Determination of Sandia Thermal Model Coefficients and ΔT for PV Modules with New Backsheet Types

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1. Introduction

- Sandia thermal model [1], one of the most extensively used models by the industry, predicts the cell temperature of a PV module using a few empirical coefficients and ΔT (temperature difference between cell and conventional backsheet).
- When the Sandia thermal model was developed before 2004, there were only a few types of polymer backsheet materials available in the marketplace and they were mainly Tedlar based backsheets.
- Due to $/watt pressure in the current highly competitive market, many module manufacturers have started using non-Tedlar based backsheets.
- We present the empirical coefficients and ΔT for the PV modules containing new types of polymer backsheets and glass substrate.
- These backsheet-specific coefficients and ΔT provide more accurate predicted cell temperatures for the modules.

2. Experimental Setup

- **Glass/Polymer Modules**
  - Glass/EVA/Cell/EVA/Backsheet
  - 156mm x 156 mm monocrystalline Si cells
  - Polymer backsheet types
    - Tedlar-PET-Tedlar (TPT)
    - PVDF-PET-EVA
    - PA-Aluminum-PET-PA
- **Glass/Glass Modules**
  - Glass/EVA/Cell/EVA/Glass
  - 156mm x 156 mm monocrystalline Si cells
  - Glass types
    - 3.2 mm-thick Solite PV glass
- **Module Dimensions**
  - 1-cell module: 8" x 11"
  - 9-cell module: 20.5" x 22"
- **Cell and Module temperature**
  - Cell temperature: T-type thermocouple was attached on the backside of solar cell before lamination. (9-cell module only)
  - Module temperature: T-type thermocouple was attached on the backsheet.
- **Module Installation and Data Acquisition**
  - Open rack installation
    - South facing
    - 45° fixed tilt
  - Data acquisition system
    - Every 30s interval
    - Cell and module temperature
    - Weather data
      - POA irradiance, ambient temperature, wind speed, wind direction

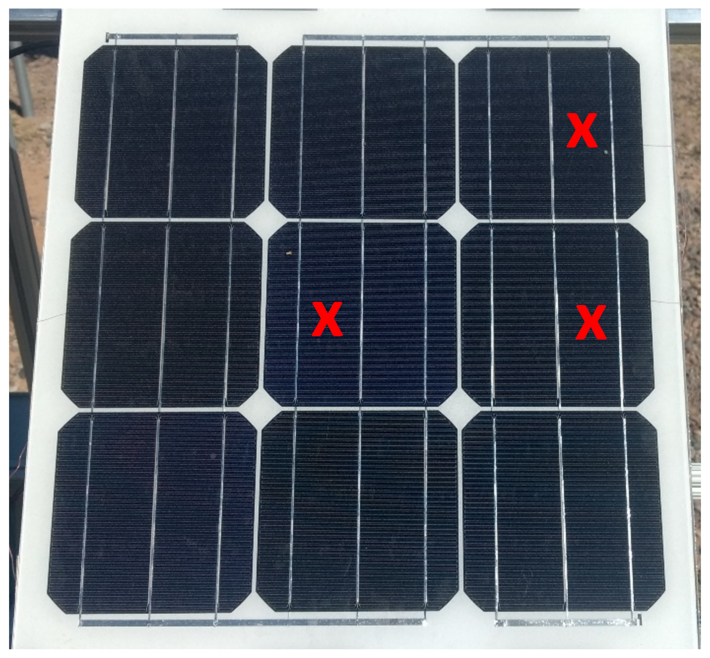

Fig. 1. 9-cell module. 'X' marks represent the placement of thermocouples on backside of the cells.

Fig. 2. A photo of 1-cell and 9-cell modules installed at open rack mount for thermal testing at Mesa, Arizona.

- **Temperature coefficients**
  - Outdoor I-V tracer was used to take multiple I-V curves with respect to temperature.
  - Test modules were stored in air-conditioned box (<20°C) until I-V measurement.

3. Sandia Thermal Model Coefficients

- Overall, the coefficient 'a' of all the 1-cell modules obtained at ASU-PRL is practically similar to Sandia thermal model coefficient.
- No coefficient 'a' difference observed between the glass/polymer module and the glass/glass module while King *et al* [1], reported −3.47 as a coefficient 'a' for glass/glass module.
- For coefficient 'b', all the values obtained from the modules used in this study are higher (smaller) than Sandia reported values, which are −0.0750 and −0.0594 for glass/polymer module and glass/glass module, respectively.

Module Operating Temperature by Sandia Model

$$T_m = E \times \left(e^{a+b\times WS}\right) + T_{amb}$$

- T_m: module temperature (backsheet temperature) (°C)
- E: plane of array irradiance (W/m^2)
- WS: wind speed (m/s)
- T_{amb}: ambient temperature (°C)
- a: empirically-determined coefficient establishing the upper limit for module temperature at low wind speeds and high solar irradiance
- b: empirically-determined coefficient establishing the rate at which module temperature drops as wind speed increases

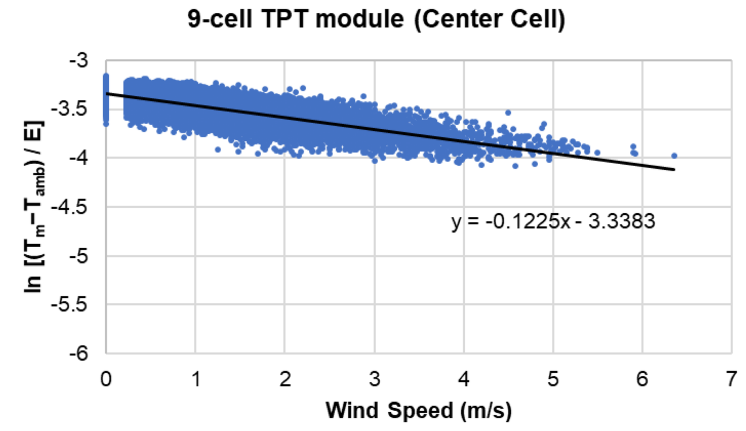

Fig. 3. Plotted empirical data to determine the coefficients (a, b). T_m was measured from center cell of nine-cell module.

Empirically determined coefficients for various type of backsheets and module configuration

Sample	Module Type	a	b
1-cell module	Glass/Polymer (PVDF-PET-EVA)	−3.60	−0.1101
	Glass/Polymer (PA-Al-PET-PA)	−3.58	−0.1080
	Glass/Polymer (TPT)	−3.52	−0.1154
	Glass/Glass	−3.53	−0.1037
9-cell module (center cell)	Glass/Polymer (PVDF-PET-EVA)	−3.38	−0.1033
	Glass/Polymer (PA-Al-PET-PA)	−3.29	−0.1125
	Glass/Polymer (TPT)	−3.34	−0.1225

4. Temperature Difference between Cell and Backsheet (ΔT)

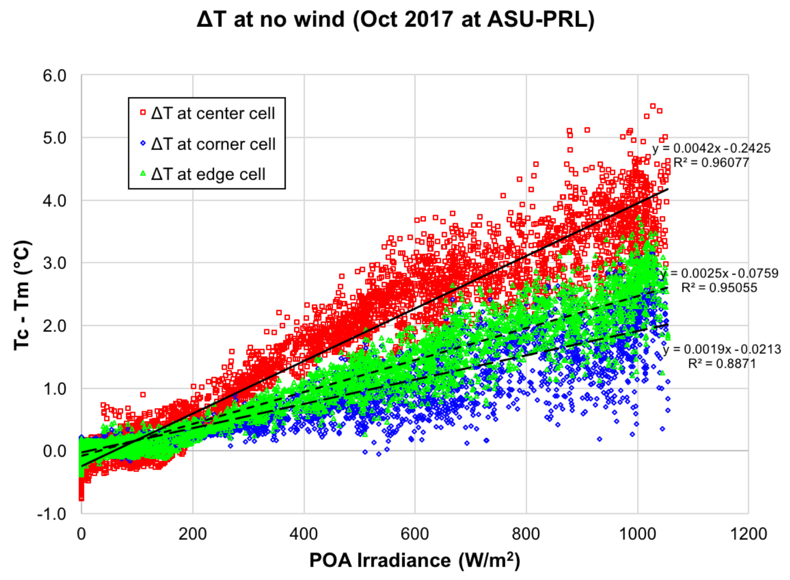

Fig. 4. ΔT with respect to irradiance for Glass/Polymer (TPT) 9-cell modules at 0 m/s wind speed

Sample	Module type	ΔT at 0 m/s WS	ΔT at 1 m/s WS
1-cell module	Glass/Polymer (PVDF-PET-EVA)	2.6	3.3
	Glass/Polymer (PA-Al-PET-PA)	2.6	3.5
	Glass/Polymer (TPT)	2.7	3.4
	Glass/Glass	2.9	3.7
9-cell module	Glass/Polymer (PVDF-PET-EVA) Center cell	3.2	3.1
	Glass/Polymer (PVDF-PET-EVA) Corner cell	2.2	2.6
	Glass/Polymer (PVDF-PET-EVA) Edge cell	1.5	2.1
	Glass/Polymer (PA-Al-PET-PA) Center cell	2.5	2.5
	Glass/Polymer (PA-Al-PET-PA) Corner cell	1.9	2.3
	Glass/Polymer (PA-Al-PET-PA) Edge cell	2.1	2.5
	Glass/Polymer (TPT) Center cell	4.0	4.1
	Glass/Polymer (TPT) Corner cell	1.9	2.4
	Glass/Polymer (TPT) Edge cell	2.4	2.8

- ΔT provided by Sandia is 2-3°C for open-rack mount.
- ΔT was center>edge>corner in 9-cell module, and it was as high as 5.5-5.8 °C at center cell.
- ΔT could be higher at 1 m/s wind speed than 0 m/s wind speed.
- Due to thermal equilibrium issue, P_{max} could be overestimated when T_m+2.5°C was used rather than T_c as shown in Fig. 5.

Temperature coefficients of 9-cell module at 1000 W/m^2 irradiance

Temperature	I_{sc} (A/°C)	V_{oc} (V/°C)	I_{mp} (A/°C)	V_{mp} (V/°C)	FF (%/°C)	P_{max} (W/°C)
T_m+2.5	0.0063	-0.0206	-0.0006	-0.0232	-0.1812	-0.1825
T_c	0.0057	-0.0188	-0.0002	-0.0214	-0.1658	-0.1667

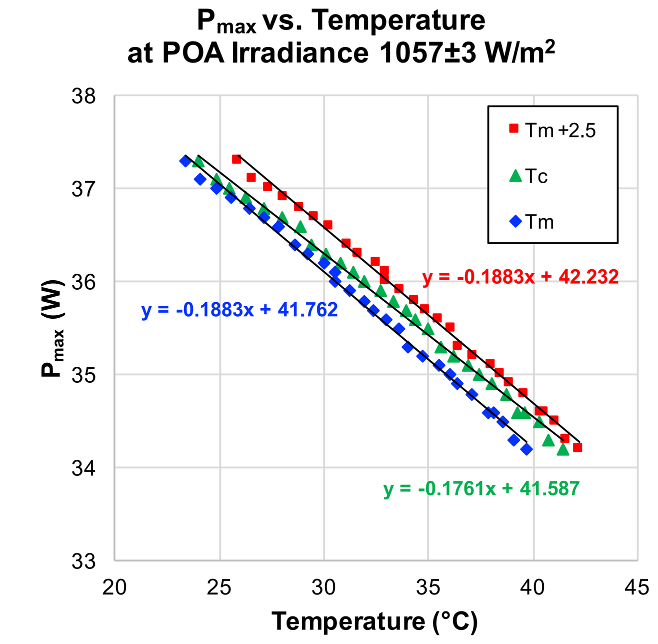

Fig. 5. P_{max} temperature coefficient using cell temperature, module temperature and converted cell temperature (T_m+2.5°C).

Reference

[1] D. L. King, W. E. Boyson, and J. A. Kratochvil, "Photovoltaic array performance model," Sandia Rep. No. 2004-3535, pp. 1–43, 2004.

Acknowledgements

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