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Look Mom, No MET Station!

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Key Idea

Photovoltaic (PV) devices measure effective irradiance (F) and cell temperature (T) more directly than meteorological (MET) stations.

This *PV-based sensing* approach requires—

- A field-deployable PV device, e.g., cell/module
- A good performance model, e.g., 1 or 2 diodes
- A calibration "matrix", e.g., IEC 61853-1 [1]
- A measurement time series of—

current-voltage (I-V) curves

– OR –

short-circuit current & open-circuit voltage point pairs: I_{sc} & V_{oc}

Technical Foundation

Formulate a single-diode model (SDM) in terms of—

Effective Irradiance: $F = \frac{I_{sc}}{I_{sc0}}$ ← prevailing ← STC (no TC)

Cell Temperature: T ← prevailing (at junction)

I_{sc0}, the PV device's short-circuit current at standard test conditions (STC), does *not* depend on a spectrally dependent temperature coefficient (TC).

Under certain homogeneity assumptions, a six-parameter SDM is given by—

$$0 = I_{ph} - I_{rs}\left(e^{\frac{q(V+IR_s)}{N_s n k_B T}} - 1\right) - G_p\,(V + I R_s) - I,$$

with auxiliary equations—

$$I_{ph} = I_{rs}\left(e^{\frac{q I_{sc} R_s}{N_s n k_B T}} - 1\right) + G_p I_{sc} R_s + I_{sc},$$

$$I_{rs} = I_{rs0}\left(\frac{T}{T_0}\right)^3 e^{\frac{q E_{g0}}{n k_B}\left(\frac{1}{T_0} - \frac{1}{T}\right)},$$

$$n = n_0, \quad R_s = R_{s0}, \quad G_p = G_{p0}, \quad I_{sc} = F I_{sc0}.$$

where the subscript 0 denotes a value at STC [2, 3].

The SDM is calibrated by measuring observables (green) and inferring model parameters (blue) [2]. Other auxiliary equations for series resistance R_s and parallel conductance G_p are readily handled.

PV-Based Sensing of F and T

The SDM-calibrated PV device becomes an irradiance and temperature sensor by re-tasking the parameter fitting problem solved with PVfit in Fig. 1.

Knowing the six SDM parameters and at least two distinct points on an I-V curve measured at constant irradiance and temperature, one can fit the remaining two unknown parameters F and T in the SDM.

I_{sc} and V_{oc} are a minimal number of easy-to-observe points, which are particularly sensitive to changes in F and T, respectively. (Cf. TC-based methods.)

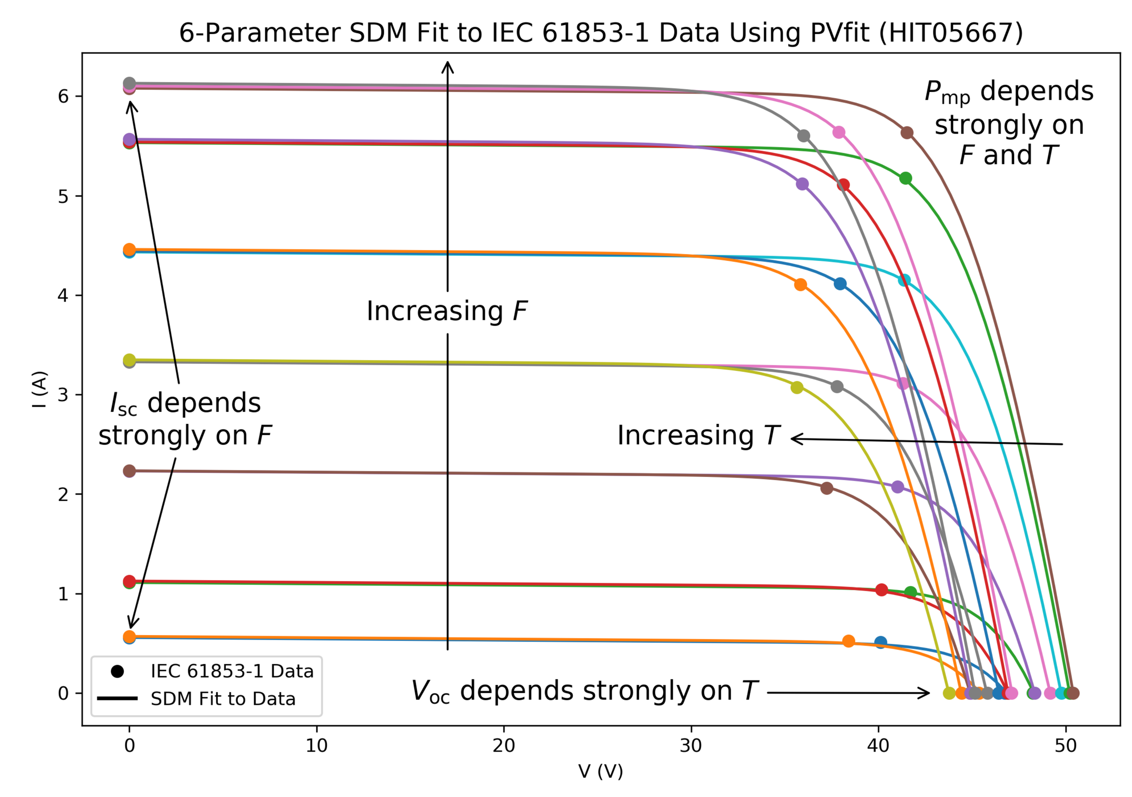

Figure 1: SDM fit to IEC 61853-1 data for a 72-cell HIT module.

Key Result

Diode-based performance models calibrated using IEC 61853-1 enable new PV-based irradiance and temperature sensors that do *not* rely on temperature coefficients.

Demonstration of PV-Based Sensing of F and T Using PVfit

Two PV-based sensors were tested on various PV modules in the (m)PERT outdoor I-V curve data set from the National Renewable Energy Laboratory (NREL) [4], which included I_{sc}, V_{oc}, plane-of-array (POA) irradiance, and module back-surface temperature with each I-V curve, and an IEC 61853-1 calibration for each module. Fig. 2 shows one day of results for the module in Fig. 1 with I-V curves at 5-minute intervals in Cocoa, FL. Discrepancy between the two sensors is largest at low F and may be related to larger SDM inaccuracy there.

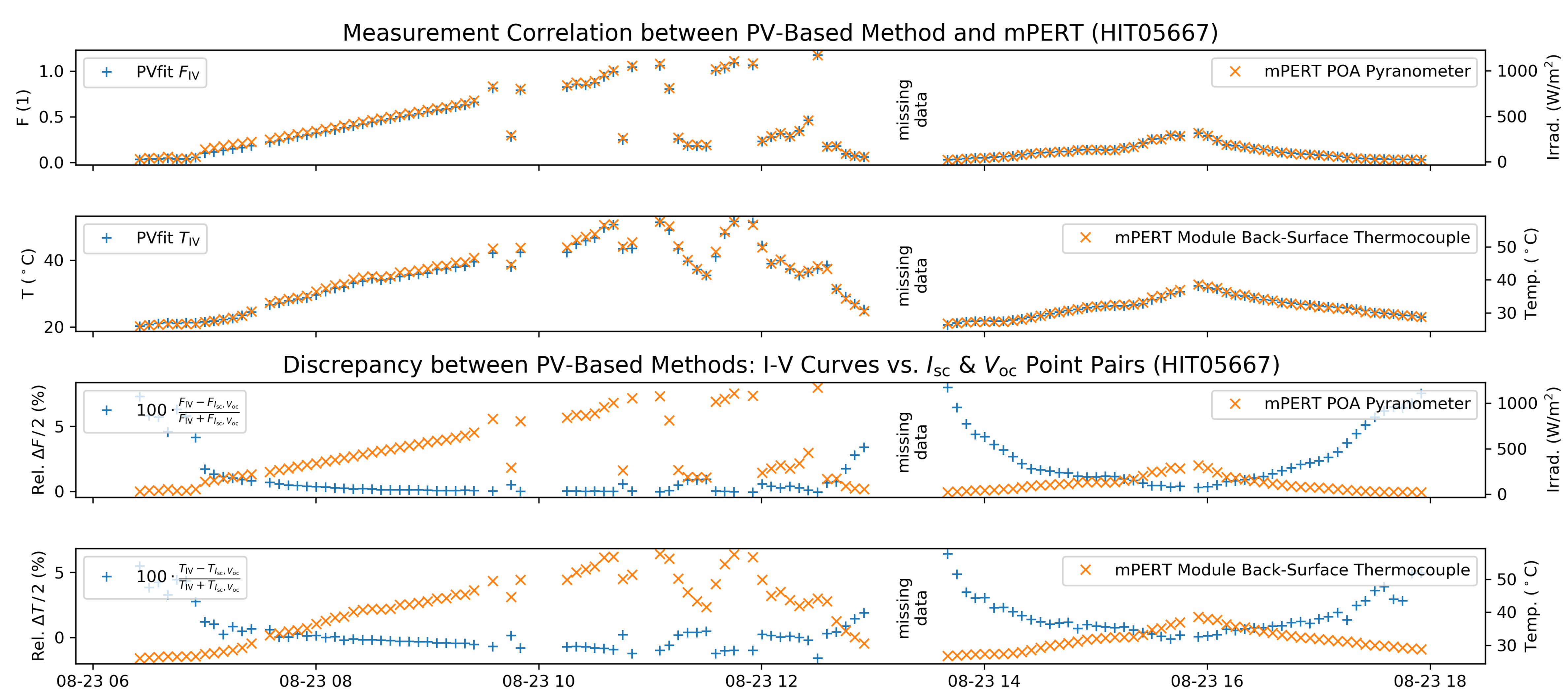

Figure 2: Demonstration of PV-based sensing methods using PVfit for one day of mPERT data under variable conditions.

Potential Benefits & Outlook

- Focuses effort on better PV device models.
- Avoids questionable temperature coefficients.
- Potentially lowers cost (cf. soiling measurements).
- Needs inter-comparison with traditional results from MET stations and PV-based instruments.
- Can these PV-deployment-specific F and T measurements better validate traditional models?
- Can PV-based sensors outperform traditional power prediction methods (inc. transpositions)?

References

[1] IEC Standard 61853-1 1st edition. *Photovoltaic (PV) module performance testing and energy rating – Part 1: irradiance and temperature performance measurements and power rating.* International Electrotechnical Commission (IEC), 2011.

[2] Mark B. Campanelli and Behrang. H. Hamadani. Calibration of a single-diode performance model without a short-circuit temperature coefficient. *Energy Science & Eng.*, 6(4):222–238, August 2018.

[3] Mark B. Campanelli and Carl R. Osterwald. Effective Irradiance Ratios to Improve I–V Curve Measurements and Diode Modeling Over a Range of Temperature and Spectral and Total Irradiance. *IEEE JPV*, 6(1):48–55, January 2016.

[4] W. Marion et al. User's Manual for Data for Validating Models for PV Module Performance. *NREL/TP-5200-61610*, April 2014.

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