Sandia National Laboratories

Comparative Analysis of 12 Photovoltaic Performance Models

Lelia Deville, Marios Theristis, Bruce H. King, and Joshua S. Stein

Objective

Compare freely available photovoltaic (PV) performance models using varying PV technologies

PV Systems

- Seven PV Lifetime [1] systems were modeled (see Table 1)
- Meteorological data were collected on site directly next to systems

Figure 1: PVLT systems located at Sandia National Labs in Albuquerque, NM.

Meteorological and System Input Data

- Meteorological data were filtered to remove nighttime and erroneous data measurements

Table 1: System information for seven PV Lifetime systems used in study.

Manufacturer & Model	Cell Technology	# of Modules	Installation Date
LG 320N1K-A5	N-PERT Si	4 strings of 12 (48)	June 2018
Panasonic VBHN325SA16	HIT Mono Si	4 strings of 12 (48)	June 2018
Canadian Solar CS6K-270P	Poly-Si	4 strings of 12 (48)	October 2017
Canadian Solar CS6K-275M	Mono-Si	4 strings of 12 (48)	October 2017
Hanwha Q Cells Plus Q.Plus BFR-G4.1 280	Poly-Si PERC	4 strings of 12 (48)	October 2017
Hanwha Q Cells Peak Q.Peak BFR-G4.1 290	Mono-Si PERC	4 strings of 12 (48)	October 2017
Mission Solar MSE300SQ5T	Mono-Si PERC	4 strings of 12 (48)	May 2019

- Characteristic system data used in all models were sourced from IEC 61853-1 tests performed at CFV Solar Test Laboratory in Albuquerque, NM

PV Performance Models

PV performance models can help predict system performance, financial outcomes, serve as a planning tool, be used at any stage of system development, and vastly range in complexity

pvlib-python [2]

- SAPM
- PVWatts (PVW)
- CEC
- Desoto (DES)
- PVSyst (PVS)

pvpltools-python [3]

- ADR
- Heydenreich (HEY)
- MotherPV (MOT)
- PVGIS (PVG)
- MPM5/6
- Bilinear Interp. (BIL)

Table 2: Necessary inputs and produced outputs of twelve performance models.

	Sandia Array Performance Model (SAPM)	PVWatts	Single Diode Models (CEC, DES, PVS)	Matrix Models (ADR, HEY, MOT, PVG, MPM5, MPM6, BIL)
Input Parameters				
Effective Irradiance	✔	✔	✔	✔
Measured Module Temp	✔*	✔*	✔*	✔
SAPM Coefficients	✔			
Rated Power & Temperature Coefficient		✔		
PAN File Coefficients			✔	
Temperature & Irradiance Matrix Data				✔
Output Values				
Isc	✔		✔	
Imp	✔		✔	
Vmp	✔		✔	
Voc	✔		✔	
Pmp	✔	✔	✔	
Normalized Efficiency				✔

*These modules use cell temperature, which is calculated from module temperature using pvlib.temperature.sapm_cell_from_module

Error Metrics

- Normalized Mean Bias Error (NMBE) was used to reflect the prediction bias of the models

$$NMBE = \frac{\sum_{i=1}^{4}\left(\frac{P_M - P_O(i)}{P_O(i)}\right)}{4} * 100$$

Results

- Power predicted by performance model was compared to power output of all strings in a system

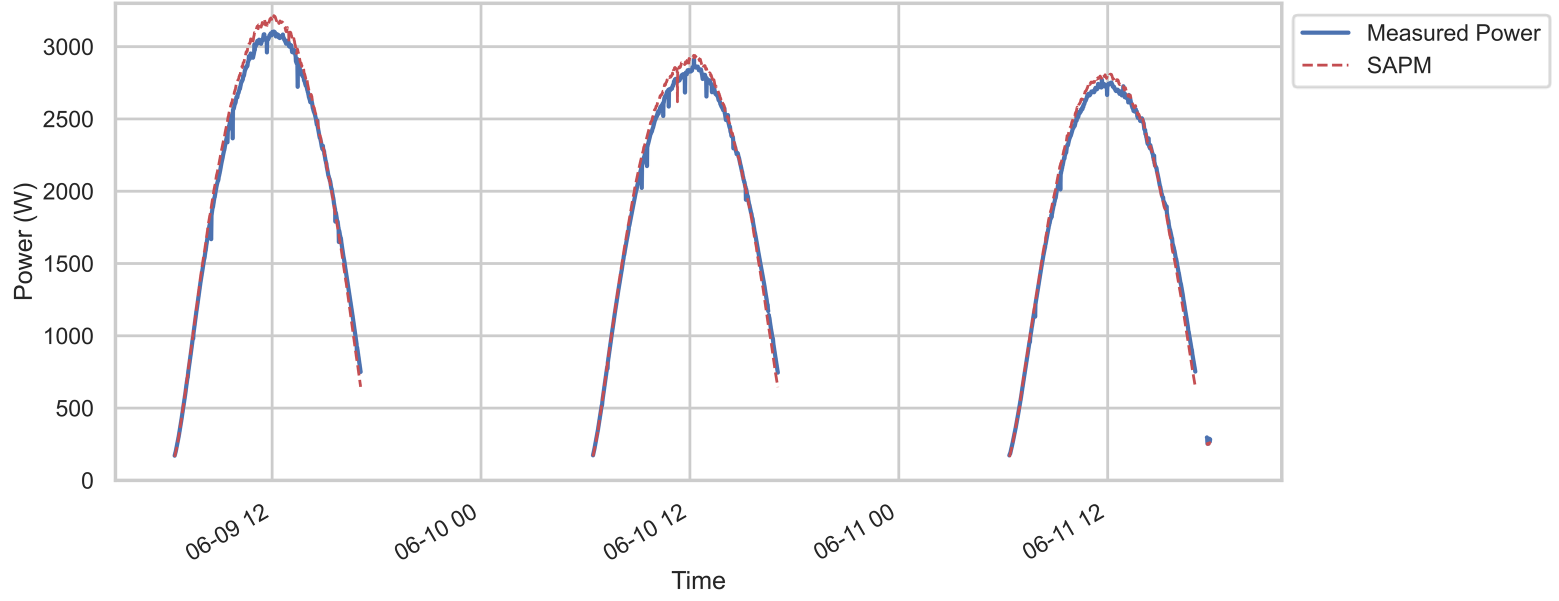

Figure 2: Example of power output for Canadian Solar 275W system & SAPM predicted power for three days in June 2020.

- All models agree within 6% for annual energy output

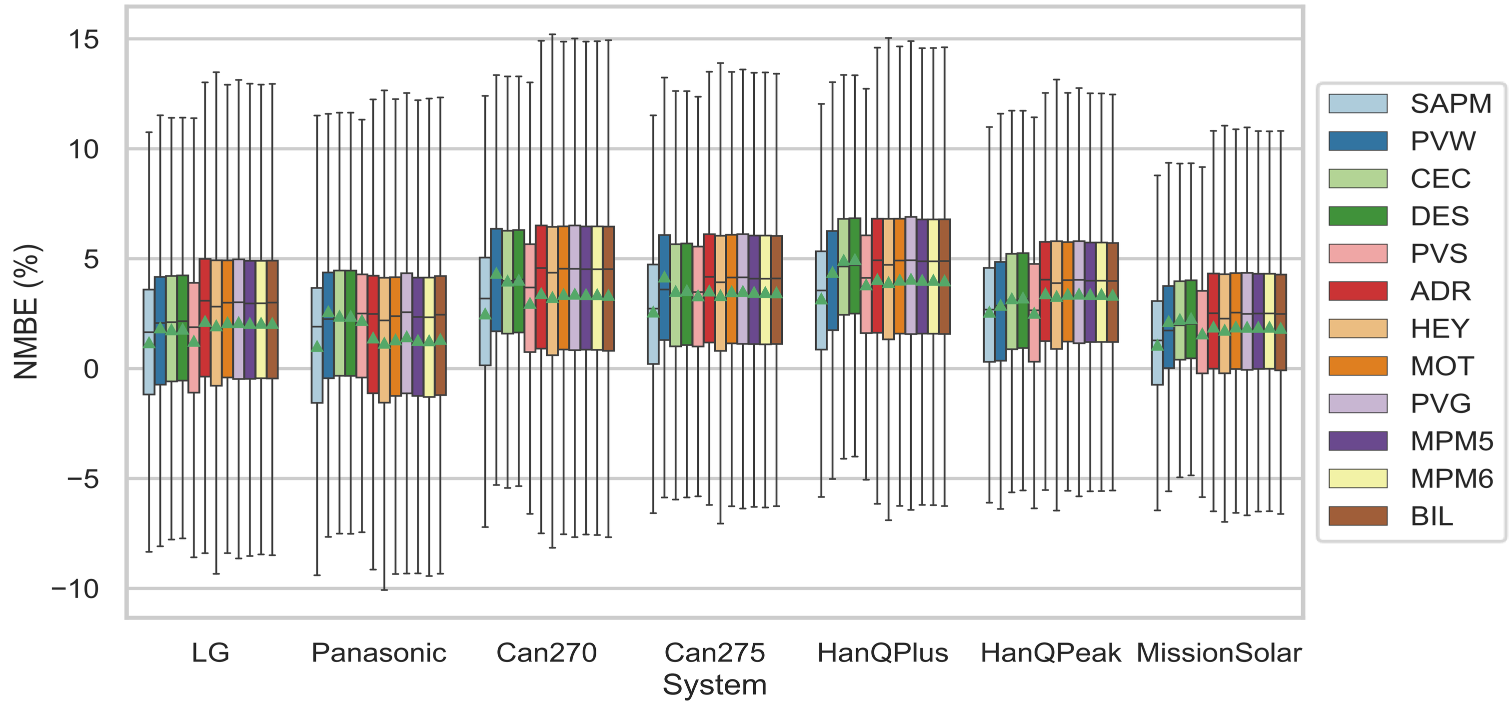

Figure 3: NMBE for all PVLT systems across all models.
All mean and median NMBE are <5% of the measured values.

- Models exhibit varying seasonal performance amongst the systems studied

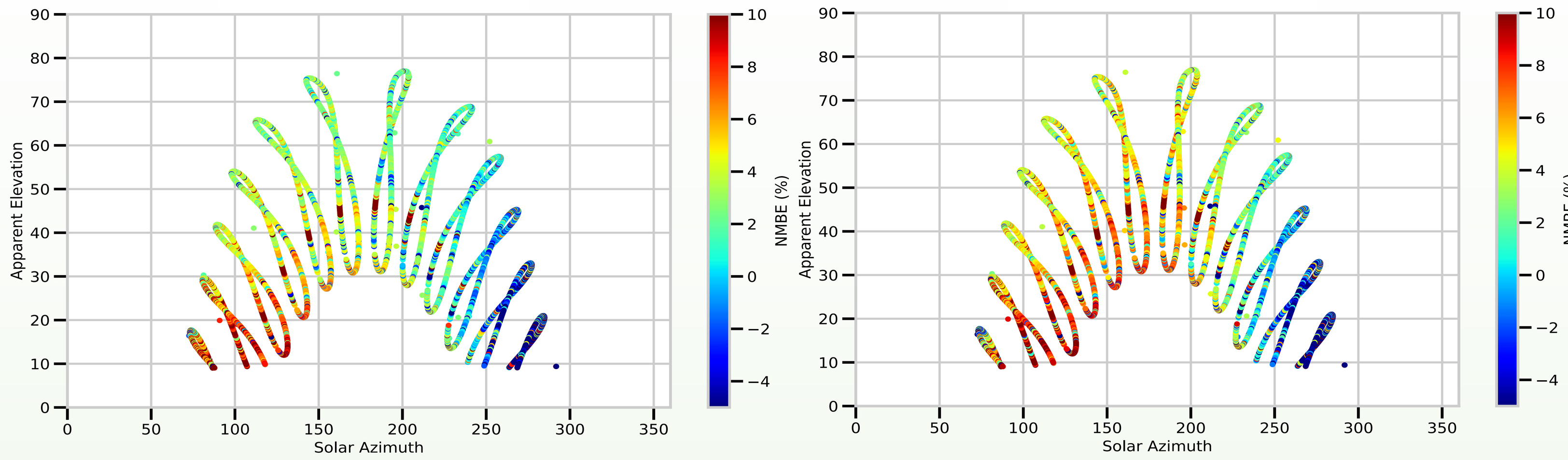

Figure 4: Analemma diagrams for the Canadian Solar 275W system with NMBE for the SAPM (left) and they Heydenreich Model (right) .

References

[1] J. S. Stein, et al. "PV Lifetime Project: Measuring PV Module Performance Degradation: 2018 Indoor Flash Testing Results," 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) 2018, pp. 0771-0777.

[2] William F. Holmgren, et al. "pvlib python: a python package for modeling solar energy systems." Journal of Open Source Software, 3(29), 884, (2018).

[3] A. Driesse, et al. "PV Performance Labs Tools for Python", (2020), GitHub repository, https://github.com/adriesse/pvpltools-python

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology &Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. SAND2022-5282 C

Sandia National Laboratories