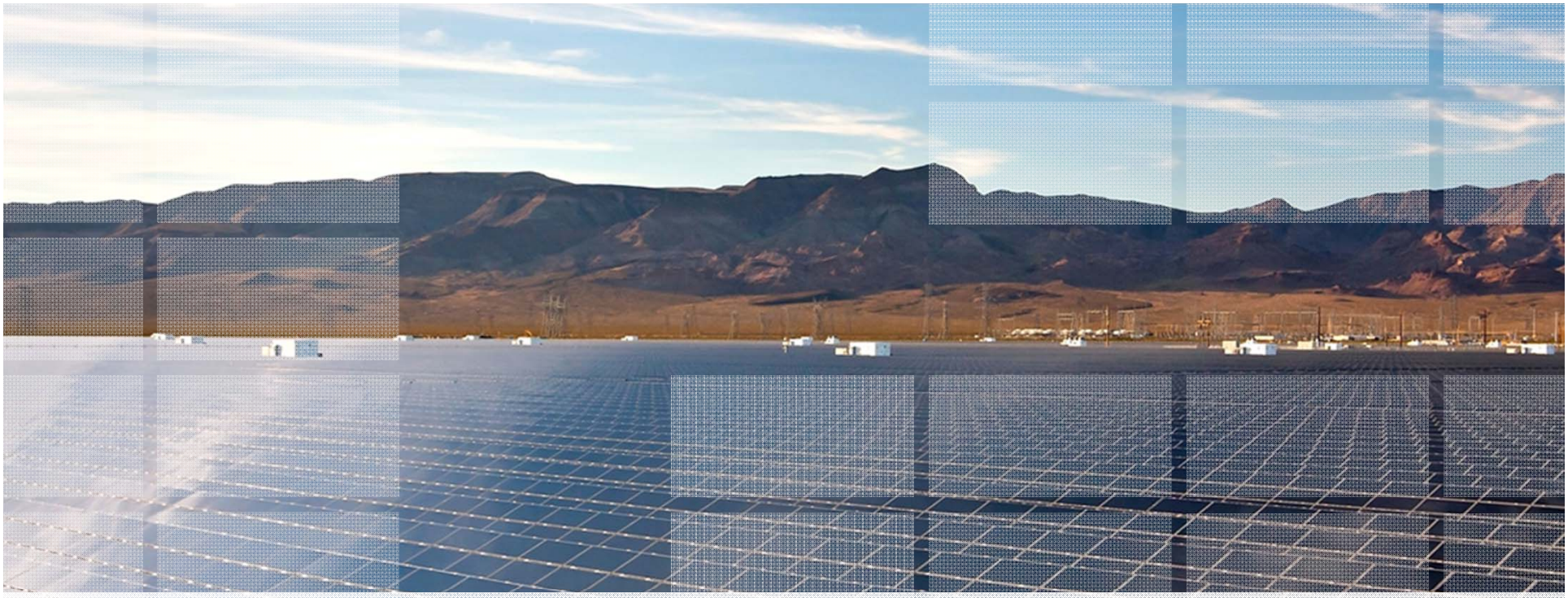

A Systemic Inverter Reliability Perspective

Sandia 2013 Inverter Reliability Workshop

Michael Schenck • Advanced Plant Architecture

April 30, 2012 • mschenck@firstsolar.com

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Topic Review

- First Solar Plant & Location Overview
- Overview of Reliability
- *Component* Review
- ‘Soft’ Failures Review

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First Solar at a Glance

Over 7GW produced worldwide and nearly 3GW contracted pipeline

Cost competitive with conventional energy sources today

Delivering utility-grade PV energy solutions to global power buyers

Largest utility-scale developer and EPC and O&M provider in the industry

Fully integrated PV solutions optimized for project specific economics

Founded in 1999 and publicly traded on Nasdaq (FSLR)

Leading Global Provider of PV Energy Solutions

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Sempra – El Dorado
10MW (AC) | 2008

NRG – Blythe
21MW (AC) | 2009

Sempra – Copper Mnt.
48MW (AC) | 2010

Enbridge – Sarnia
80MW (AC) | 2010

Southern/Turner – Cimarron
30MW (AC) | 2010

Enbridge – Tilbury
5MW (AC) | 2010

NRG – Santa Teresa
20MW (AC) | 2011

PNM – 5 Projects
22MW (AC) | 2011

APS – Paloma
17MW (AC) | 2011

Enbridge – Amherstburg II
15MW (AC) | 2011

NextEra – Moore
20MW (AC) | 2011

NextEra – Sombra
20MW (AC) | 2011

Enbridge – Silver State N.
50MW (AC) | 2012

Constellation – St. Mary's
14MW (AC) | 2012

Verve/GE–Greenough River
10MW (AC)

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Completed EPC Projects 380MW+ (AC) | October 2012

NRG/MidAmerican – Agua Caliente 290MW (AC)

NRG – Alpine 66MW (AC)

MidAmerican – Topaz 550MW (AC)

NRG – Avra Valley 26MW (AC)

NextEra/GE/Sumitomo–DSL 550MW (AC)

Verve/GE–Greenough River 10MW (AC)

Tenaska – ISECS 130MW (AC)

Sempra – Copper Mnt. II 150MW (AC)

GE – Walpole 20MW (AC)

GE – Amherstburg I 10MW (AC)

GE – Belmont 20MW (AC)

Exelon – AVSR 230MW (AC)

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In Construction 2GW+ (AC) | October 2012

Global Reach

Worldwide presence and ~5,600 global associates

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Definition of Reliability

re·li·abil·i·ty ***noun*** \ri-ˌlī-ə-ˈbi-lə-tē\

1: the quality or state of being reliable

2 : the extent to which an experiment, test, or measuring procedure yields the same results on repeated trial.

http://www.merriam-webster.com/dictionary/reliability

re·li·able ***adjective*** \ri-ˈlī-ə-bəl\

1: suitable or fit to be RELIED on : DEPENDABLE

2 :giving the same result on successive trials

http://www.merriam-webster.com/dictionary/reliable

The classic definitions are fairly vague and somewhat circular.

They do not address performance in an explicit manner. The concept of availability, a performance metric, while not specifically excluded, is not included either.

re·li·abil·i·ty ***noun*** \ri-ˌlī-ə-ˈbi-lə-tē\

(systemic def.)

1: The ability of a person or system to perform and maintain its functions in routine circumstances, as well as hostile or unexpected circumstances

http://en.wikipedia.org/wiki/Reliability

The Systemic Definition captures the essence of reliability as it applies to PV systems.

As the definition implies : System performance, component reliability/failure means are known/quantified. Response to external stimuli is understood; the system is predictable. Causality and correlation is also understood.

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Inverters : an under-documented machine

Inverter datasheets (and other inv documentation) lack data necessary to perform Systemic Reliability Analysis.

Module parameterization

- Data sheets are not enough
  - Expect some variation in module model even within a technology

25th European Photovoltaic Solar Energy Conference and Exhibition, September06 –10 2010, Valencia, Spain

SIMULATION OF IRRADIATION AND TEMPERATURE DEPENDENT EFFICIENCY OF THIN FILM AND CRYSTALLINE SILICON MODULES BASED ON DIFFERENT PARAMETERIZATION

B. Müller, U. Kräling, W. Heydenreich, Ch. Reise, K. Kiefer
Fraunhofer Institute for Solar Energy Systems ISE

ABSTRACT: For reliable energy yield predictions an accurate modeling of the PV module behavior is essential. In this analysis we compare two different possibilities for acquiring the necessary parameters: indoor measurements and data sheet values. We found that temperature coefficients of power given in data sheets can be used for yield prediction without introducing higher uncertainties. On the other hand the derivation of model parameters for the modeling of irradiation dependent efficiency of PV modules based on data sheets is associated with high uncertainties. In a sample of 50 PV modules only for 15 modules parameters from data sheets could be derived with a sufficient accuracy.

Keywords: Energy Rating, Modeling, Module

Inverters have at least the same complexity or are more complex than modules. Hundreds of pages of documentation are required to document inverter operation.

Inverter Datasheets do not contain adequate resolution to quantify operation – yet the industry accepts this (datasheet level detail) as the appropriate norm.

After reviewing a random sampling of Inverter Datasheets, all had one or more of the following issues:

- 'Marketing' rounding (Current * Voltage ≠ Power)
- Incorrect application of CEC and/or Euro Efficiency
- Incomplete DC Voltage range information, MPPT, Application Scope
- Obscured temperature dependent relationships
- Lack any sort of traditional Reliability Data MTBR/MTTR/MTTF data
- Lack any sort of Software Testing/Validation Standards

Inverters are underappreciated as complex machines.

*Module slide from A Panchula, PV Performance & System Modeling. Specific examples of inverter datasheets can be provided upon request, omitted here for time.

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Reliability vs. Availability

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Availability counts as a relevant performance metric. It is not a 1:1 relationship with inverter reliability.

- Gray area between failure and lower performance
- Combination of individual component reliability and system design
- Downtime matters
- Measurement (visibility)

*Adapted from Presentation by T Levitsky, NREL 2011.

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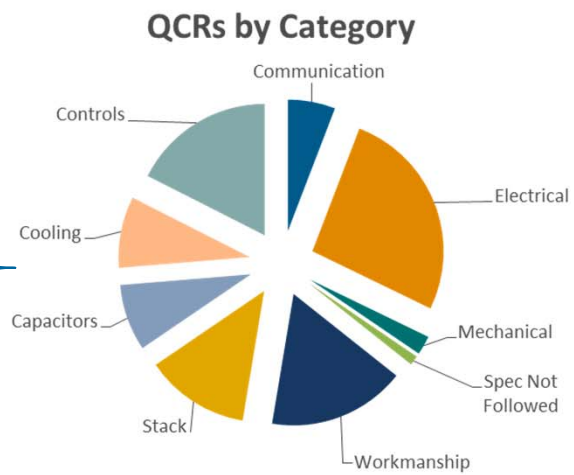
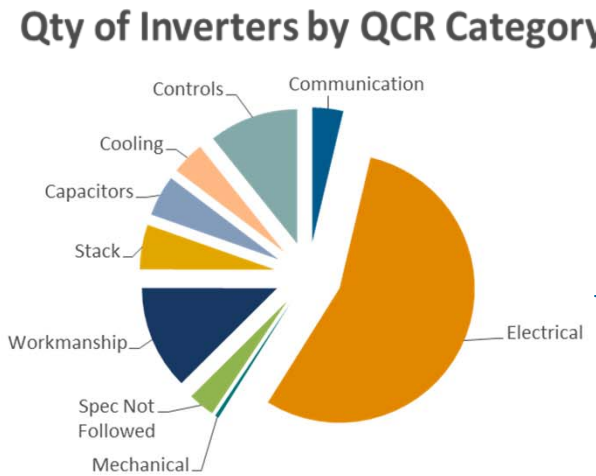
Quality Control Report (QCR) : *Component* Perspective

An appreciable number of inverters have at least one QCR; some have had multiple. While several are attributed to Workmanship issues (from the inv factory, delivery, etc), some inverter QCRs are wildly applied.





A review of random QCRs indicate that many Stacks, Capacitors, Controls, Comms, and Electrical issues are often 'addressed' by software.

This may suggest that many hardware failures are linked to software problems and perhaps reclassified.

Energy impacts of <u>hardware</u> failures can be quantified with proper support/documentation from the vendor. For mature vendors, these are often based on field qualification programs.

Reliability models can use this data to articulate total system Throughput or Availability and are well understood in mature power electronics industries.

Energy impacts of <u>soft</u> failures are inadequately quantified by the inverter vendors. Software error handling and state diagrams often lack formal (published) documentation.

Reliability models will be limited in their ability to calculate True Cost of Ownership or all inclusive Availability Models.

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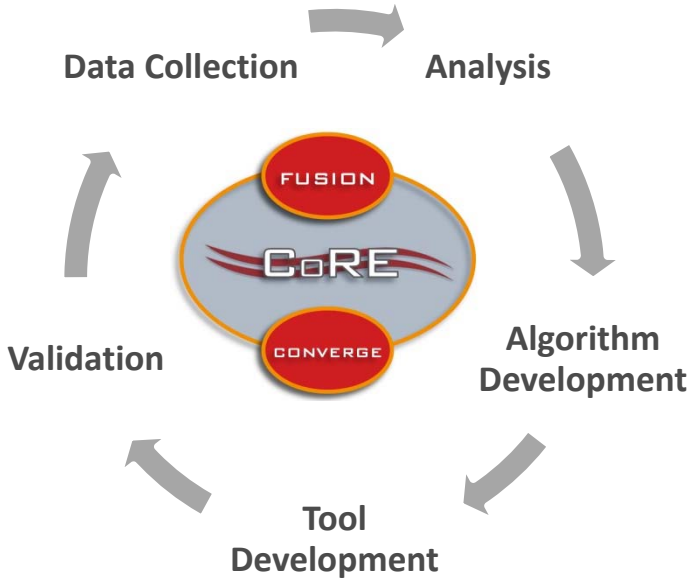
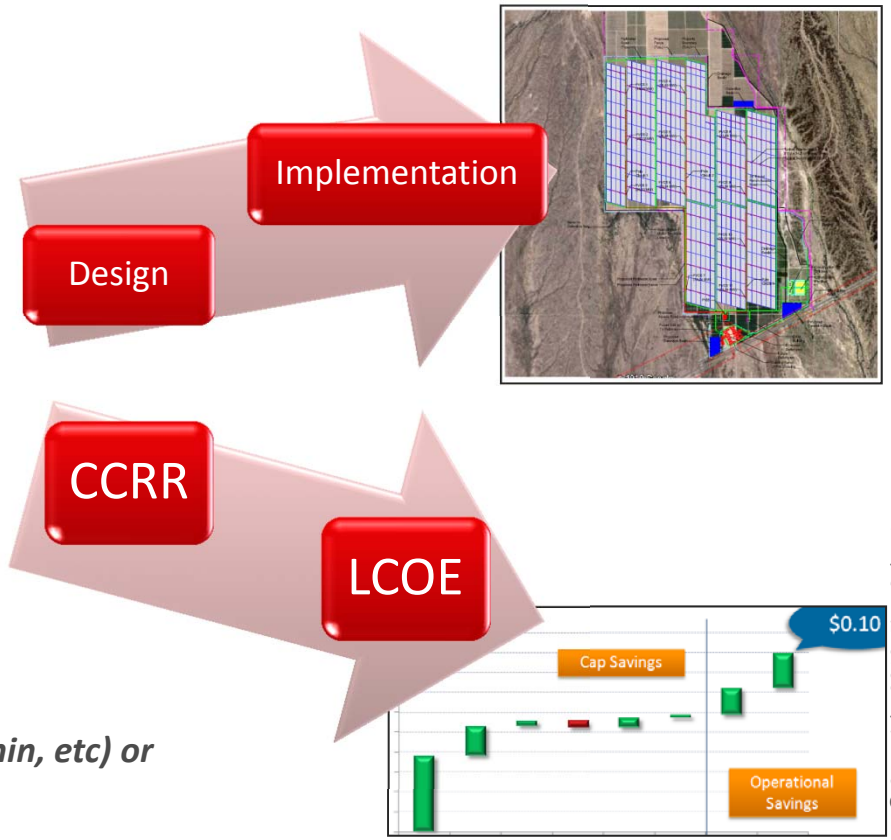
*Inverter Quality data as reported by FSLR Quality Department, in the form of a QCR. This report contains the issues, root cause, damages, and the fix. Categories modified for clarity.

FS:CoRE – The Big Picture

An internal advanced engineering development tool which drives energy & power based decisions.





Dynamic loss modeling tool leverages temporal data (1s, 1 min, etc) or simulated/8760 data for complete system characterization.

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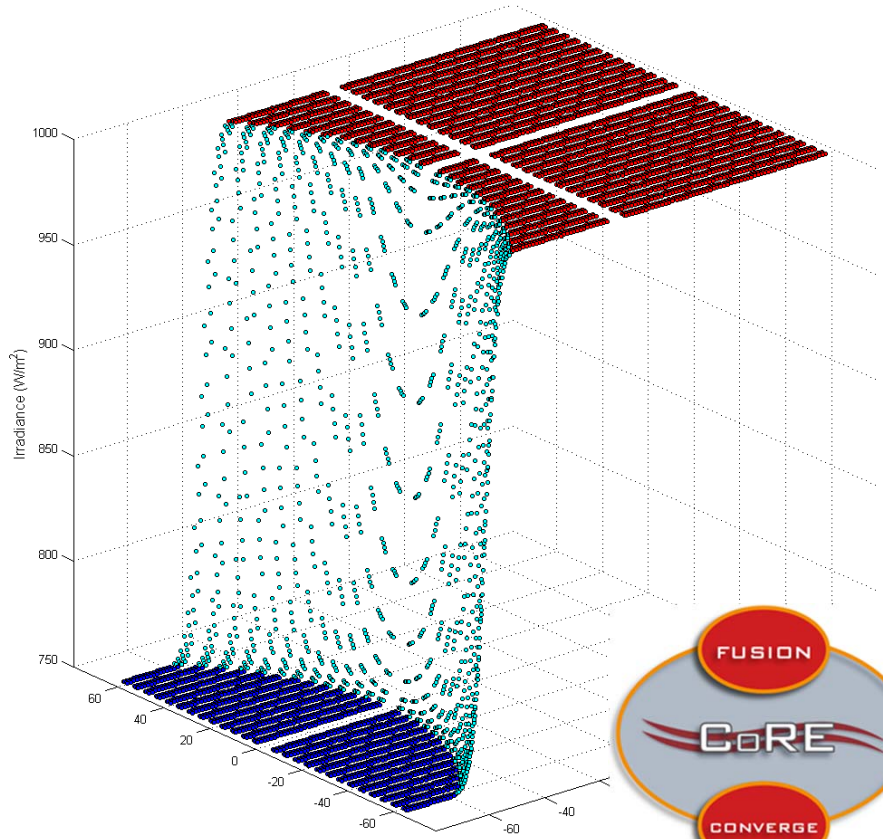
Fundamental Array Design Tool

- Array Variables
  - Module, characteristics; Output power
  - Number of modules per string, Number of strings wide, DC/AC Ratio, etc
  - Spacing (modules, rows, roads)
- Cloud Variables
  - Size (rectangular), Transmission
  - Cloud edge shape (transmission profile)
  - Cloud motion direction, length
- MPPT Variables
  - Number of horizontal trackers
  - Number of vertical trackers
- Critical BoS Components
  - Inverter Specification Review
  - MVAC collection network
  - Grid Compliance



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FS : CoRE : Fusion - *Automated Error Detection*

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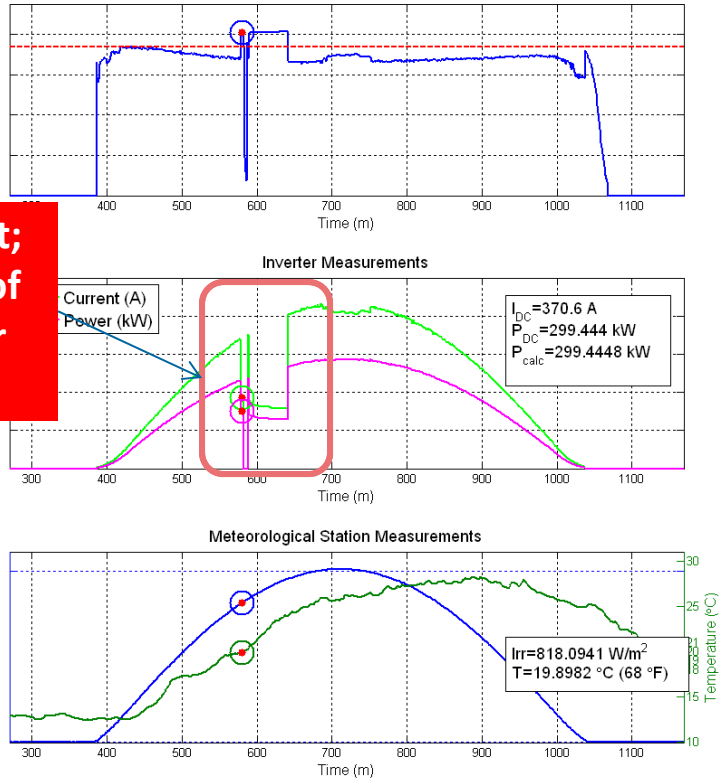
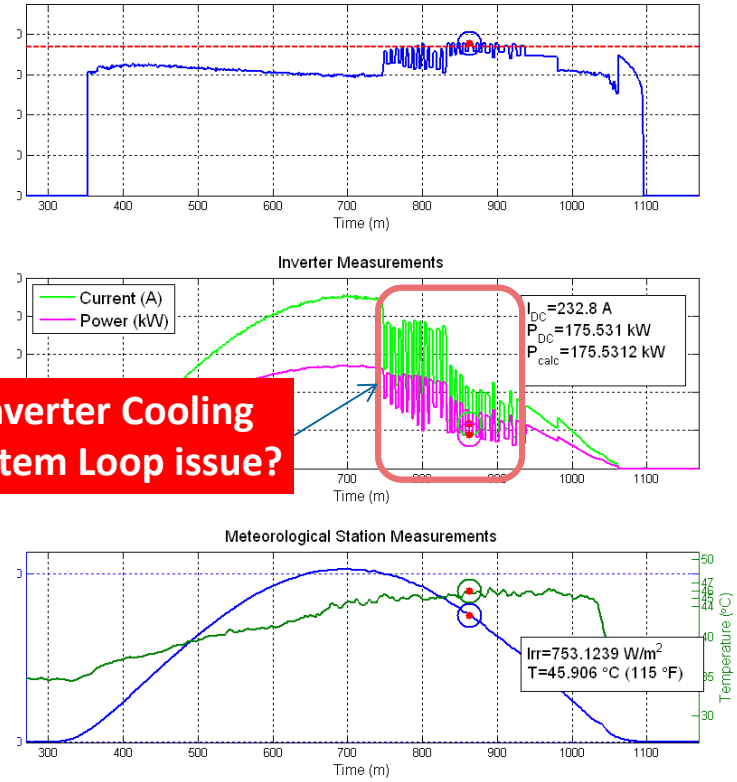
>300 kWh lost; On the edge of total Inverter Shut-Down





Inverter Cooling System Loop issue?

Identified dozens of failure signatures with ~12 significant contributors.

Soft Failure: Inverter Dropout Behavior

Example: Sample Clipping Event

- Conditions: Variable day with peak irradiance conditions .

  The module temperature is a positive indicator of local irradiance levels. The large swings in array voltage is more a function of inverter MPPT hunting or inverter operation and not fundamental module behavior.

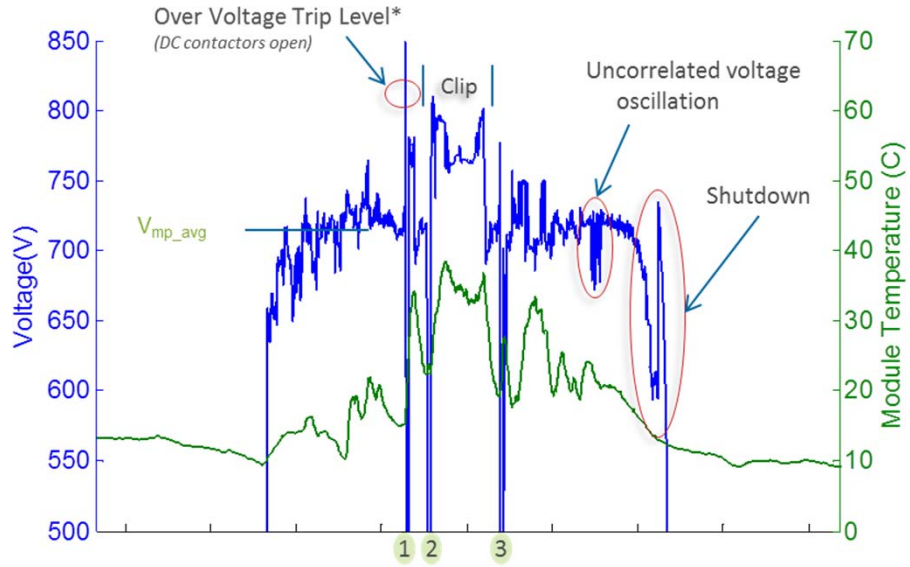
- Clipping Event combined with a Voltage Trip (1,3). Event 2 is not clear.

  Variable conditions compound voltage swing and tracking problems. Once the inverter moves off of MPPT, DC bus voltage rises rapidly. Inverters will repeatedly shut down to 'handle' an over voltage event. Inverter timing will dictate total energy loss.

- Array design within inverter speciation

  The voltages, current, DC/AC ratio, Vmp window were all reviewed & approved by the inverter vendor.

- Hourly data masks this behavior.



Events 1,3
Inverter Records DC Over-Voltage Trip.
10-15 min shutdown, per occurrence.

Event 2
Log indicated DC Over-Voltage trip events.
Low module temp corresponds to low irradiance – the event does not correspond with an irradiance spike. Also, the system did not capture a voltage rise. Therefore, the data does not corroborate an over-voltage event as the cause.

Annual Energy losses could exceed 0.75% if issue left unmitigated.
How is this represented in the traditional PV Reliability perspective?

**Peak voltage reading not credible as it is recorded on the inverter side of the DC contactor. | Array conditions: <1.2DC/AC ratio, 15 module string count, 1000Voc. FS Series 3 module.*

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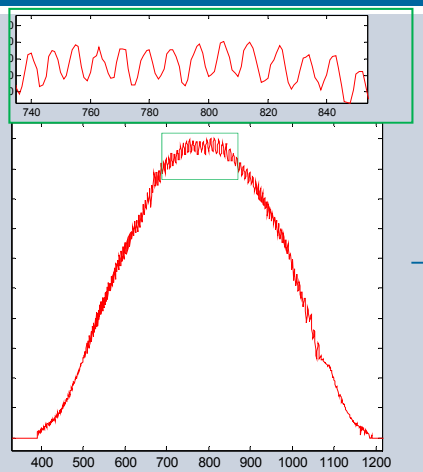
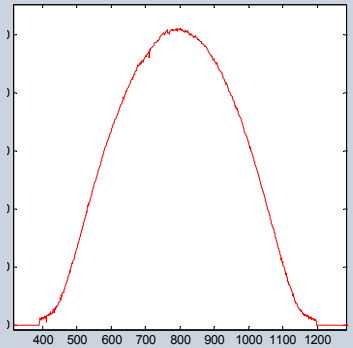
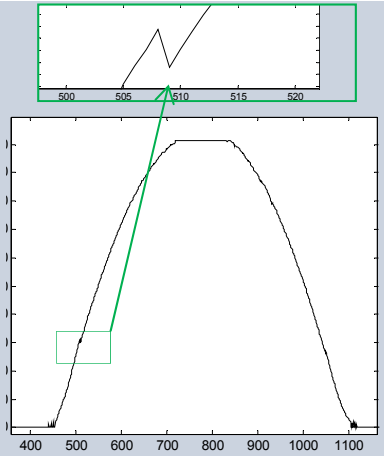
Soft Failure: Inverter Power Variation & Energy Loss

Underperformance Detected. Inverter Power Oscillation	Software solution implemented.	Underperformance Detected. Power Loss : VAR command
		
Instability in the '1-minute data' of AC and DC measured power observed. The ~1-3% power oscillation period varies. Observations of both AC & DC power were recorded and were not correlated.	The oscillation appears to be resolved. No unusual behavior noted – system appears normal.	Consistent **~2-5% downward step change** of power output in response to a Reactive Power command. Oscillation issue remained, although at a reduced level (not shown here).

Non-negligible energy deviation (actual vs predicted) was recorded.
Percentage of inverter sample affected by the Oscillation, Step Change or Both : >80%

*Inverter waveform data as reported by inverter to SCADA system. Behavior validated by field measurement.

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Closing Thoughts

- The traditional PV Inverter Reliability perspective does not adequately quantify and delineate PV power plant behavior.
  - Commercially available tools are limited in their ability to produce a comprehensive view of complex PV system interactions.
  - Forces integrators, design engineers to develop their own tool
- Soft failures can easily dominate inverter losses
  - Energy output & yield is impacted in unexpected (and undocumented) ways.
  - System architecture and therefore profit is limited by 'data sheet level' data analysis.

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