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Systems Long Term Exposure Program: Analysis of the First Year of Data

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Abstract

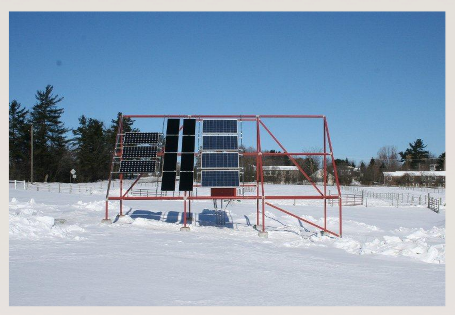
While indoor accelerated testing of products is important for development, it is equally important to conduct field-testing to determine performance and degradation under real world conditions. To address this need, Sandia has developed an outdoor small systems evaluation laboratory. The Systems Long Term Exposure (SLTE) project spans three geographic locations: one in a hot/dry climate, one in a hot/humid climate and one in a cold climate. Identical systems representing three commercial technologies are installed at each location. In this paper, we present the results and analysis from the first year of monitoring of these systems.

System Descriptions

The systems at each location are mounted at local latitude tilt. Each system is MPPT tracked by a grid-tied residential inverter. Systems are instrumented for continuous monitoring. Localized irradiance sensors provide reference conditions for comparison to measured energy production.


Florida


New Mexico


Vermont

Technology	Size, W	System Voltage, V	Inverter
mono-Si	690	146	SMA SunnyBoy 700U
Thin Film	580	177	
mc-Si	880	146	

Location	Climate
Florida Solar Energy Center (FSEC)	Hot/Humid
New Mexico State University (NMSU)	Hot/Dry
University of Vermont (UVM)	Mostly Cold

Instrumentation and Data Acquisition

Each system is instrumented with a Campbell CR1000 for continuous monitoring. Localized irradiance sensors provide reference conditions for comparison to measured energy production. Data is recorded once a minute.

Parameter	Units	Sensor/Transducer
AC Power	Watts	OSI Power Transducer
DC Current	amps	Empro current shunt
DC Voltage	volts	Caddock voltage divider
Irradiance	Watts/meter^2	EETS Ref Cell
Module Temp	°C	Type-T Thermocouple
Ambient Temp	°C	Campbell Sci. Temp Probe

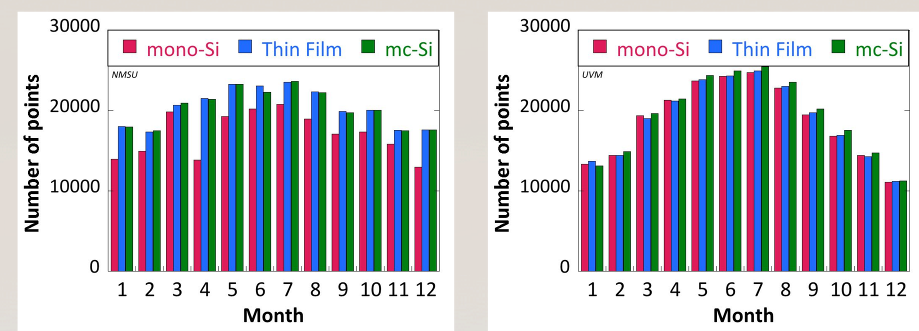
Summary

- The Systems Long Term Exposure program run by Sandia will operate for a period of 3-5 years. Continuous monitoring of these systems will provide climatic and degradation comparisons between several technologies.
- Analysis of the first year of operation is underway and has revealed several challenges in long-term monitoring of fielded systems and data filtering.
- Annual Performance Ratio calculations can be misleading when comparing technologies and climates.
- Annual Pr between Thin Film and c-Si are nearly the same, however thin film generally shows less variation with climate and season.
- Early exploration of temperature differences reveals that high efficiency mono-Si systems can run 2-4°C cooler than other technologies.

Data Filtering and Analysis

Monthly data records were assembled into a single annual data file for filtering, processing and analysis. For each site, annual data files were globally filtered by irradiance to remove overnight or incomplete data records. Next, filters were applied to individual data records for each system. Filtering conditions are listed below.

Filter	Condition
Irradiance	< 25 W/m^2
AC Power	< 5 W
DC Current	< 0; > 1.25 Isc
AC/DC Ratio	> 1.0



A consequence of filtering was uneven removal of data for the mono-Si system located in New Mexico. This system displayed noise in the power measurement and, as a result, on average about 10% more data was removed. Another consequence was that longer summer months contained more data than shorter winter months.

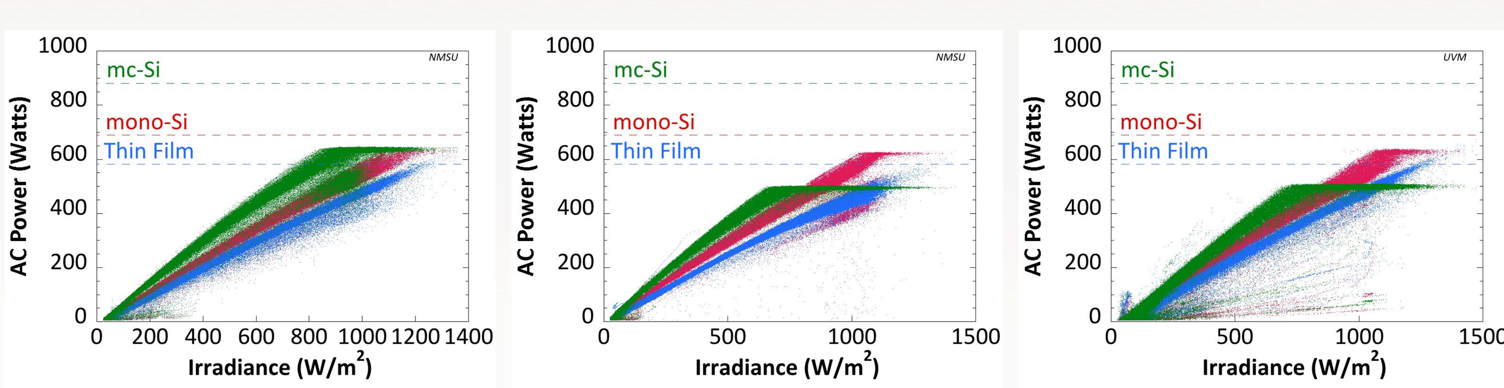
After the filtered data sets were assembled, PV system yield (Y_f) and reference yield (Y_r) were calculated for each 1-minute data point. These were then used to calculate Performance Ratio for each 1-minute time period (referred to here as the instantaneous performance ratio) as well as other time intervals of interest. Note that the Performance Ratio across longer time intervals does not equal the average of the instantaneous Performance Ratios; Y_f and Y_r must be summed separately. Since all performance ratio calculations were made using a summation of Y_f and Y_r values calculated for each 1-minute data point, comparisons could be made between data sets regardless of of the number of data points available.

$$Y_f = \frac{P_{ac}}{60\left(P_{nameplate}\right)} \text{ (kWh/kW)} \qquad Y_r = \frac{E}{60\left(E_0\right)} \text{ (hours)} \qquad P_r = \frac{\sum Y_f}{\sum Y_r} \text{ (dimensionless)}$$

Annual Energy and Observations

Annual energy production and Performance Ratio for each system and location are tabulated below. On an annual basis, the mono-Si and Thin Film systems performed nearly identically, with the Thin Film system having a slight edge in the Hot/Humid and Mostly Cold climates. In contrast, the mc-Si system performed slightly behind the other two in the Hot/Humid climate and significantly behind in the other locations. However, AC Power plotted against Irradiance revealed that the inverters used for the mc-Si systems at NMSU and UVM were configured to a lower maximum power than at FSEC, leading to significant clipping. The onset of this clipping was at an Irradiance as low as 650 W/m^2, contributing to the generally lower performance of the mc-Si systems. The mono-Si system also displayed some clipping, but only at high irradiance, above 1000 W/m^2. In general, all systems in the Mostly Cold climate underperformed compared to the other locations.

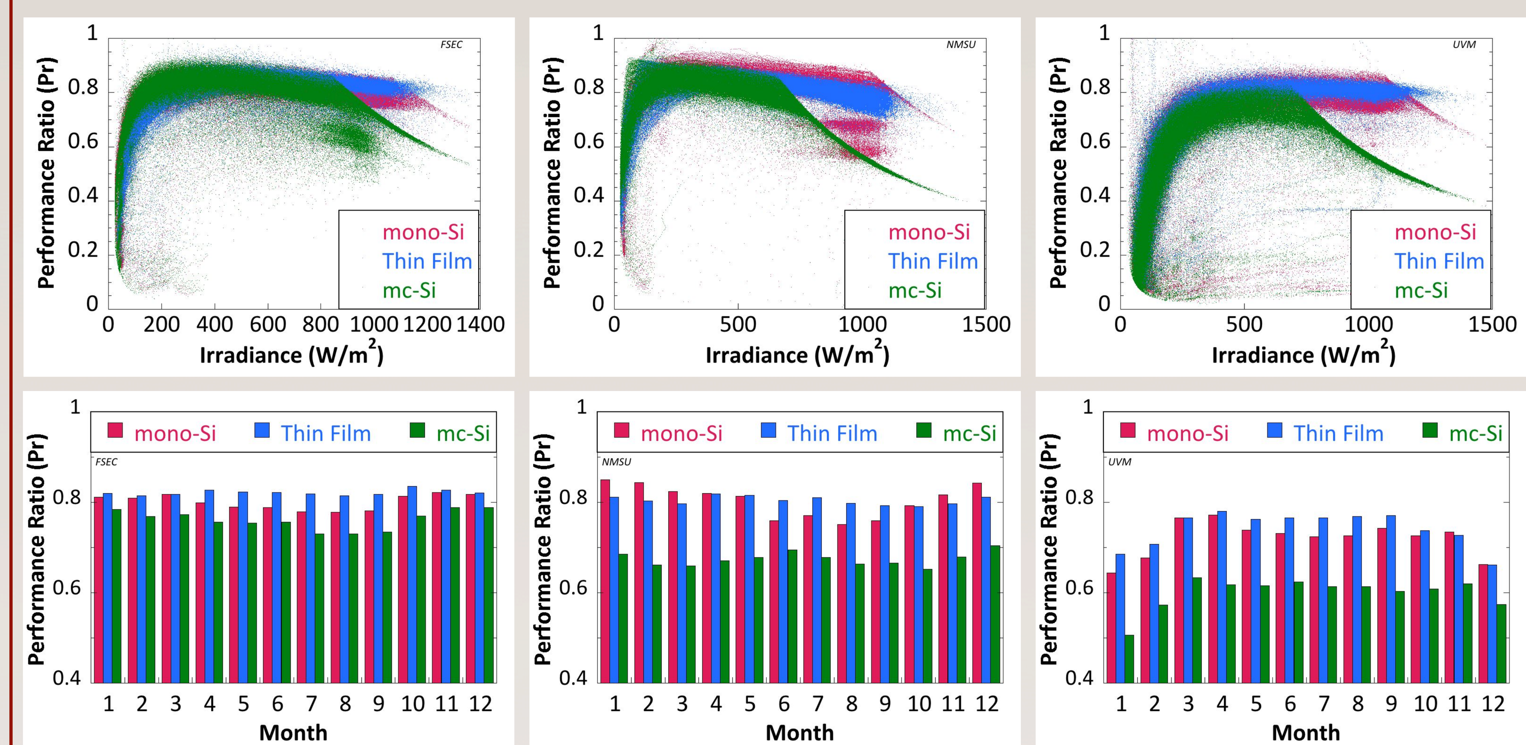
	mono-Si		Thin Film		mc-Si	
Site	kWh	Pr	kWh	Pr	kWh	Pr
FSEC	1072	0.80	924	0.82	1298	0.76
NMSU	1060	0.80	1100	0.80	1385	0.67
UVM	842	0.73	732	0.75	898	0.61



Florida New Mexico Vermont

Performance Ratio Comparisons

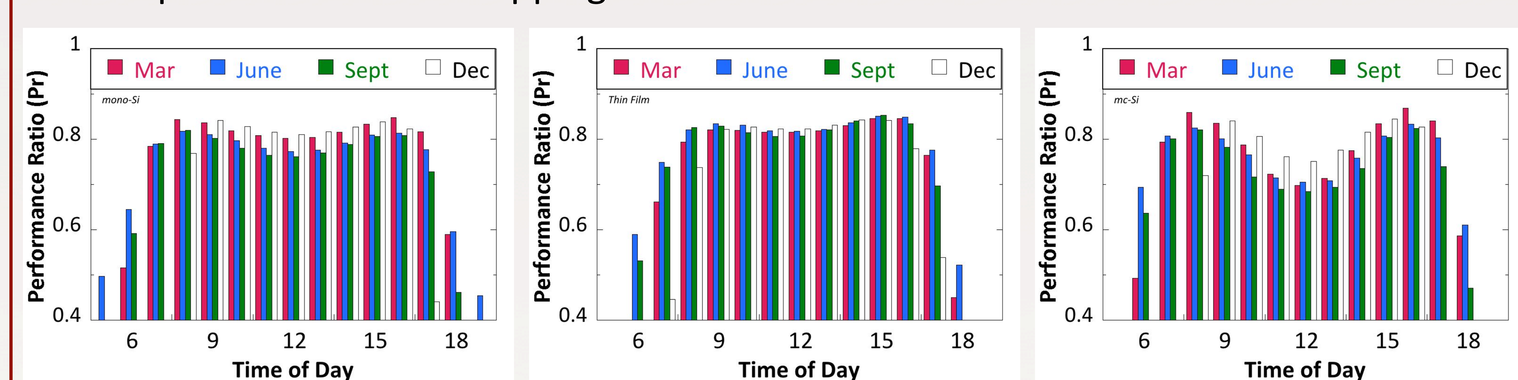
Plots of Performance Ratio against Irradiance show the same trend as seen in the comparison of AC Power against Irradiance. The effects of inverter clipping can be seen in both the mc-Si systems and the mono-Si systems. The trends below the clipping range reveal a few differences in system performance. In Florida, the maximum observed Pr for all three systems was nearly the same. In New Mexico, the mono-Si system had a peak Pr that was noticeably higher than the other systems, while in Vermont the mc-Si system had a noticeably lower peak Pr.



Florida New Mexico Vermont

A monthly comparison of Pr at the three sites revealed mild seasonal variability in Florida and New Mexico and pronounced seasonality in Vermont. Across all technologies, Pr was at it's lowest during the winter months in Vermont. All three mono-Si systems displayed a dip in performance from March to September. Peak performance for the mono-Si systems in the hotter locations was during the winter months and near the equinoxes in the cold climate. The thin film systems had flat performance throughout the year in the hotter climates and during the summer months in the cold climate. The mc-Si system in Florida had a dip in Pr during the summer, however the system in New Mexico experienced a slight increase, peaking in June. This likely was a side effect of the system operating at peak power as a result of inverter clipping.

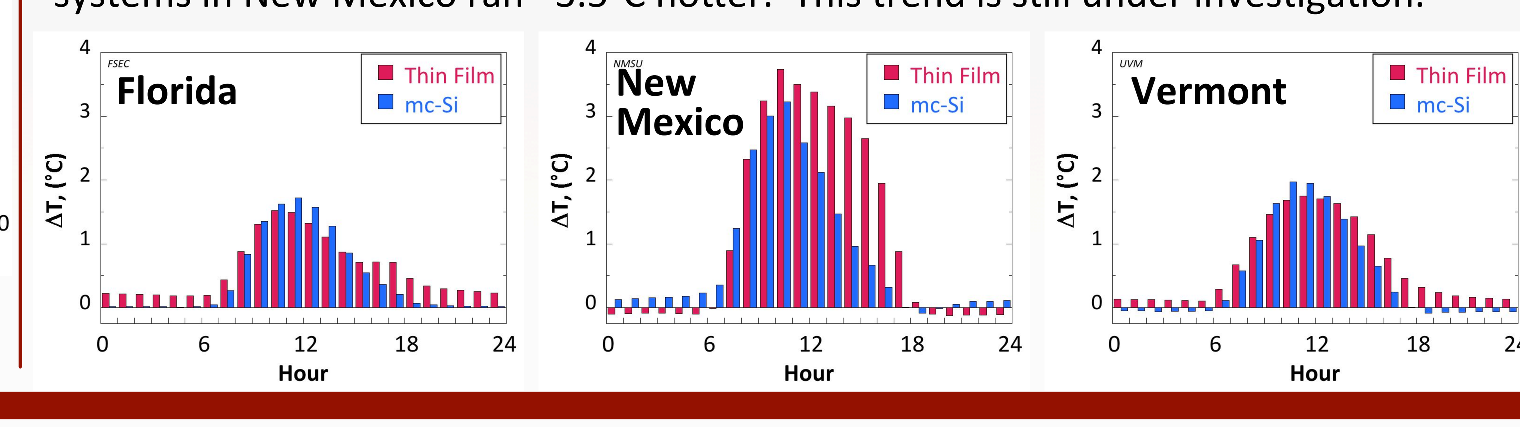
To investigate the effects of time of day, Pr was calculated for 1 hour time blocks for one month during each season. This calculation was only made for the systems located in Florida. The seasonal effects noted above can be seen in each plot. The relatively flat response of the thin film system is even more evident here, as is the deep trough in Pr during the middle of the day for the mc-Si system as a consequence of inverter clipping.



mono-Si Thin Film mc-Si

Temperature Difference

The mono-Si systems ran cooler than the other two systems. Daily differences in module temperatures between the other two technologies and mono-Si are plotted below. On average, systems in Florida and Vermont ran 2° hotter at peak, while systems in New Mexico ran ~3.5°C hotter. This trend is still under investigation.



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