Presented at the 2013 Sandia PV Performance Modeling Workshop
Santa Clara, CA. May 1-2, 2013
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Modeling Needs for Performance Guarantees

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Performance Guarantees

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The goal: provide insight into the operation of a PV power plant including modules, DC BOS, inverters, AC components through modeling and analysis.

What is not included in PG:

- Weather
  - Irradiance/Tamb/Windspeed
  - Soiling
  - Spectrum
- Availability
  - Part of the O&M contract, usually has strict definitions many times binary

What is really needed from a model

- Input measured weather
  - Soiling measured
  - Spectrum modeled
- Exclude availability
  - Replicate power plant operation
- Compare easier
  - Examination of each of the measurement points on the power plant

We want a power plant whose fuel source happens to be free.

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Separating energy estimation from energy analysis

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Use sub-hourly modeling

- Systematic error occur anytime the power plant operation changes state.
  - Off-On (ignored)
  - Clipping to Not-clipping on both the inverter and plant level
  - Thermal derating of inverters
- Thermal model--Use the best available model

Go specific on Inverter modeling

- Validating the efficiency curves
- Modeling thermal and altitude effects
- PF effects

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Hourly Models

- Hourly averages have been shown to be inadequate in "Transient weather conditions" (Ransome and Funtan),
- Low-hanging fruit:
  - Hourly performance analysis when the PV system changes state
  - Better thermal models should be adopted to improve accuracy.

WHY HOURLY AVERAGED MEASUREMENT DATA IS INSUFFICIENT TO MODEL PV SYSTEM PERFORMANCE ACCURATELY

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ABSTRACT: Many commercially available PV Sizing and modelling programs use a simple dc performance model of a PV module multiplied by hourly weather data plus a simple model of "balance of systems" (BOS) losses to estimate the yearly ac energy output.

Studies of the meteorological data, dc module and ac inverter performance every 15 seconds in ISET, Germany show that hourly averaging of weather data overemphasises the importance of low light levels in yearly energy generation. Transient weather conditions show more inverter clipping than would be expected from hourly weather averages.

Higher maximum irradiances coincident with lower than hourly predicted module temperatures are also found, which mean higher module and inverter currents and powers need to be considered in component sizing.

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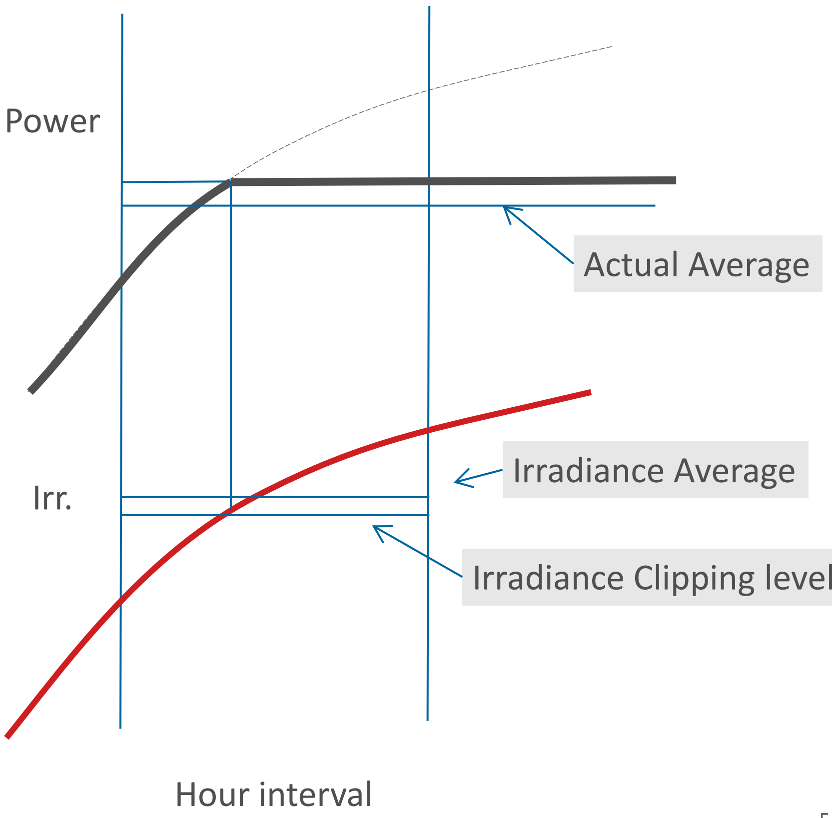
Change of state energy variation

- Averaging data over hours where inverters spend time both at capacity and below capacity (transition hours) results in an over-predict of energy generated.
- During transition hours not all irradiance can be converted to AC energy due to inverter clipping therefore simple averaging is incorrect.
- This results in an over-prediction of the hourly modeled AC power during this hour. On an hourly basis this has been measured to be as large as a 10.4% overprediction.



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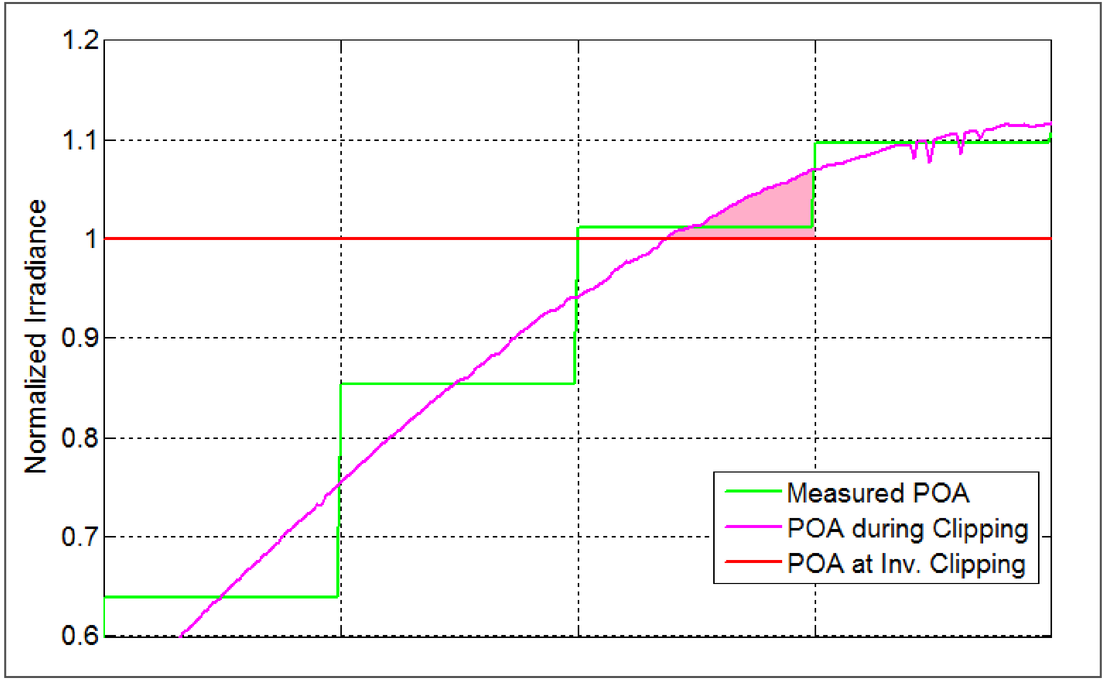
Proposed Solution with hourly averages

- The hourly average irradiance for the transition hour is above the threshold at which the inverters will clip.
- The difference between the clipping threshold (red line) and the 1-min measured irradiance (highlighted in pink) will represent the amount of energy that is not available for energy conversion.
- Quantifying this will provide the amount of over-predicted energy.



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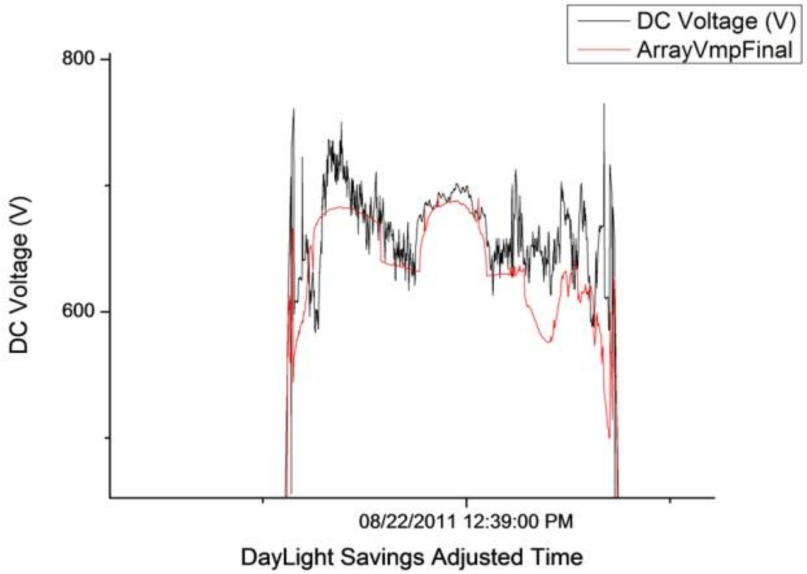
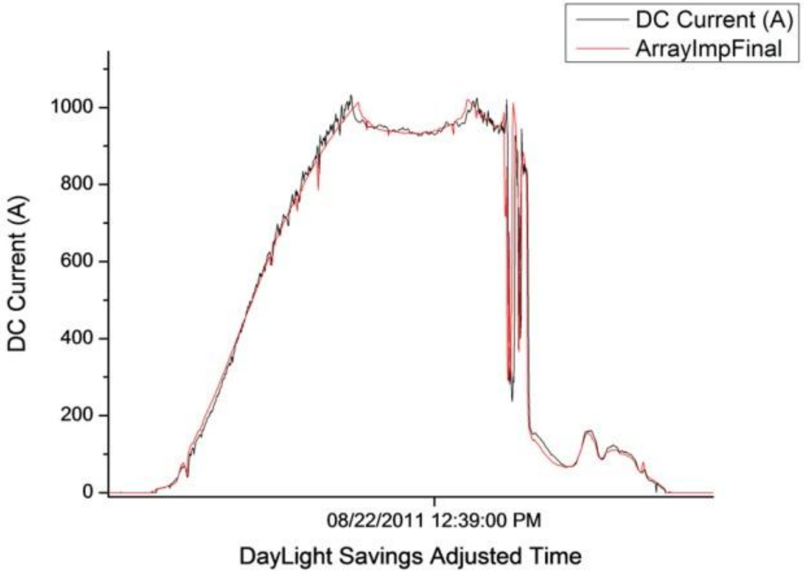
Better Solution: Don't use one-hour averages

- One minute spikes in voltage control not replicated
- Clipping time and level matches extremely well.





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Problem Description

- The default thermal loss parameters used in hourly-averages heat-balance modeling large free-field PV plants result in slightly conservative estimates of DC energy generation[1].
- Updating these thermal loss parameters can lower the annual mean absolute error from ~3.2 °C to 3.0 °C which can result in 0.3% additional modeled annual DC energy generation.
- Further work is underway to minimize this error by employing a thermal model that is under development at First Solar. This model will reduce error and apply to sub-hourly intervals.

[1] W. Hayes, A. Panchula, and L. Nelson, "Thermal Modeling Accuracy of Hourly Averaged Data for Large Free Field Cadmium Telluride PV Arrays". IEEE-PVSC 38. Austin, TX, USA June 2012.

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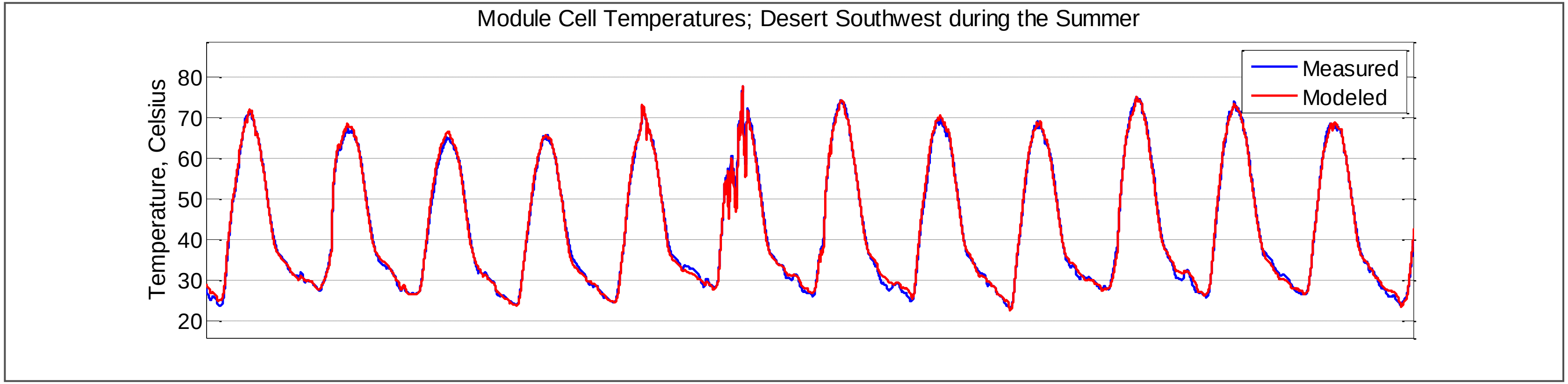
Sub-hourly Thermal Model: Preview

- First Solar is developing a transient thermal model based on Luketa-Hanlin and Stein[2] with the following fundamental requirements:
  - The model must be applicable across the range of time steps from ≤ 5 min to 1 hour.
  - The annual mean absolute error must be ≤ 2 °C.
- Results to date have been promising but require significant validation to ensure that the model will be globally applicable.



[2] A. Luketa-Hanlin and J. Stein, "Improvement and Validation of a Transient Model to Predict Photovoltaic Module Temperature." World Renewable Energy Forum 2012.

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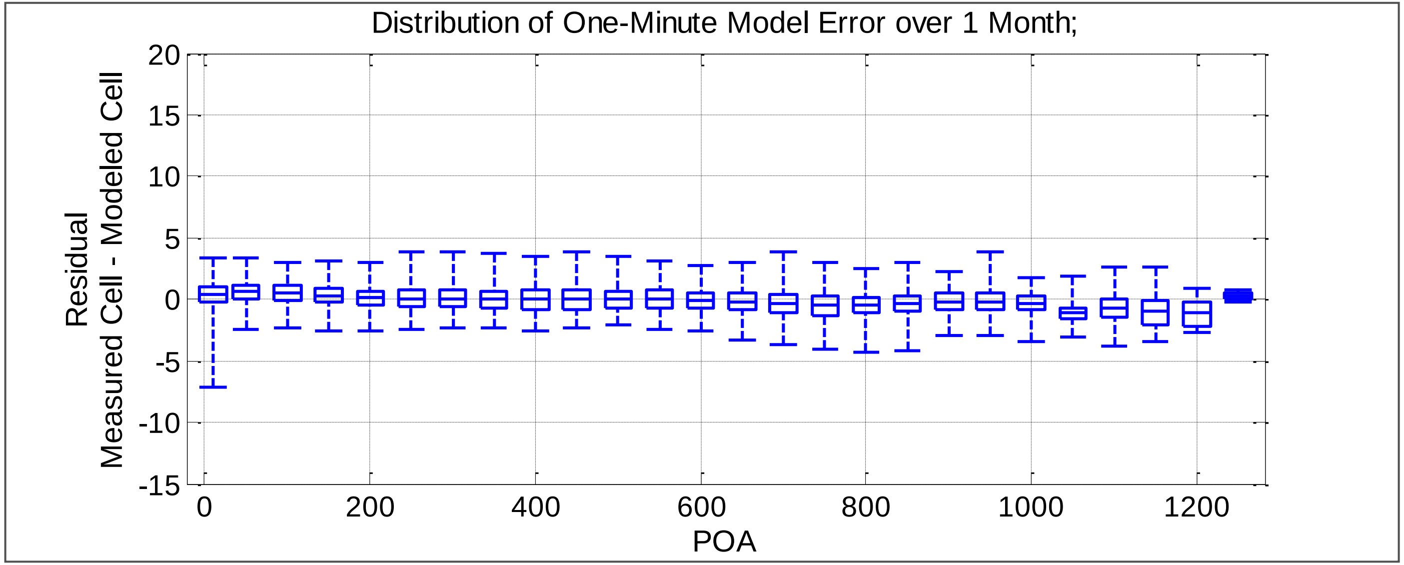
Distribution of Errors

- The distribution of errors over 1 month for the preliminary results of the thermal model being developed by First Solar (shown on slide 6) result in a root mean square error of 1.08.
- It is not expected that the final model will have this accuracy since it will need to be applicable across different regions/climates.



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Inverters beyond Efficiency

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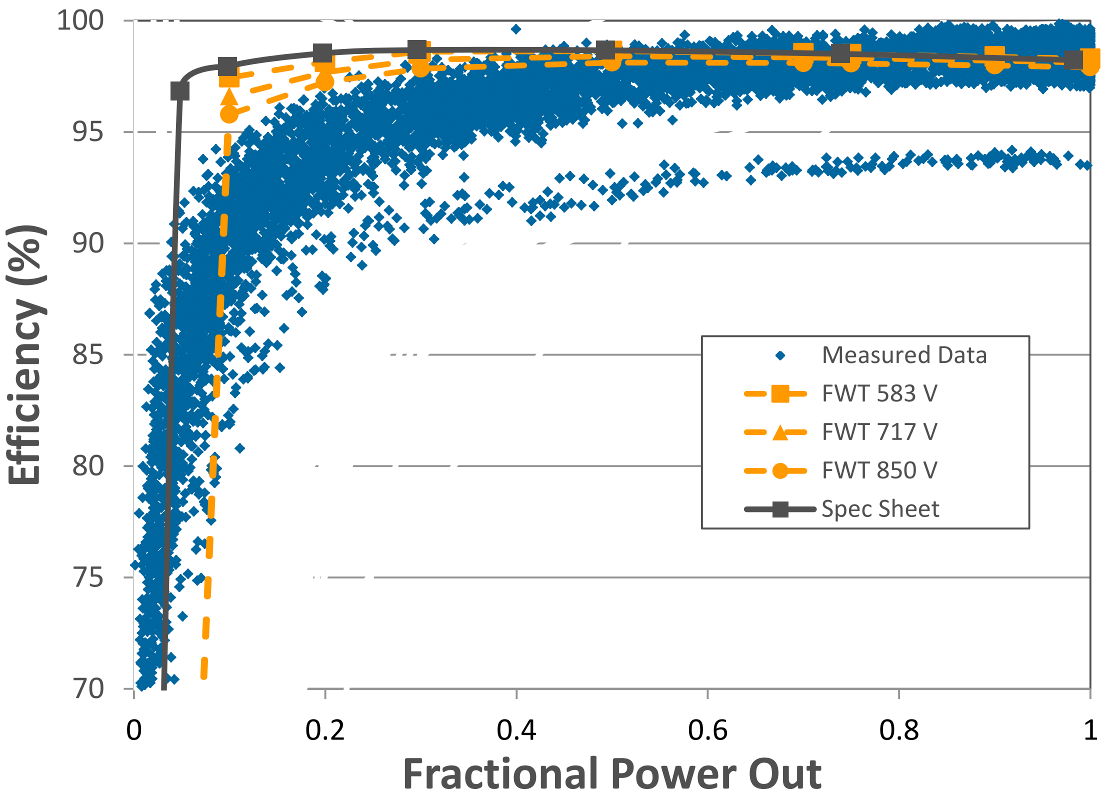
Inverter specification

- Both the measurement of inverter efficiency and the specification sheets are suspect
  - Comparing spec sheet to factory witness test to measured data tells different stories
  - Currently not a huge source of energy variance, but clearly many problems in both measurement and modeling.



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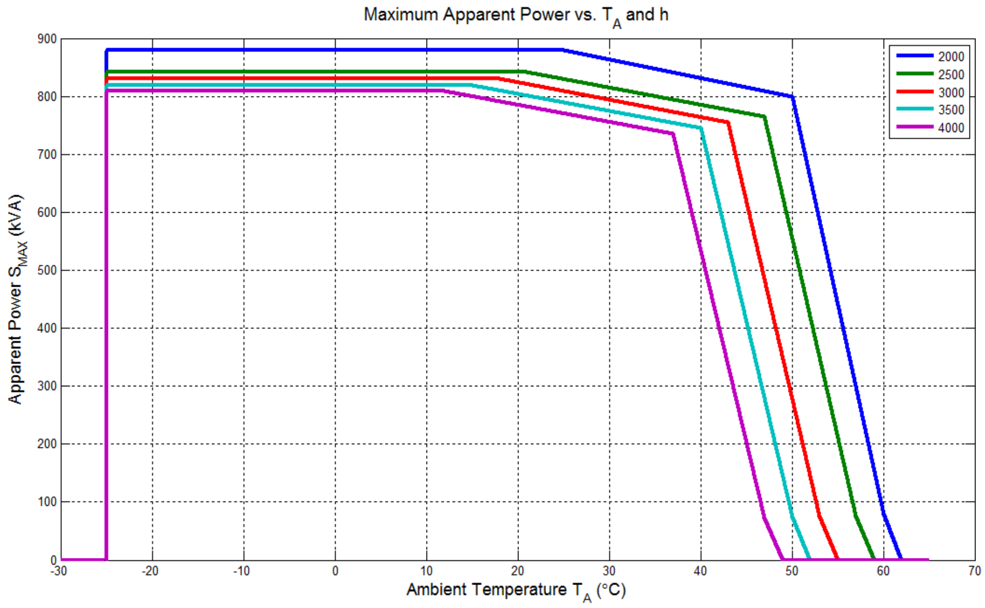
Inverter controls

- Generally ignored in the inverter models
  - Power factor interactions with utilities scale control requests
  - Auto-derating due to the Tamb and Altitude (m)
  - True cooling loads



Apparent power vs Tamb and altitude from an inverter manufacturer

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Application of thermal derate

- Application of the thermal derating curve is straight-forward but critical for power plant sizing, inverter selection, and for performance guarantees
  - Loss of apparent power could show as a energy generation failure if not understood.