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Uncertainty in Module Temperature Coefficients

Trina Solar Ltd.
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U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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Overview and Purpose

- We have seen variation among temperature coefficients determined for the same module when using different methods
- We think the underlying cause is inaccurate determination of average cell temperature
- We will outline research to find more accurate and repeatable methods for determining average cell temperature

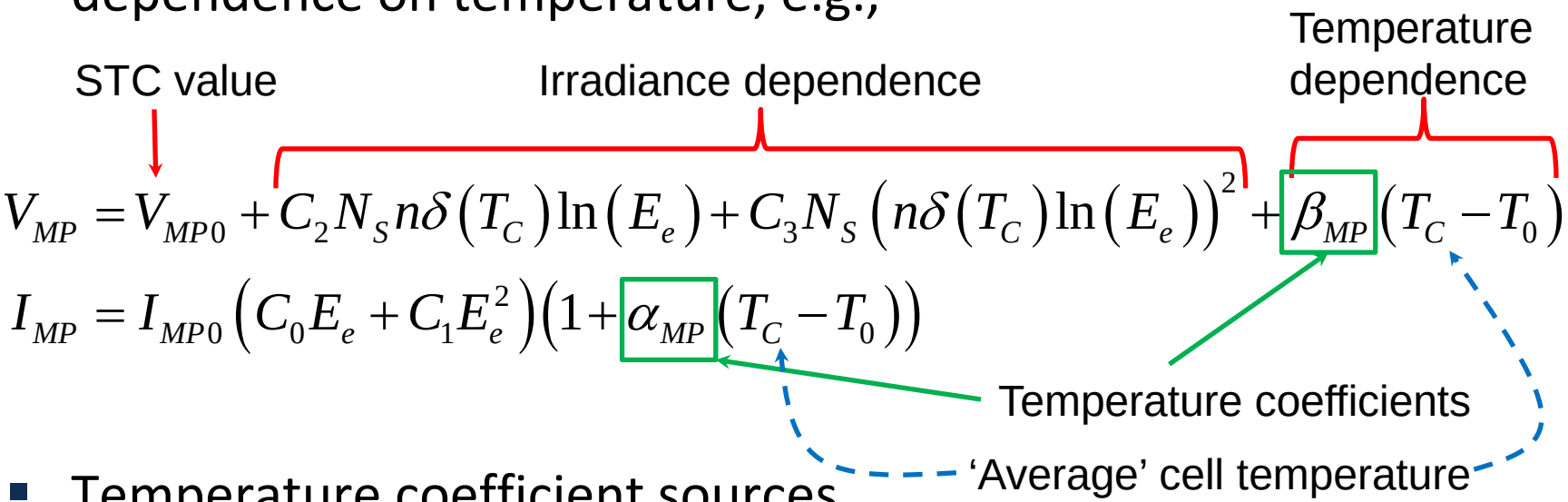
TABLE I
COMPARISON OF TEMPERATURE COEFFICIENTS FROM INDOOR AND OUTDOOR METHODS

Module	βVmp (%/°C)		γPmp (%/°C)	
	Indoor	Outdoor	Indoor	Outdoor
mcSi	–0.29	–0.31	–0.29	–0.32
mcSi	–0.42	–0.46	–0.40	–0.50
pcSi	–0.43	–0.46	–0.42	–0.48
HIT	–0.30	–0.30	–0.30	–0.33

Source: Hansen, Farr, & Pratt, 2014, Correcting Bias in Measured Module Temperature Coefficients, 40th IEEE PVSC, Denver, CO

Background

- Module performance modules generally assume linear dependence on temperature, e.g.,



- Temperature coefficient sources
  - Data sheet : scaled values from cell-level testing (?)
  - Measurement
    - Hold module at constant irradiance
    - Sweep IV curves while changing module temperature

What is T_C?

For voltage, T_C is average cell temperature

$$
\begin{aligned}
V_{\text{mod}} &= V_{STC,\text{mod}} + \Delta V_{Irr,\text{mod}} + \Delta V_{Temp,\text{mod}} \\
&= \sum \left(V_{STC,cell} + \Delta V_{Irr,cell} + \Delta V_{Temp,cell} \right) \\
&= N_S V_{STC,cell} + N_S \Delta V_{Irr,cell} + \sum_i \beta V_{cell} \left(T_{C,i} - T_0 \right) \\
&= V_{STC,\text{mod}} + \Delta V_{Irr,\text{mod}} + \beta V_{\text{mod}} \frac{1}{N_S} \sum_i \left(T_{C,i} - T_0 \right)
\end{aligned}
$$

For current, use same value of T_C for consistency

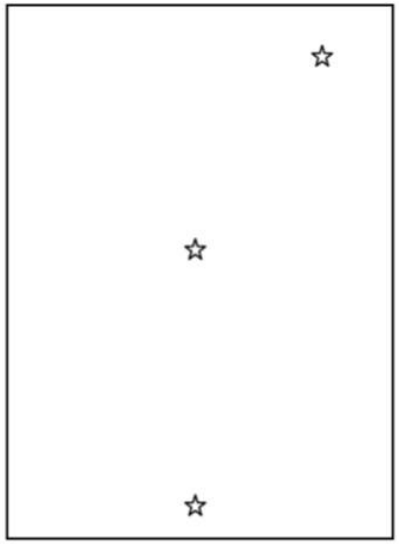
- Temperature coefficient for power depends mostly on βV_{MP}

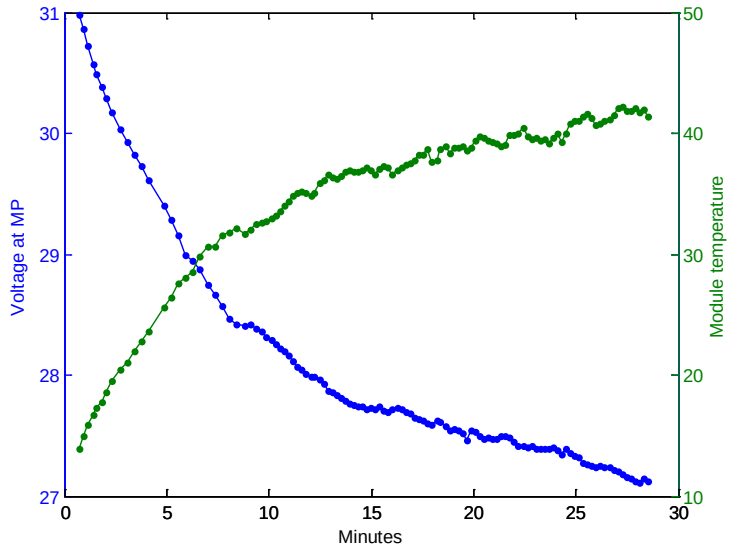
$$\gamma P_{MP} = I_{MP} \beta V_{MP} + V_{MP} \left(I_{MP} \right) \alpha I_{MP}$$

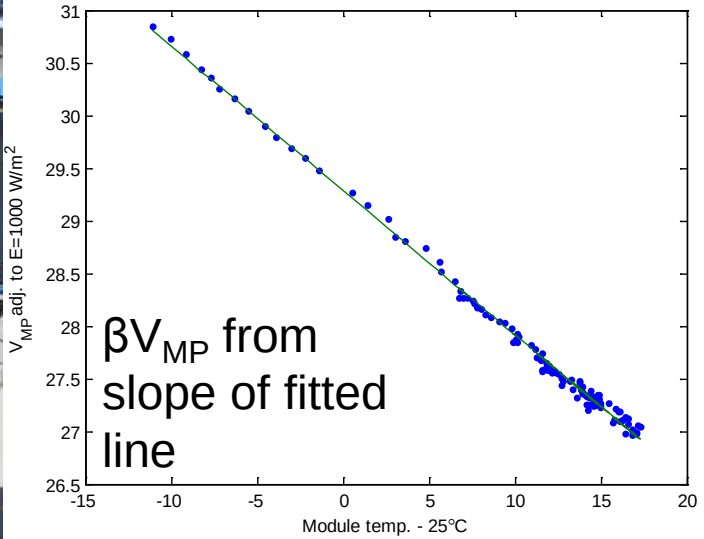
when αI_{MP} has units of 1/T rather than A/T

Outdoor test method

1. Module is mounted to 2-axis tracker, is covered to cool to ambient. Backsheet is instrumented with 3 TCs and covered with insulation.
2. Module is uncovered and IV curves are swept while module warms to operating temperature







Indoor test methods

Source

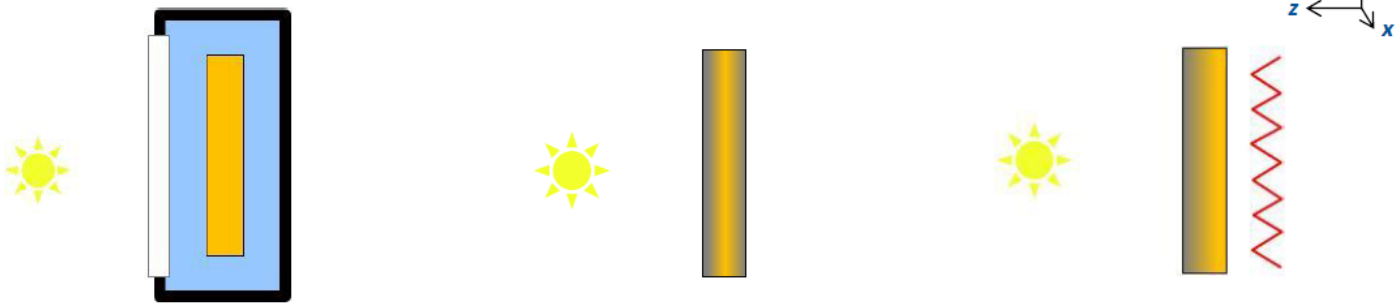
Cells may or may not be at steady-state, equal temperature

May 5, 2014

TOWARD RELIABLE MODULE TEMPERATURE MEASUREMENT: CONSIDERATIONS FOR INDOOR PERFORMANCE TESTING

MONALI JOSHI, BLACK & VEATCH
RAJEEV SINGH, PV EVOLUTION LABS

Variety of indoor temperature control methodologies currently in use , all of which may be consistent with 61853 guidelines, but differences can lead to largely different results



"Oven"

- Module heated on all sides by laminar flow of hot gas
- In-situ IV curve measurement
- Uniform temperature profiles possible
- Equilibrium possible

"Hot Potato"

- Module heated in thermal chamber; placed in ambient
- IV curves assessed while cooling (no temp control)
- Non-uniform temperature profiles possible
- Non-steady state

"Back-side Toaster"

- Constant, adjustable heat source at back surface
- Uniform x-y thermal profile possible
- Non-uniform thermal profile in z
- ~ Steady state possible

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INDOOR MODULE PERFORMANCE CHARACTERIZATION CONSIDERATIONS

Factors impacting accurate and repeatable temperature measurements:

- Directionality of heat source
- Uniformity of heat source
- Hold time at temperature
- Number, type, location of sensors
- Calibration

Source

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Lack of specificity in many of these factors in 61853-1 leaves room for lab-to-lab variation

Inter-lab comparison

- Indoor testing per IEC 61215 and 61853-1
- Round robin with 5 labs

Source

RESULTS FROM FLASH TESTING AT MULTIPLE IRRADIANCES AND TEMPERATURES ACROSS FIVE PHOTOVOLTAIC TESTING LABS

3rd PV Performance Modeling Workshop
May 5, 2014, Santa Clara, CA

Junaid H. Fatehi[1], Cherif Kedir[2], Charles Tumengko[3], Nick Riedel[4], John L. R. Watts[5]

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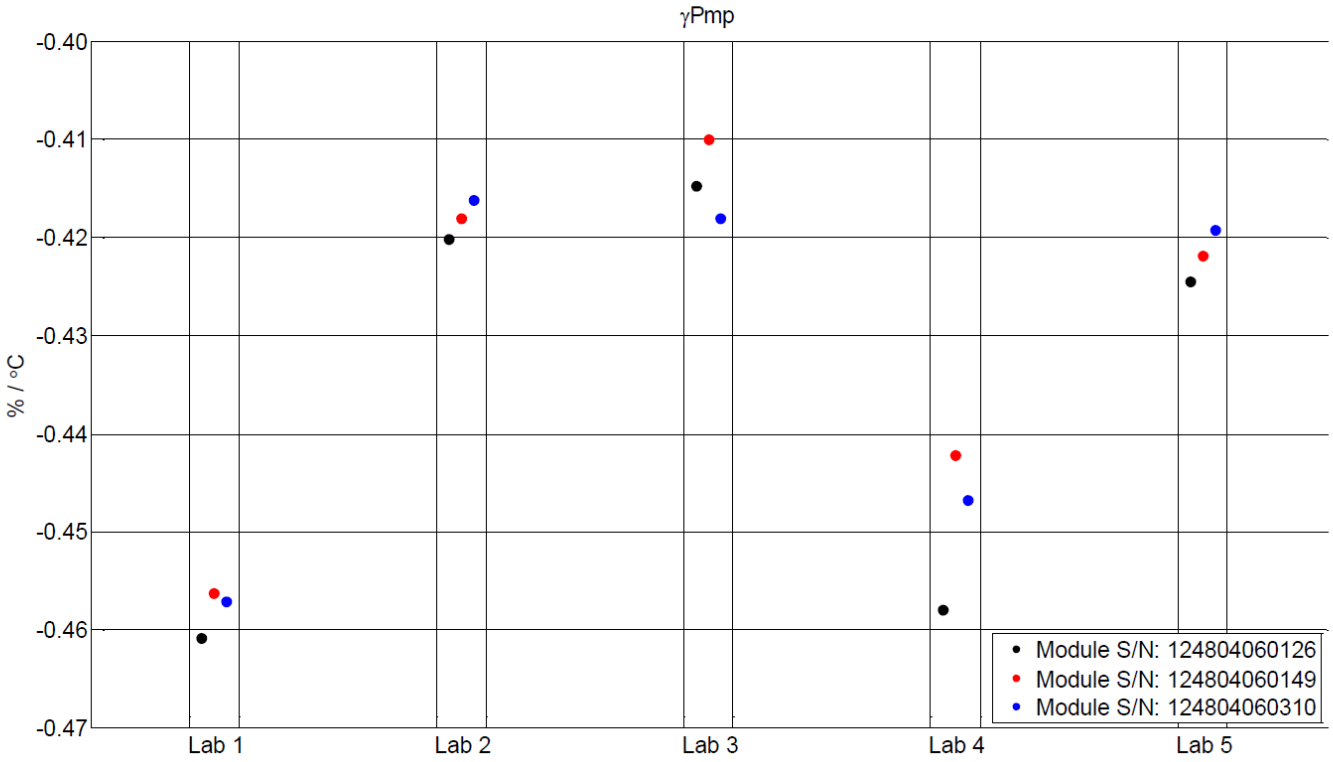
[5]PV Evolution Labs, Berkeley, CA

Maximum Power Temperature Coefficient



Indoor vs. Outdoor

- CFV Solar Test Laboratory measured temperature coefficients for several modules, both indoors and outdoors
  - Indoors – HALM flash tester with integrated temperature chamber – module is isothermal during test
  - Outdoors – two-axis tracker with initially shaded module – temperature varies among cells; cell temperature is transient
- βV_{MP} and hence γP_{MP} values were systematically different

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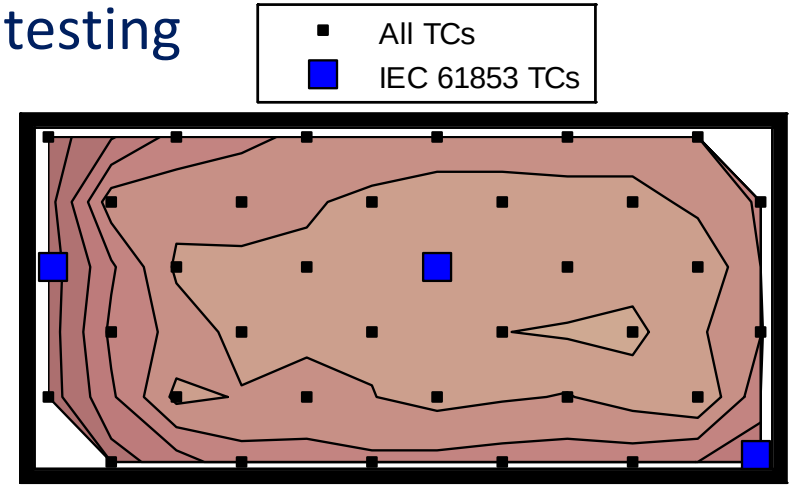
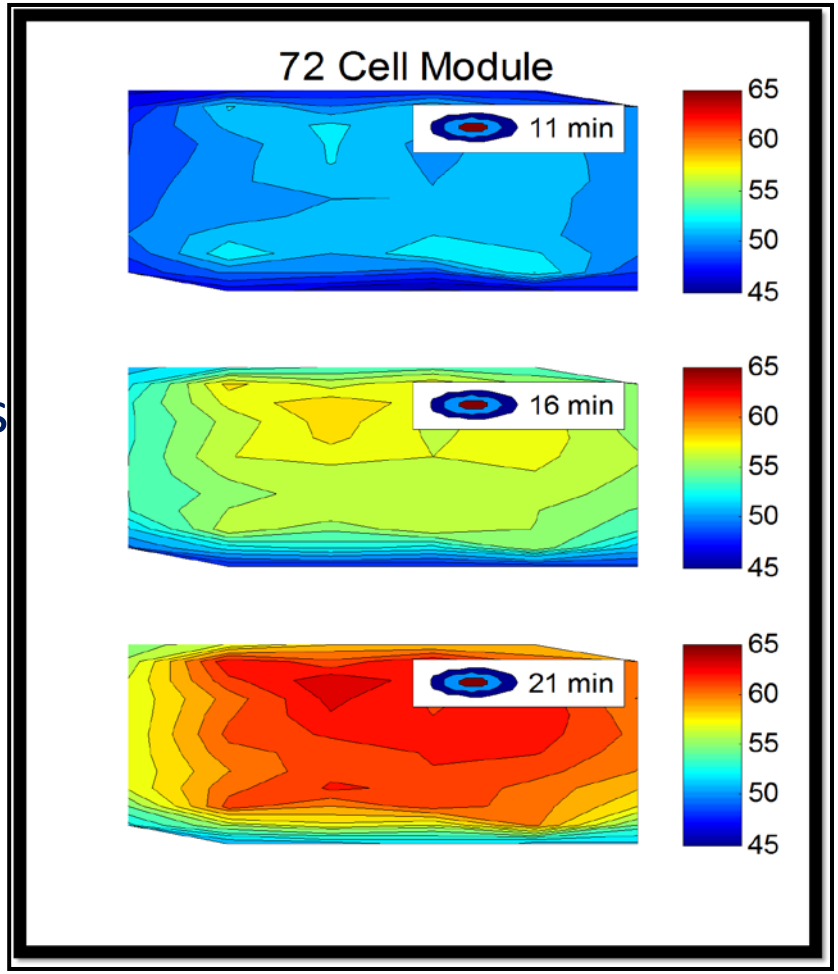
Why the differences?

- Suspect that IEC 61853-1 3 TC arrangement consistently under-estimates average cell temperature
- We instrumented a 72 cell module with 36 thermocouples (every other cell) and repeated testing

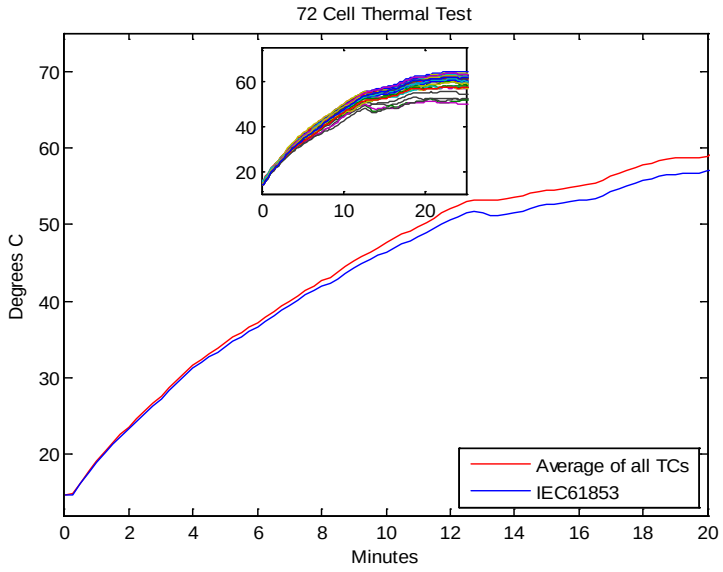


Module temperature profiles during temperature coefficient testing



Observations

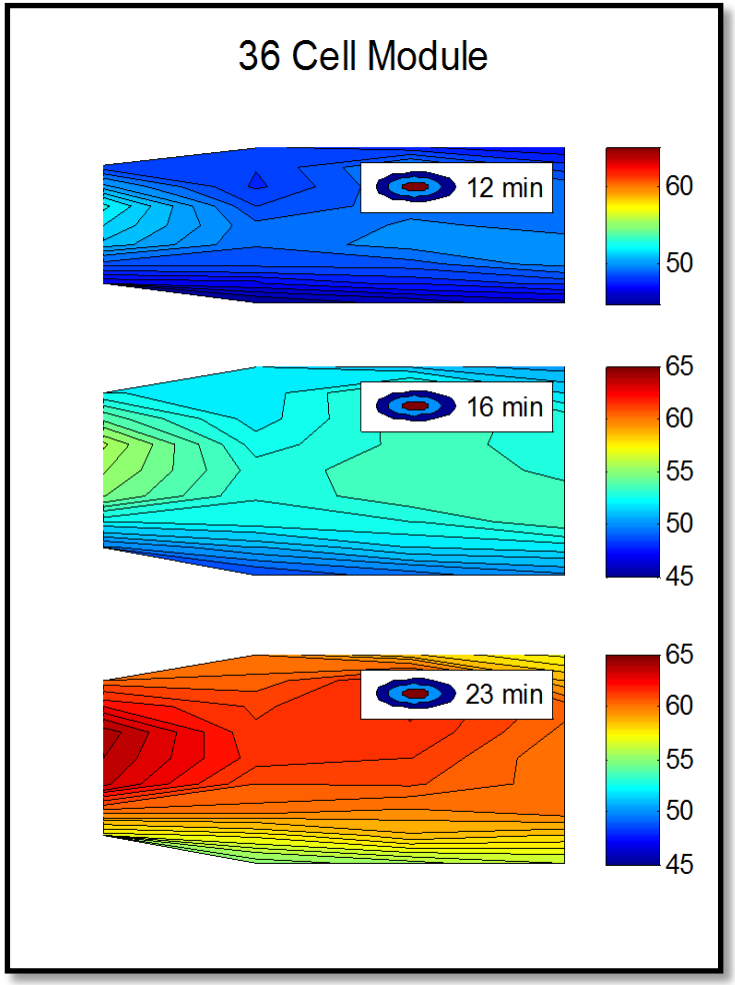
- TC placement by IEC 61853-1 can underestimate ‘average’ cell temperature
  - Cause bias in module temperature coefficients
- If cell temperatures are unequal during test (e.g., outdoor and some indoor methods) need more accurate method to determine ‘average’ cell temperature



	αIsc (1/° C)	αImp (1/° C)	βVoc (V/° C)	βVmp (V/° C)
Indoor	3.36E-04	-2.49E-04	-0.1358	-0.1441
All TCs	3.56E-04	-1.87E-04	-0.1335	-0.1421
IEC 61853	3.77E-04	-1.97E-04	-0.1413	-0.1505

FY15 research

- Develop rigorous laboratory methods to reliably determine temperature coefficients with uncertainty 1%.
- Key challenge is to accurately measure ‘average’ cell temperature when modules are not isothermal
  - Significant thermal effects of junction box, module edge materials
- Ideas (so far)
  - Measure backside temperatures by a combination of thermographic cameras and a few reference thermocouples.
  - Construct easily-attachable sensor arrays with many thermocouples.



Considerations

- Bias in module temperature coefficients → bias in annual energy
  - Probably not great in magnitude (~0.05%) but enough to draw attention
  - Increases perception of uncertainty in testing and modeling
  - Negatively impacts confidence in system financial viability
- Could consider using more detailed models that account for individual cell temperatures
  - \+ Requires only cell-level temperature coefficients (easier to measure)
  - \- Adds great complexity to PV performance modeling
  - \- Likely introduces parameters which we don't currently know (e.g., module heat capacity)
  - Prefer not to pursue this approach

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Thank you