NREL
NATIONAL RENEWABLE ENERGY LABORATORY

DETERMINING OUTDOOR CPV CELL TEMPERATURE

CPV-7, Las Vegas, Nevada

Matthew Muller

4/4/2011

NREL/PR-5200-51369

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Outline

- Why cell temperature is needed under outdoor conditions
- Proposed shutter procedure for calculating cell temperature
- Results from shuttering multiple modules and a single cell
- Conclusions/Ongoing work

IEC 62670, CPV Power Ratings

Concentrator Standard Test Conditions (CSTC)

Tcell = 25C
DNI = 900 W/m^2
G173/AM 1.5

Cell Temperature Fixed

Temperature Coefficients

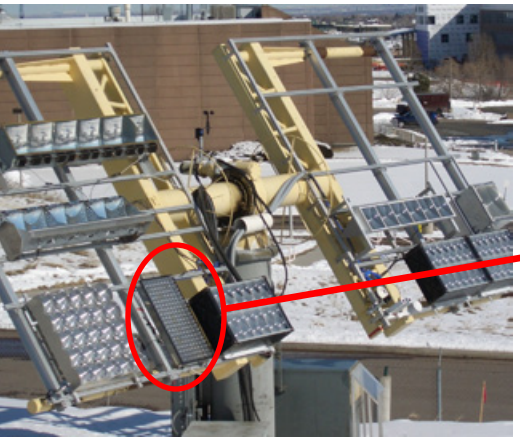
Concentrator Standard Operating Conditions (CSOC)

Tambient = 20C
DNI = 900 W/m^2
Wind Speed 2m/s
G173/AM 1.5

Calculate Cell Temperature

Shutter Procedure as Applied at NREL

1. Cover module aperture area and let module cool so cell and heat sink temperature are approximately equal.
2. Set up Keithley multimeters to measure module Voc and heat sink temperature via a fast response platinum RTD.
3. Meteorological measurements are being recorded on the tracker
4. Use code to initiate and synchronize the Data acquisition system
5. Snap the cloth off the module.
6. Record measurements for approximately 2 minutes
7. Analyze results



Procedural Equation and Assumptions

$$T_{cell} = T_{h,0} + (V_{max} - V_{oc(t)})/(N_s \cdot \beta_{Vocr}) \qquad (1)$$

N_s = Number of cells in series in module

T_{cell} = Calculated cell temperature

$T_{h,0}$ = heat sink temperature at shutter initiation

V_{max} = maximum measured V_{oc} for shutter procedure

$V_{oc(t)}$ = V_{oc} measured with time

β_{Vocr} = V_{oc} temperature coefficient, -0.0045 (V/°C)

Eq. 1. "Primary assumption"

Cell temperature does NOT increase significantly above the heat sink temperature during the removal of the cloth

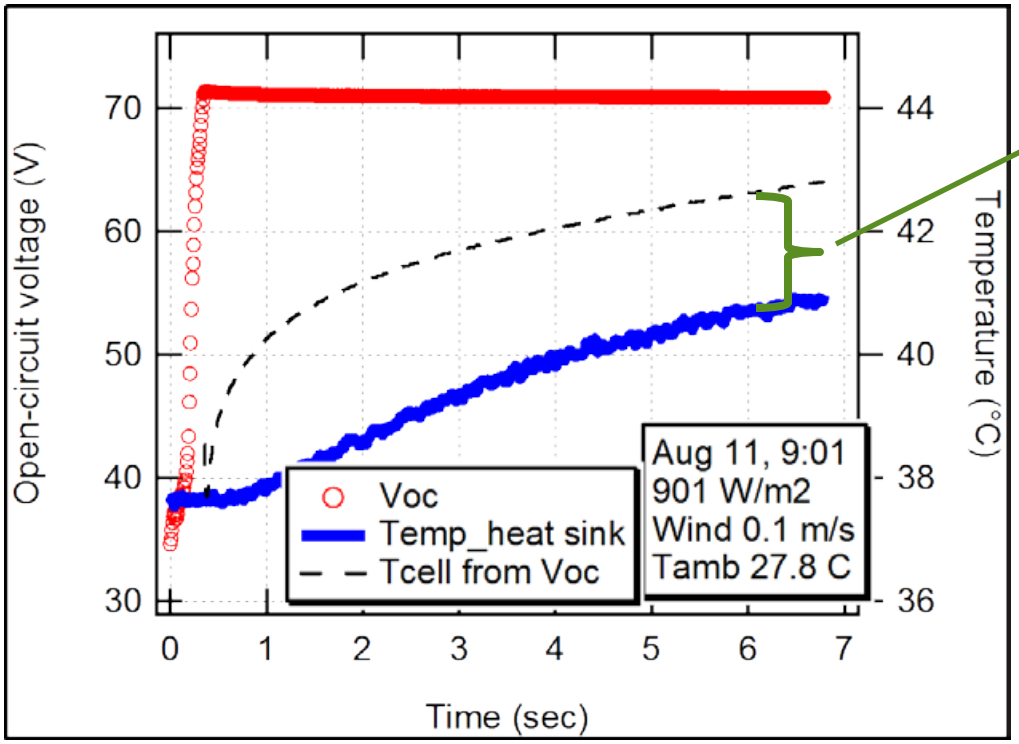
Secondary assumption

Measurements of meteorological conditions can be used to translate calculated cell temperature to CSOC with acceptable uncertainty

(not explored in this work as efforts focused on validating the primary assumption)

Example of Shuttering Results

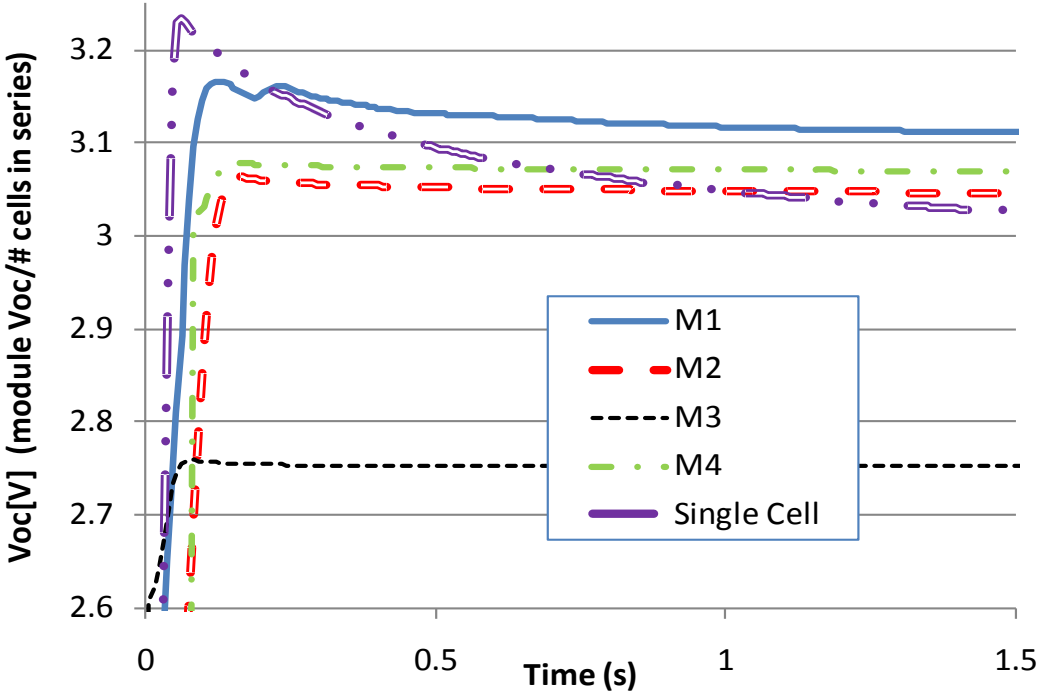
- The red shows the measured rise in Voc as the shutter is removed. Voc peaks and then is followed by decline as the cell heats up.
- The blue shows that the heat sink temperature is level for almost a second and then begins to heat.
- The black dashed line shows the calculated cell temperature rises rapidly over the first 1-2 s and then climbs steadily with heat sink temperature



- If "primary assumption" is true, this suggests, for the given meteorological conditions, that the cell temperature is only about 2C above the measured heat sink temperature

Voltage Transients for Multiple Modules and a Single Cell

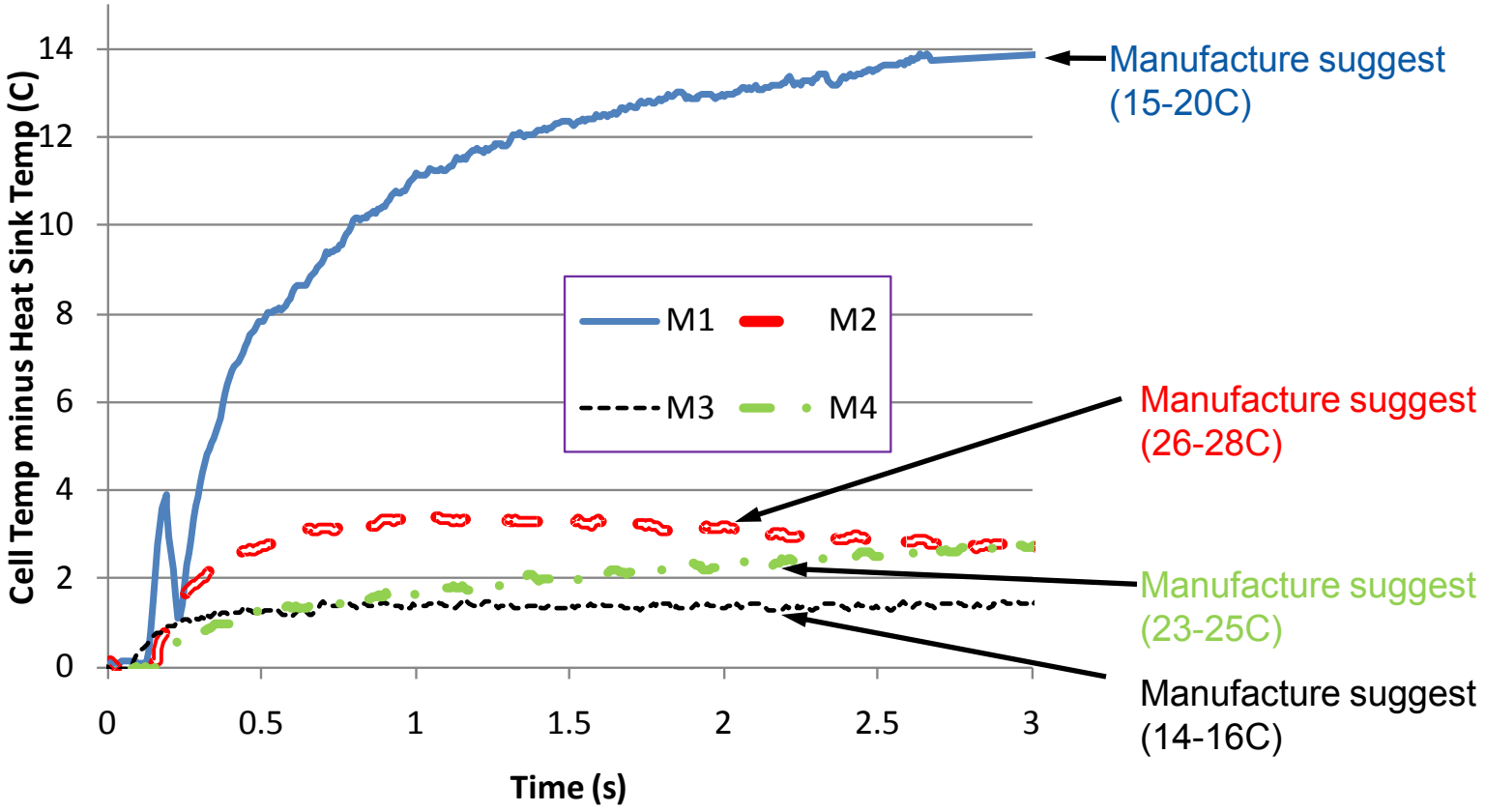
- The time to reach the maximum Voc varies from about 0.05 to 0.15 seconds. This range is consistent with module size.
- The fastest shutter time that could be achieved for a typical module (~m wide) was about 0.1 s
- The voltage declines at varying rates, in order from fast to slow (SC,M1,M2,M3,M4)
- One would expect the decline rate/heating rate to have some dependence on thermal package design (unfortunately this information is unknown)
- A relationship was found between the rate of decline and the number of rows of cells the shutter must cross. (SC, M1 have 1 row) (M2, 4 rows) (M3, M4 > 10 rows)



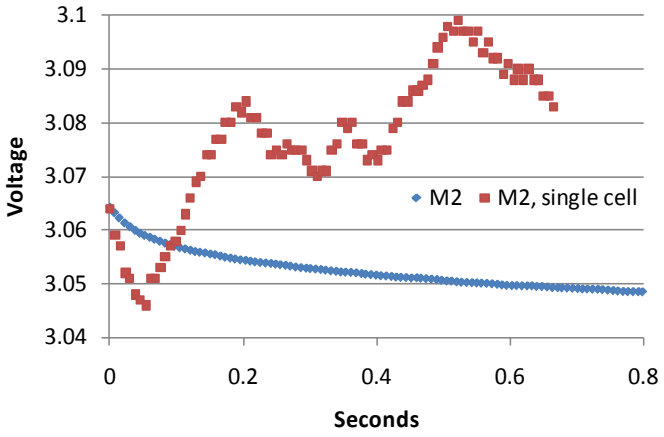
- Why does the number of rows matter?
- The more rows there are, the longer the upper most row is fully exposed to light while the bottom row is only getting diffuse light.

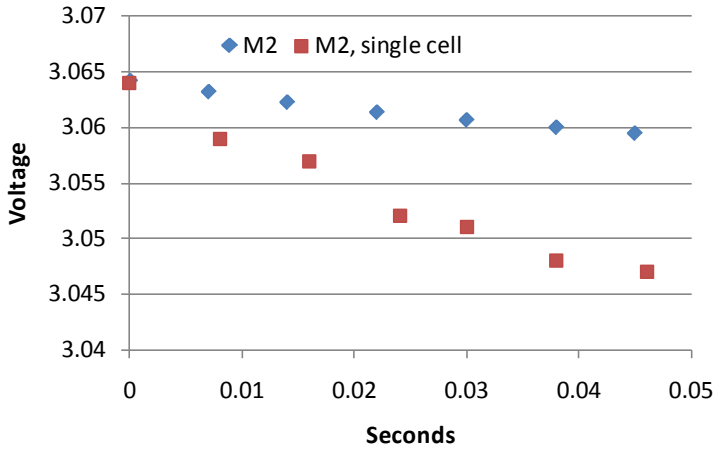
Calculated Delta T Between Cell and Heat Sink

The results of initial shutter testing deviate significantly from manufacturer suggested rise in cell temperature for similar meteorological conditions



Shuttering a Single Cell within a Module



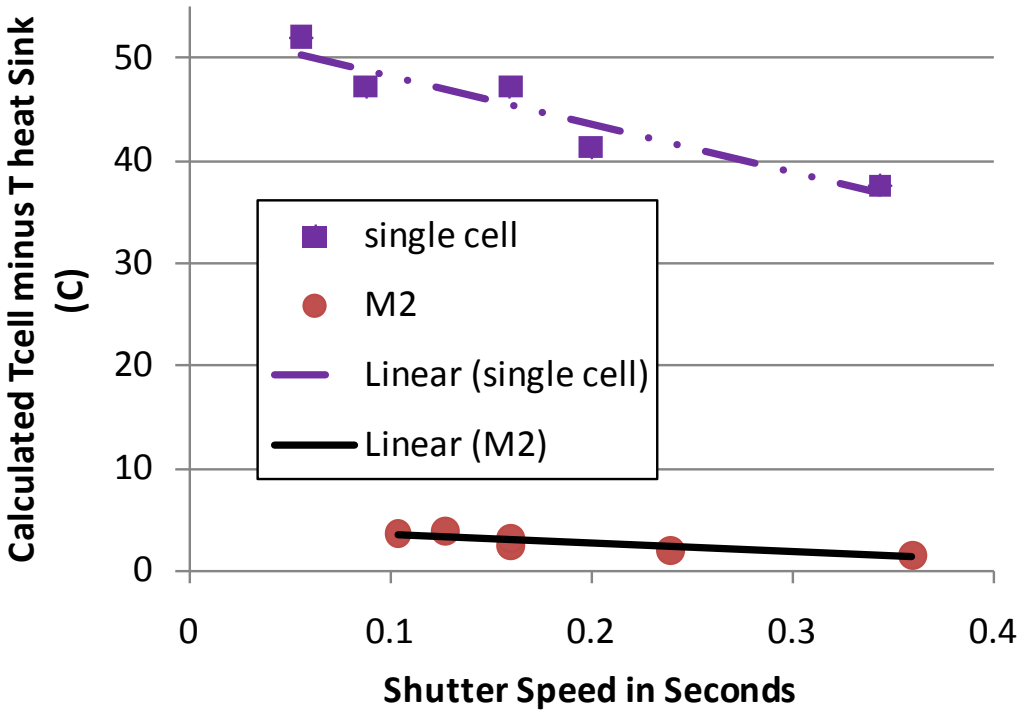


- This method presented problems as diffuse light made it to surrounding cells in the module

- Attempts were made allow all cells to see diffuse light before shuttering but the graphs show that data was not clean.

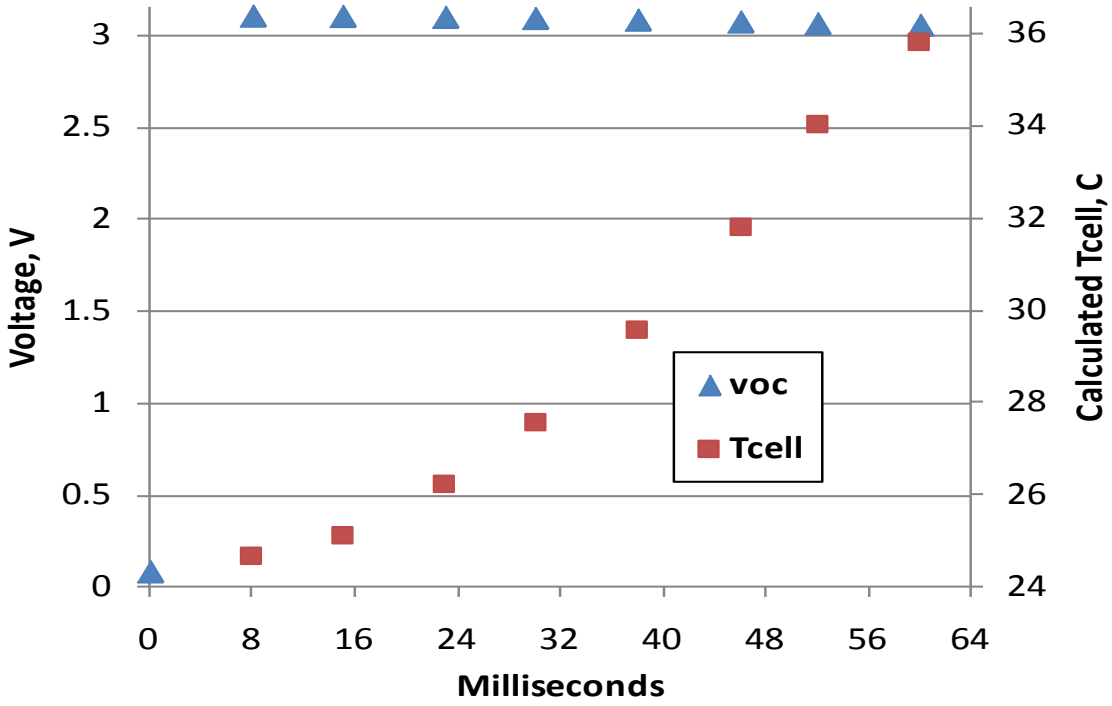
- With these limitations in mind, drops in Voc were measured that were 3-4 times faster than the results from the entire module even though shutter speed wasn't increased

Varying Shutter Speed to Understand Procedure Uncertainty



• As expected, slower shutter speeds introduce more error into the cell temperature calculation but it is not clear how fast the shutter needs to be or what the uncertainty is for the fastest speeds achieved

An Extremely Fast Mechanical Shutter on a Single Cell



- In 52 ms, the decline in voltage suggests that the cell temperature has risen 11C.
- This indicates that upper rows of cells can rise significant amounts if shuttering = 0.1s
- A caution to indoor flash testing (I-V sweeps should take < 30 ms), Sweep in both directions to confirm cell temperature has not risen

Conclusions

- For 3 out of 4 modules tested at NREL, cell temperatures calculated using the shuttering procedure are10-25C lower than the suggested values from module manufacturers

- At this point little is known about how the each manufacturer determines cell temperature or the accuracy of their procedures.

- Practical limitations to shuttering
  - Fastest shutter speed ~0.1 s
  - It is difficult to evenly and consistently remove the shutter
  - Largest modules?

- No definitive conclusion has been reached thus far in regards to the accuracy of the shuttering procedure.

- Ongoing modeling efforts and additional data collection are focused on establishing the uncertainty of the shuttering procedure.

Thanks!

Questions?