
2018 PV Systems Symposium’s 10th PVPMC Workshop
Objective

Problem

• **Reference modules** used for soiling & irradiance measurement
• Module **temperature** needed
• Back-of-module temperature sensors inconvenient, add **cost $**

Solution

• Determine module temperature from **Voc**
• Use **equivalent cell temperature** method, modified from IEC 60904-5
• Use I-V sweeps in **soiling & irradiance** monitoring system
• **Lowers system cost**
Soiling System with Reference Module

Clean Reference Cell
Measure irradiance

Soiled Reference Module
Sense soiling power loss

Daily Automatic Washing

Cell Wash System
(Reservoir, Pump, Level/Flow Sensors, Heaters)

Measurement & Control Electronics
(Module IV Sweep, Cell Irradiance Measurement, Data Analysis, Wash Control)
Back of Module Temperature Sensor

SolarPro, May/June 2015
Atonometrics Voc Temperature Method

Modified** Equations Based on IEC 60904-5 (2011):

\[
T = 25 \, ^\circ\text{C} + \frac{1}{\beta} \left[ \frac{V_{oc}}{V_{oc,STC}} - 1 - a \cdot \ln \left( \frac{I_{sc}}{I_{sc,STC}} \right) \right]
\]

\[
a = \frac{\frac{V_{oc,NOCT}}{V_{oc,STC}} - 1 - \beta \cdot (T_{NOCT} - 25 \, ^\circ\text{C})}{\ln \left( \frac{I_{sc,NOCT}}{I_{sc,STC}} \right)}
\]

**Equations modified to use module datasheet parameters for two known irradiance/temperature combinations, STC & NOCT:

\[
\beta \ (V_{oc, \text{ temp co.}}, \ V_{oc,STC}, \ I_{sc,STC}, \ V_{oc,NOCT}, \ I_{sc,NOCT})
\]

 Assumes datasheet parameters are accurate.
 But can also be field-calibrated by customers / users.
Example Results

Data filtered to irradiance >100 W/m²
Temperature Difference vs. Irradiance

The graph shows a scatter plot with data points representing the temperature difference (Voc Temp - RTD Temp in degrees Celsius) vs. irradiance (W/m²). The relationship is modeled by the linear equation:

\[ y = 0.0036x + 0.3095 \]
Reasons for Temperature Differences

• Accuracy of datasheet values
• Irradiance
  – Cell is hotter than back surface
• Wind speed
  – Cell is hotter than back surface
• Temperature non-uniformity
  – Back surface RTD measures one point only
• RTD thermal mass
  – RTD temperature changes more slowly than cell temp. RTD can be higher/lower depending on cloud movement.
Conclusions

• Voc temperature method can be used to eliminate module temperature sensors
• Atonometrics formulation uses datasheet values
• Advantageous for reference modules:
  – More convenient
  – Lower cost
• Potentially more accurate
  – Irradiance, wind, time lag, and temperature non-uniformities all contribute to back-surface RTD error
• May require an in-field calibration procedure to fine-tune datasheet values