_{200}}{P_{m_0}}$$

- Results in a model using 3 parameters: P_{m_0}, γ, and P_{200}
- k=0.011 for Mobil, 0.009 for SunPower, 0.030 for Shell

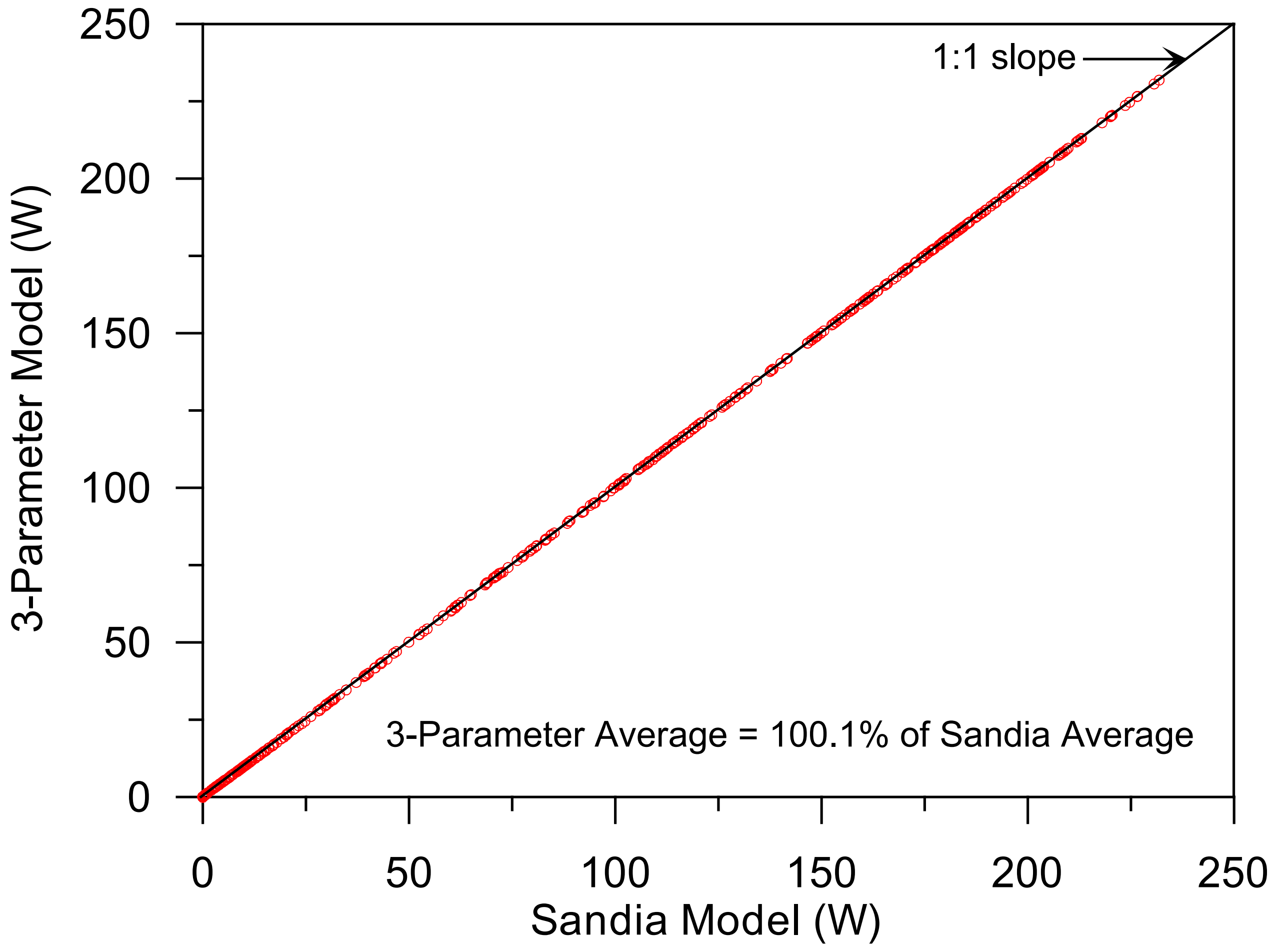


Error in watts normalized by P_{m_0}

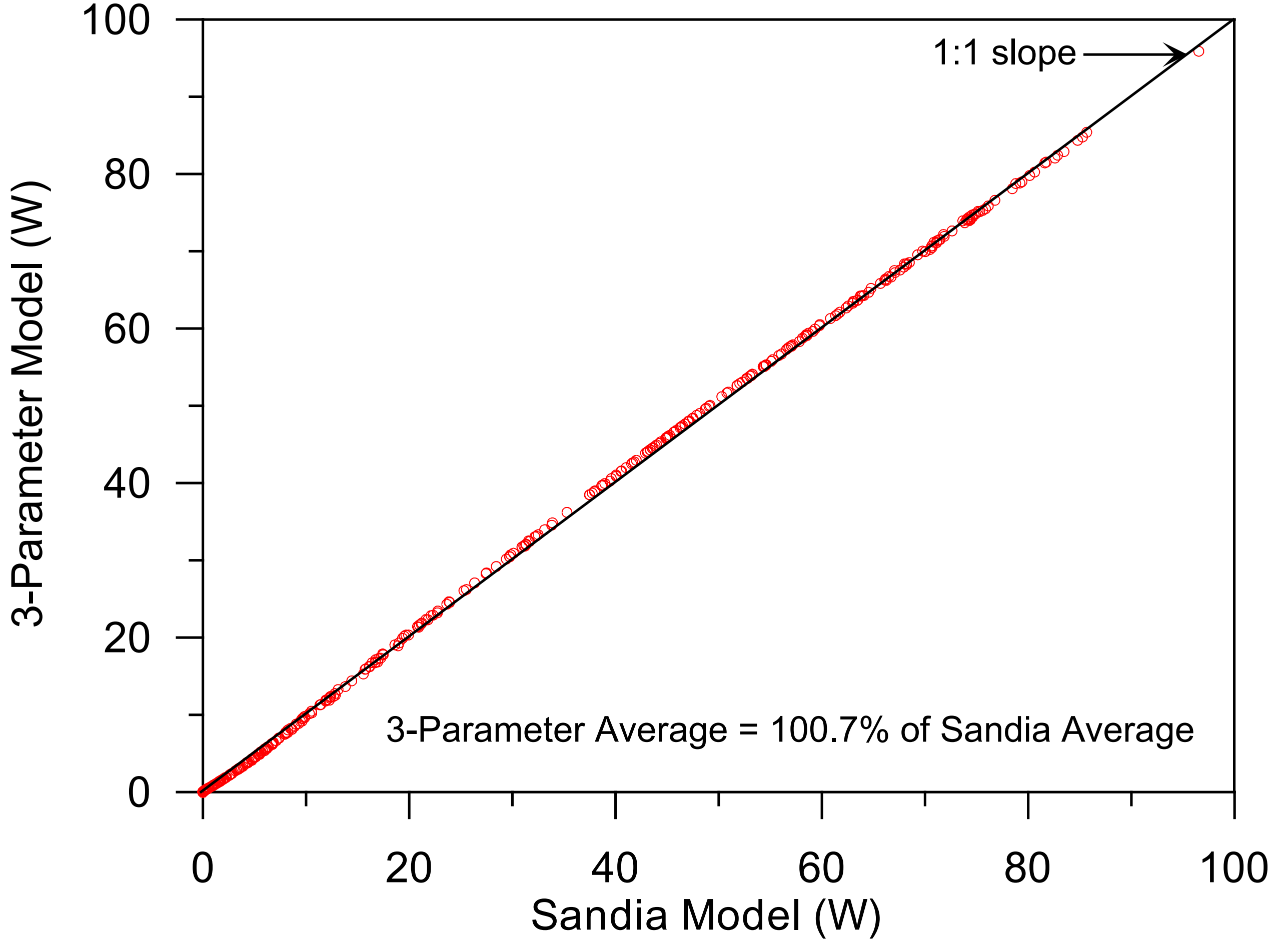
3-Parameter versus Sandia for Mobil Module



3-Parameter versus Sandia for SunPower



3-Parameter versus Sandia for Shell



Summary

The historical PV model in PVWatts is acceptable for estimating the energy production of PV systems.

- Even larger nonlinearities with respect to irradiance only impact estimates on the order of 3%, which may be inconsequential considering other sources of error: resource data, manufacturer's ratings, long-term degradation, shading, availability, etc.
- The addition of a 3rd parameter to the model could reduce errors associated with nonlinearity if the additional data proved reliable.