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HCPV Characterization: Analysis of Fielded System Data

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Introduction

- Sandia has been involved in various aspects of PV system modeling and analysis for over 20 years
- Module-level characterization has expanded over the last 10 years to include on-site system characterization – partner interactions
- CPV characterization has largely been confined to individual modules
- Recently partnered with Semprius to install a 3.5kW CPV system
- Presentation will highlight analysis of operational system performance data

System Description and Instrumentation

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System

- 40 prototype Semprius modules - 3.5 kW (nominal)
- 1100X concentration ratio, 32.6% efficiency at CSTC
- Feina two-axis tracker and Kaco inverter
- Instrumentation Package
- Campbell Scientific CR-1000

Relevant Measured Quantities

- DNI
- GNI
- Ambient Temperature
- Module Temperature
- Wind Speed
- AC and DC Power, Voltage and Current (reported by the inverter)

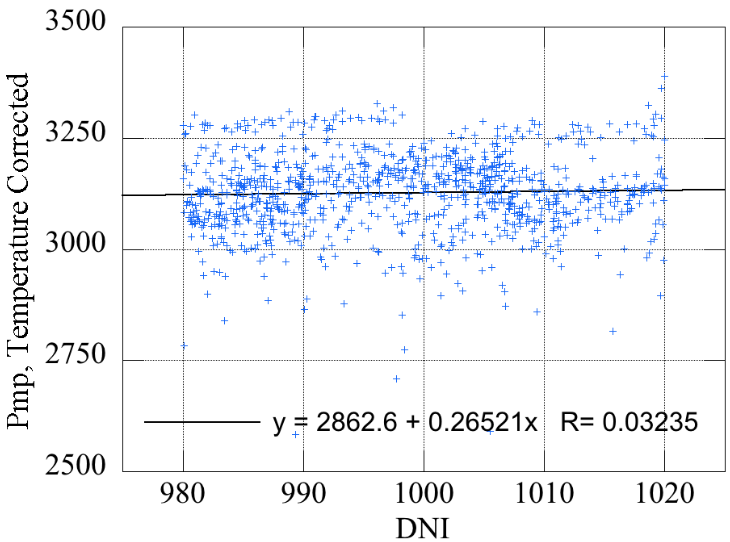
Data Filtering Conditions	
DNI, W/m^2	> 50
DNI/GNI	0.04 – 0.95
AC Power, W	> 150
DC Voltage, V	415 - 465
AC/DC Ratio	< 1.0

Sampling interval, sampling period, data size

CSTC Performance

- Filtered data was binned to conditions bracketing CSTC
- Binned data was temperature corrected using coefficients from a similar module
- Temperature corrected data was plotted against DNI
- Reference conditions were determined by regression analysis

Binning Conditions for CSTC Determination	
DNI, W/m^2	990 – 1010
DNI/GNI	> 0.85
Spectrum, AMa	1.45 – 1.55
Wind Speed, m/s	< 2.5
# of Data Points	1084



$$P_{mp0} = \frac{P_{mp}}{1 + \gamma_{Pmp}(T_c - T_0)}$$

$$I_{mp0} = \frac{I_{mp}}{1 + \alpha_{Imp}(T_c - T_0)}$$

$$V_{mp0} = V_{mp} - \beta_{mp}(T_c - T_0)$$

$$T_c = T_m + \frac{E}{E_0}\Delta T$$

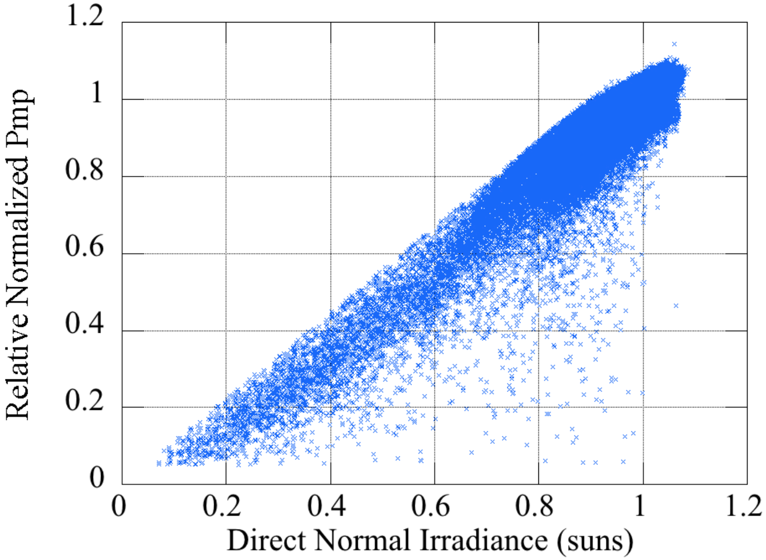
CSTC Performance

- V_{mp} from the system closely matched expectations from flash testing of the individual modules
- P_{mp} and I_{mp} from the system were observed to be ~10% lower than expected from flash testing
- Possible sources of loss
  - Mismatch, expected to be ~ 3%
  - Daily and seasonal variations in spectrum, expected to be 3-5%
  - Discrepancy in Cell Temperature model
  - Uncertainty in data reported by the inverter
- Values determined for the system were used for all subsequent analyses

CSTC Values			
Test Condition	P_{mp}, W	I_{mp}, A	V_{mp}, V
Nameplate	3500	8.08	433
Flash	3503	7.624	459
System	3128	6.829	461

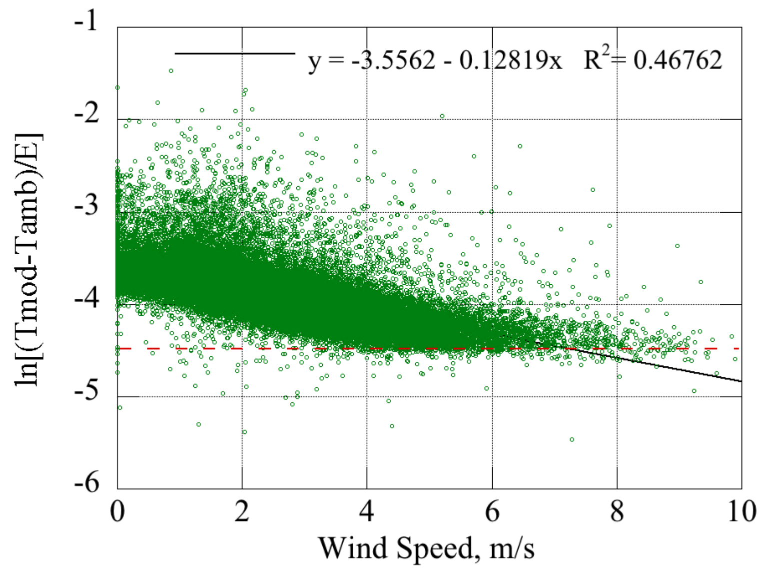
DC Power and Irradiance

- Data was filtered to remove wind speeds greater than 5 m/s
- Temperature corrected P_{mp} was normalized by $P_{mp,CSTC}$ and plotted against DNI (suns)
- Data appears as a wide band along a linear trend
- Vast majority of points are clustered above $E_e > 0.6$, a consequence of typical irradiance conditions at Sandia.
- Scattered points at lower Pmp are indicative of partial shading
- Data was not corrected for spectrum



Wind Speed and Module Temperature

- The effect of wind speed on module temperature was explored following the methodology of the Sandia Array Performance Model
- Data suggests that there is a threshold at $\ln[(T_{mod}\text{-}T_{amb})/E] = 4.5$, corresponding to a temperature difference of ~11°C at 1000 W/m^2
- This implies that the modules reach a steady state condition at which further increases in wind speed do not result in further cooling



$$T_m = E\{e^{a+b\cdot WS}\} + T_a$$

Monthly Variation in Energy Yield

- One clear-sky day was selected from each month
- DC Performance ratio was calculated for each day
- Clear trend toward lower PR_{DC} during winter months
- Average and Peak DNI values indicate that irradiance stays high during the winter
- Cooler temperatures should result in higher output
- One possible explanation can be found in examining seasonal response to air mass

Date	DC Energy, kWh	PR_{DC}	DNI, W/m^2	
			Avg	Peak
16-Aug	8.258	0.95	899	980
23-Sept	8.600	0.93	955	1023
21-Oct	7.226	0.90	944	1010
9-Nov	6.984	0.90	972	1029
12-Dec	6.530	0.87	976	1036
21-Jan	6.848	0.86	925	1063
21-Feb	7.383	0.90	982	1036
16-Mar	9.443	0.89	1006	1076

$$Y_{f,DC} = \frac{E_{DC}}{P_{mp,CSTC}} \quad \left[\frac{kWh}{kW} = h\right]$$

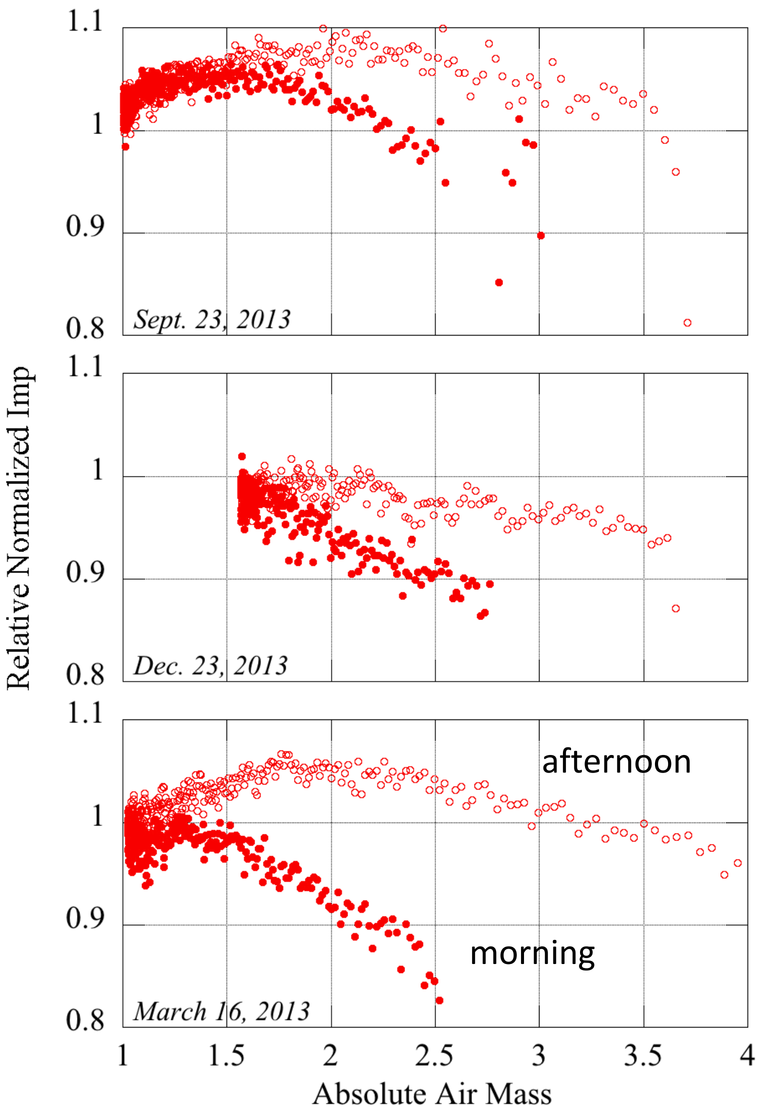
$$Y_r = \frac{E_{DNI}}{E_0} \left[\frac{kWh/m^2}{kW/m^2} = h\right]$$

$$PR_{DC} = \frac{Y_{f,DC}}{Y_r}$$

DC Current vs. Air Mass

- Temperature corrected I_{mp} was normalized by $I_{mp,CSTC}$ and plotted against absolute air mass for days near seasonal changes
- Peak in I_{mp} at AMa=2 is consistent with testing under more controlled conditions
- Significant split between morning and afternoon is thought to be due to difference in spectrum that is not captured by AMa
- Normalized I_{mp} was consistently higher at the equinoxes than at the solstice

Possible explanation for seasonal dip in PR_{DC}



Summary

- Eight months of operational data from a 3.5 kW R&D CPV system was analyzed
- V_{mp} at CSTC conditions matched flash data while P_{mp} and I_{mp} were ~ 10% lower.
- Possible causes include string mismatch, seasonal variation in solar spectrum and discrepancy in the cell temperature model
- An apparent limit to the degree of module cooling that can be expected from wind speed was observed
- The system was observed to display variation in seasonal performance, likely due to variations in spectrum