SAND2014-19741C

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PV Module Model Calibration Using Monitored Data

6th World Conference on Photovoltaic Energy Conversion
Kyoto, Japan, November 26, 2014

Clifford W. Hansen, Katherine A. Klise, Joshua S. Stein
Sandia National Laboratories, Albuquerque, New Mexico, USA
Yuzuru Ueda
Tokyo University of Science, Tokyo, Japan
Keiichiro Hakuta
NTT Facilities, Inc., Tokyo, Japan

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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Overview

- Goal: extract parameters for module performance models from outdoor electrical measurements
- Best models are obtained using a 2-axis tracker
- Can we obtain ‘good enough’ models using fixed tilt racking?

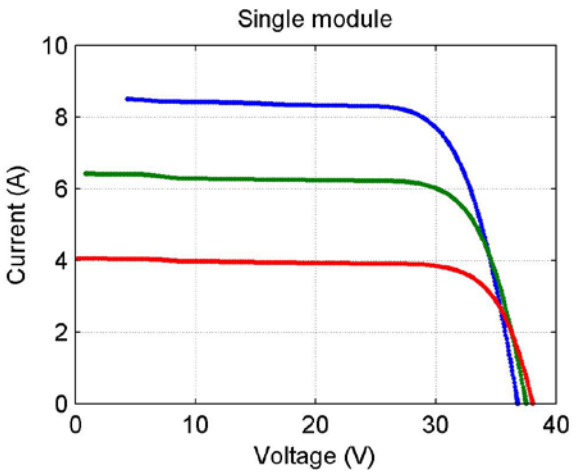
Data from systems at fixed tilt

Most common ↓ Least common

Most common ↓ Least common

- **Weather**
  - POA irradiance, air temperature, wind
  - GHI (pyranometer)
  - DNI, DHI, spectrum
- **Electrical output**
  - AC Power & voltage
  - DC Power & voltage at MP only
  - IV sweeps (interrupted inverter operations, reference modules)
- Data are filtered for agreement between I_{SC} and POA irradiance
- I_{SC} is often extrapolated at high irradiance

We use these data



Models Considered

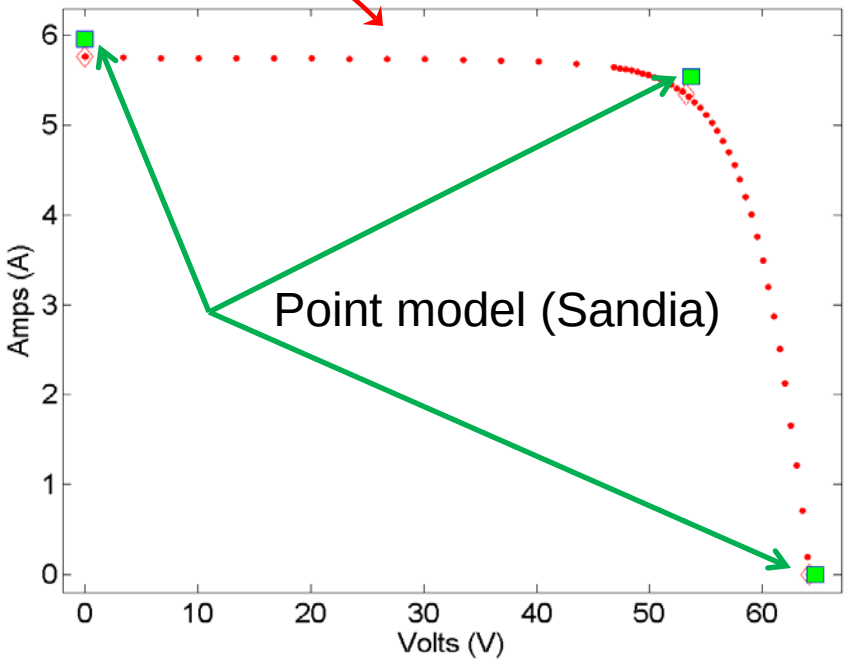
- **Single Diode Model (De Soto)**
  - IV curve described by single diode equation

$$I = I_L - I_0\left[\exp\left(\frac{V+IR_s}{nV_T}\right)-1\right]-\frac{V+IR_s}{R_{sh}}$$

  - "5 parameters" – for each IV curve
  - Additional equations describe how parameters change with irradiance, temperature
- **Point Model (Sandia)**
  - Empirical expression for I_{SC}, V_{OC}, P_{MP}

$$I_{MP} = I_{MP0}\left(C_0 E_e + C_1 E_e^2\right)\left(1+\alpha_{IMP}\left(T_C - T_0\right)\right)$$

$$V_{MP} = V_{MP0} + C_2 n N_S \delta\left(T_C\right)\ln\left(E_e\right) + C_3 N_S\left(n\delta\left(T_C\right)\ln\left(E_e\right)\right)^2 + \beta_{VMP}\left(T_C - T_0\right)$$



[1] W. De Soto, S. A. Klein, and W. A. Beckman, "Improvement and validation of a model for photovoltaic array performance," Solar Energy, vol. 80, pp. 78-88, 2006.

[2] D. L. King, E. E. Boyson, and J. A. Kratochvil, "Photovoltaic Array Performance Model," Sandia National Laboratories, Albuquerque, NM SAND2004-3535, 2004.

Model Fitting Procedure (SAPM)

- Example: estimating I_{SC0} and spectral modifier $f_1(AMa)$

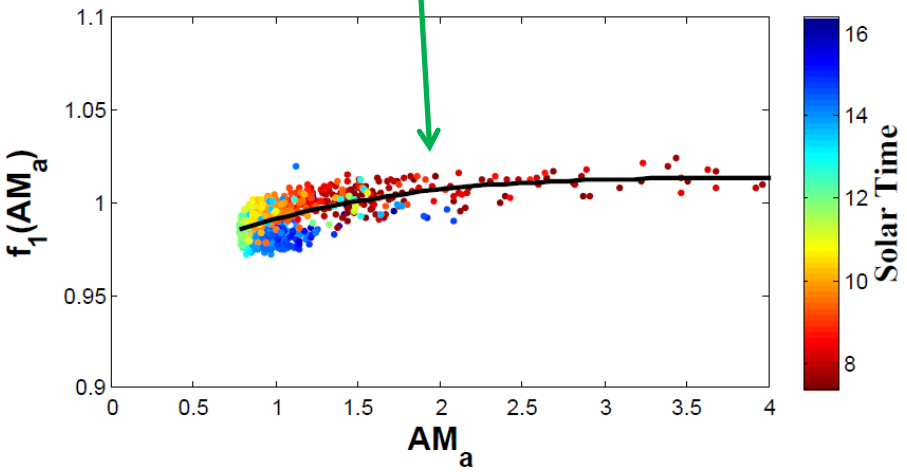
$$I_{SC} = I_{SC0}\, f_1\left(AM_a\right) E_e \left(1+\alpha_{SC}\left(T_C - 25\right)\right)$$

Measured IV curve

Measured POA irradiance

Datasheet value

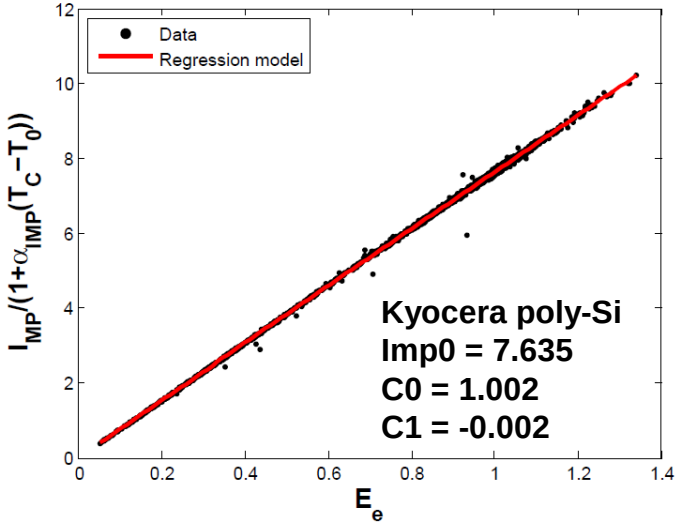
From measured Back-surface temp.



C. Hansen, D. Riley, and M. Jaramillo, "Calibration of the Sandia Array Performance Model Using Indoor Measurements " 38th IEEE Photovoltaic Specialists Conference, Austin, TX, 2012.

Estimating coefficients for I_{MP}

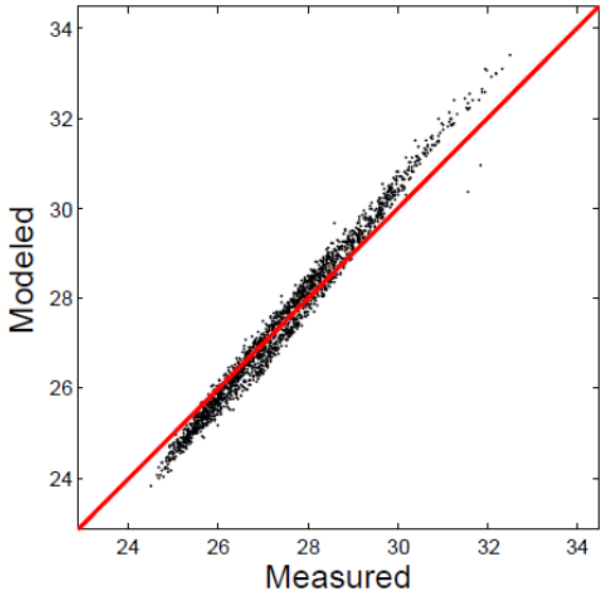
$$I_{MP} = I_{MP0}\left(C_0 E_e + C_1 E_e^2\right)\left(1+\alpha_{MP}\left(T_C - T_0\right)\right)$$



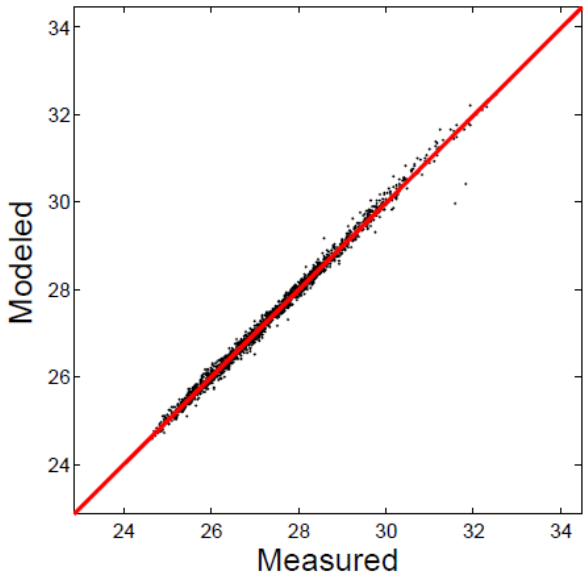
Model Fitting Procedure (SAPM)

- Data sheet temperature coefficients are adjusted

Predicted Vmp using datasheet temp coefficient



Predicted Vmp using adjusted temp. coefficient



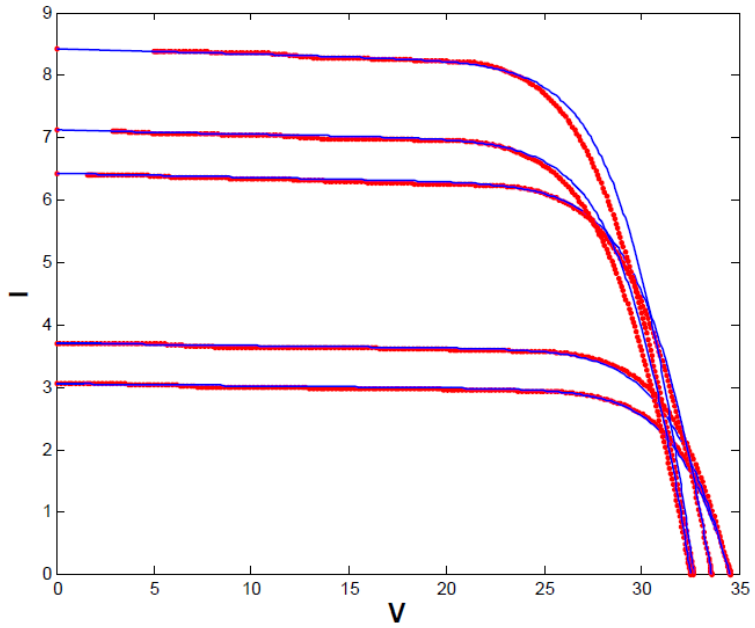
	Datasheet value	Calibrated value
β_{Vmp}	-0.155	-0.124

Model Fitting Procedure (De Soto)

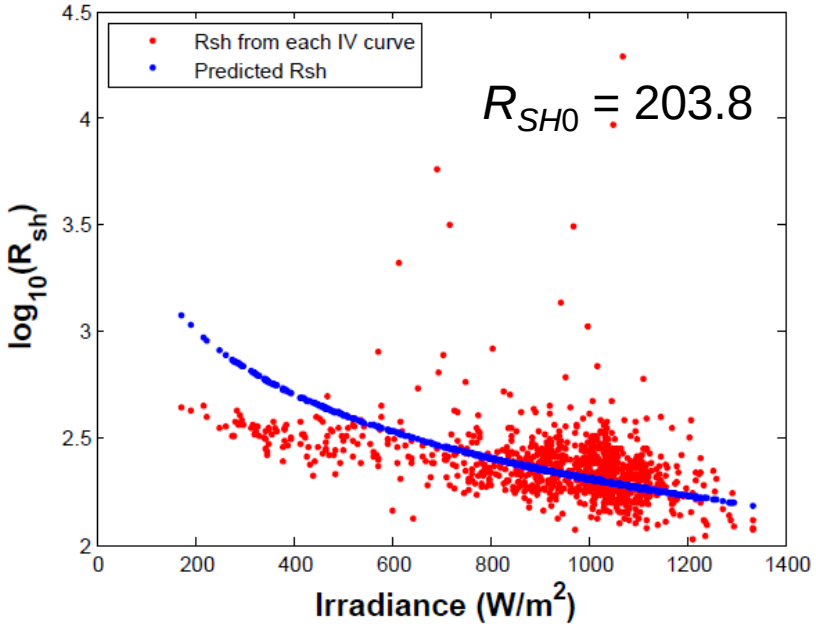
- Fit each IV curve

$$I = I_L - I_0\left[\exp\left(\frac{V+IR_s}{nV_T}\right)-1\right]-\frac{V+IR_s}{R_{sh}}$$

Data (red) and model (blue)



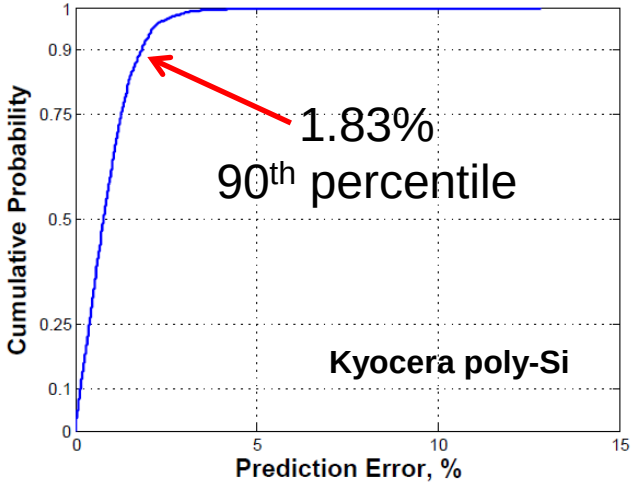
- Regress 5 parameters to irradiance, temperature
- E.g., $R_{sh} = R_{sh0}\frac{E_0}{E}$

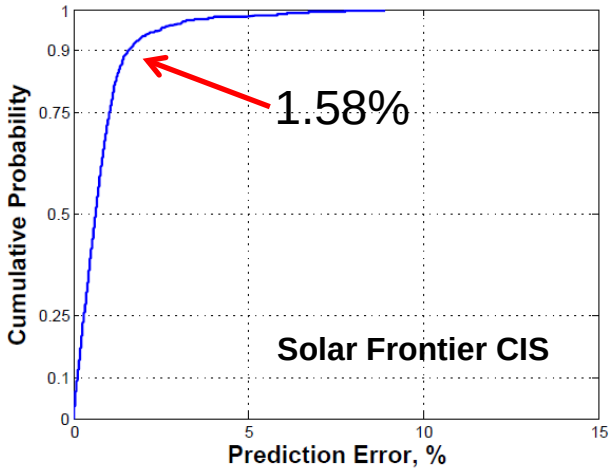


C. Hansen, "Estimation of Parameters for Single Diode Models Using Measured IV Curves," 39th IEEE Photovoltaic Specialists Conference, Tampa, FL, 2013.

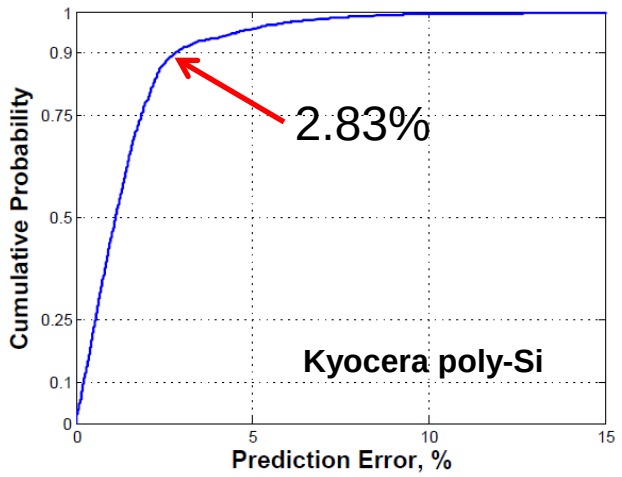
Results: P_{MP} prediction error

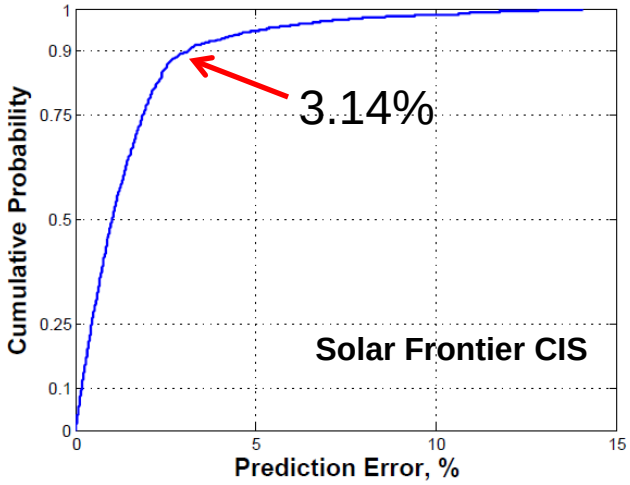
SAPM





De Soto





P_{MP} error for models using 2-axis tracker data (90th percentile)

SolarWorld mono-Si
SAPM – 0.81%
De Soto – 1.33%

Yingli poly-Si
SAPM – 0.96%
De Soto – 3.19%

Solar Frontier CIS
SAPM – 0.62%
De Soto – 2.58%

Summary

- Models calibrated using fixed-tilt data have prediction errors similar to models derived from two-axis tracker data

Module	Data Source	Sandia model	De Soto model
Poly Si	Tracker	0.96%	3.19%
	Fixed rack	1.83%	2.83%
CIS	Tracker	0.62%	2.58%
	Fixed rack	1.58%	3.14%

- Data filtering, i.e., agreement between ISC and POA irradiance, is crucial
- Open questions for research:
  - How long of a data record is required for the fixed tilt data?
  - What can we do if we only have power (not full IV curves)?

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Thank you