Distributed PV Monitoring

PV System Performance, Variability, and Observations Using High Resolution Field Data

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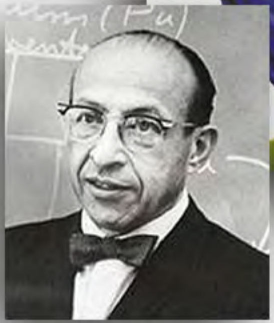
Distributed Photovoltaic (PV) Monitoring
Today's presentation outline

1. Overview
2. Solar Resource
3. Energy Performance
4. Output Variability HD
5. Voltage Observations HD

Our History…

- Founded in 1972
- Independent, nonprofit center for public interest energy and environmental research
- **Collaborative** resource for the electricity sector
- Major offices in Palo Alto, CA; Charlotte, NC; Knoxville, TN
  – Laboratories in Knoxville, Charlotte and Lenox, MA



Chauncey Starr
EPRI Founder

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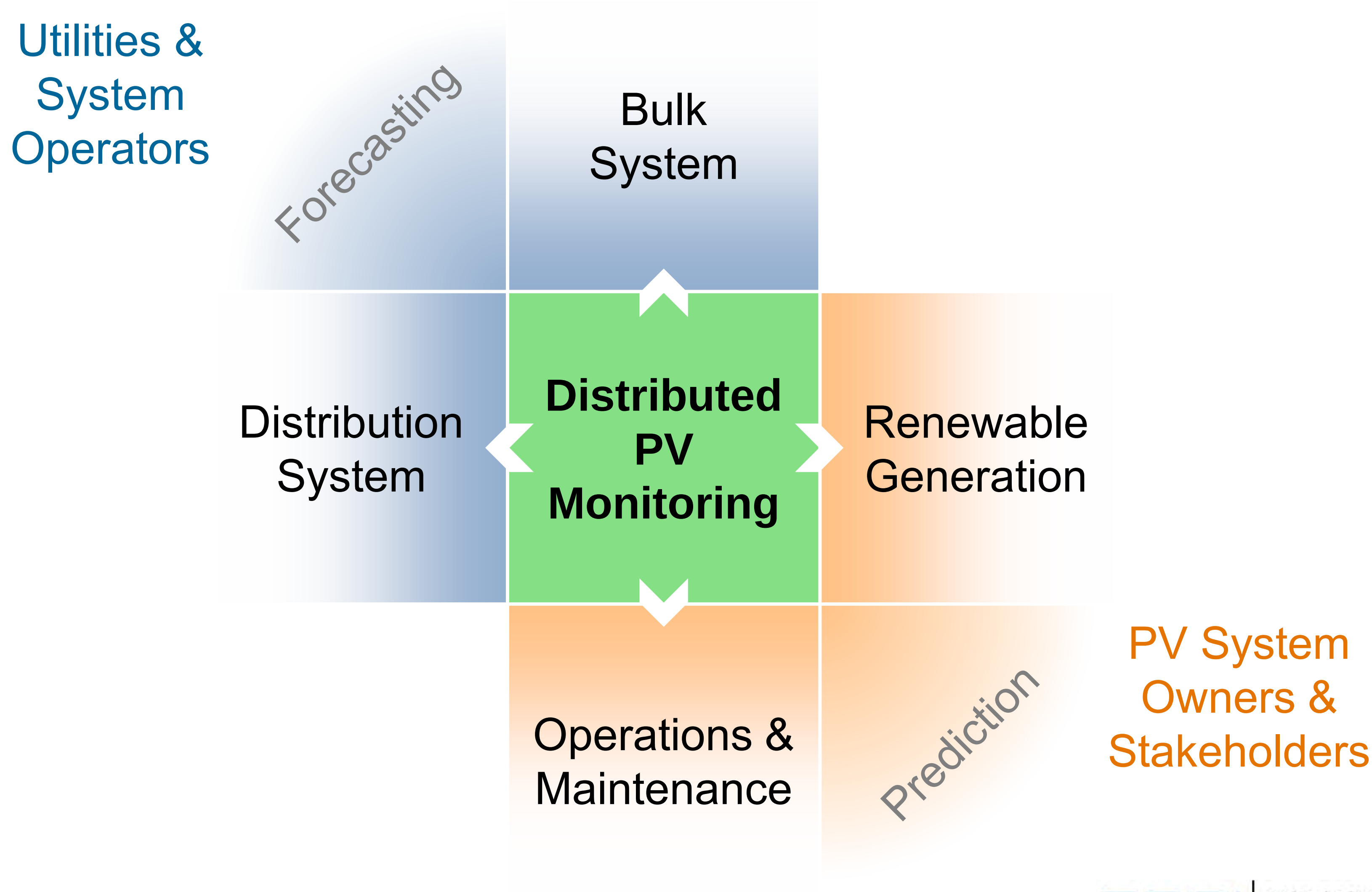
Our Members…

- 450+ participants in more than 40 countries
- EPRI members generate more than 90% of the electricity in the United States
- International funding of nearly 21% of EPRI's research, development and demonstrations
- Programs funded by more than 1,000 energy organizations

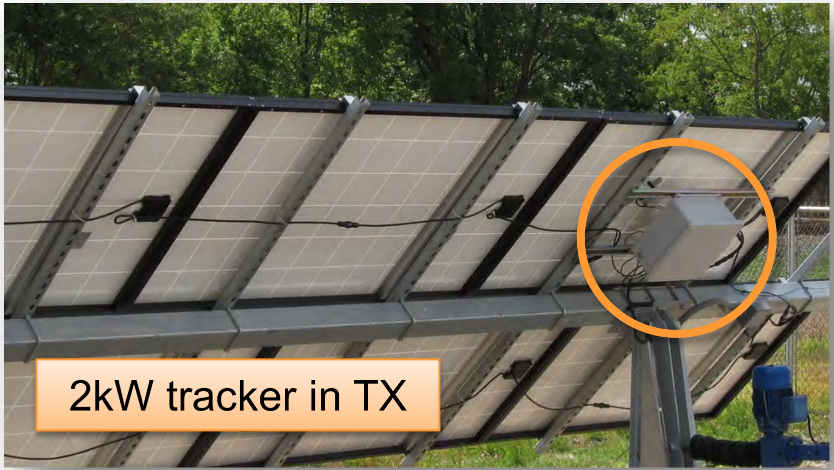
High Resolution Field Data & Geospatial Analytics

Distributed PV Monitoring supports EPRI's core PV research areas



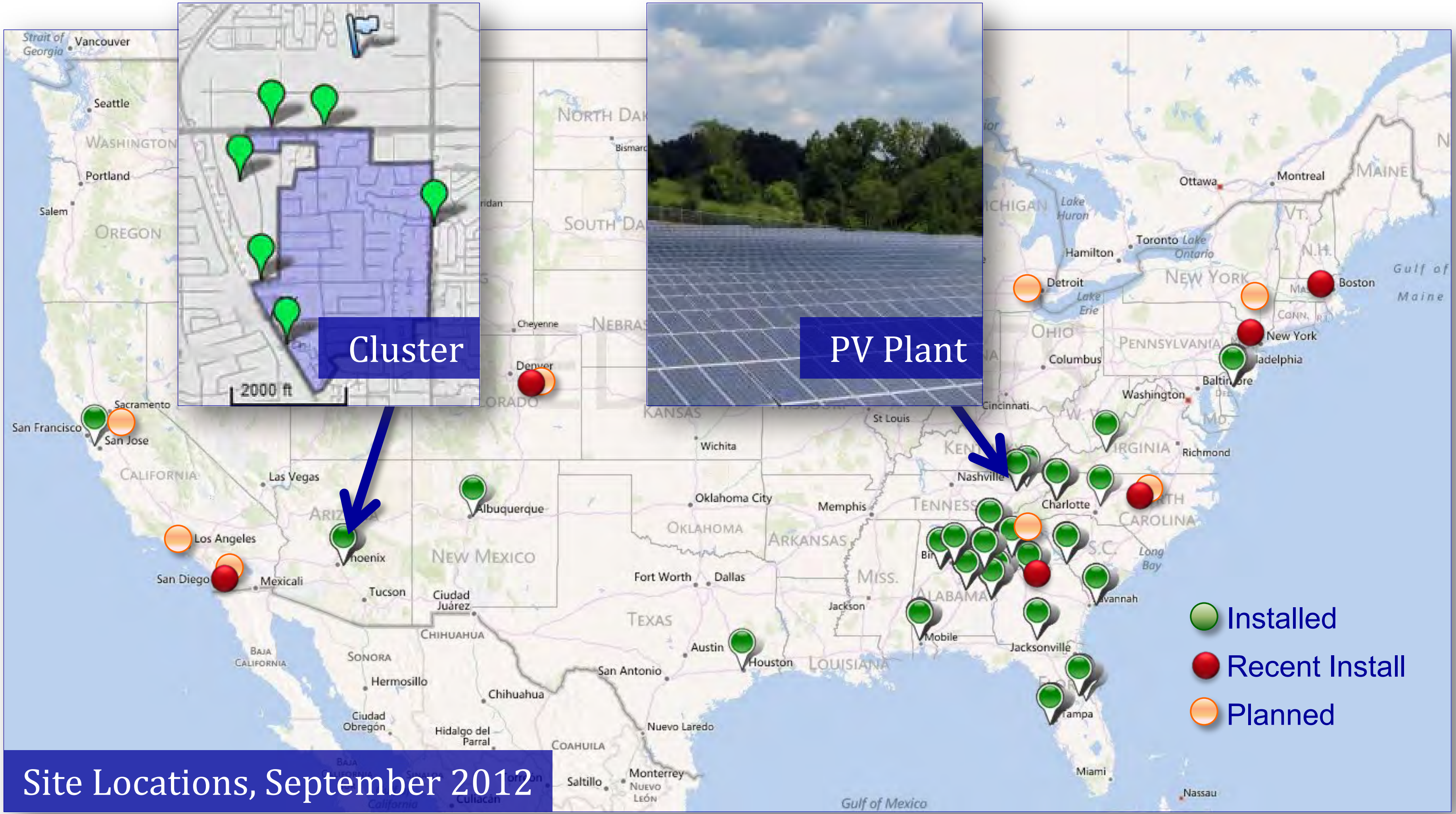
PV systems small and large are monitored

High definition monitoring captures 1-sec data on any size PV system



High-resolution PV monitoring is nationwide

Concentrated areas include Southeast, Atlantic Coast, and California



Main map: © 2012 Microsoft Corporation. Imagery © Microsoft – available exclusively by DigitalGlobe (Bing Maps Terms of Use: http://go.microsoft.com/?linkid=9710837). Inset map: Map data © 2012 Google

Monitoring for Central Inverter PV Systems

Instrumentation for solar resource, selected dc points, and ac output

Data acquisition: up to 1-second recording, automatic data transfers, internet time synchronization, remote login

Solar Resource

- **Irradiance**: plane-of-array, global horizontal
- **Weather**: temperature, humidity, wind, rain

PV Array

- **Module**: dc voltage, current, back temperature
- **Combiner box**: dc voltage, string currents

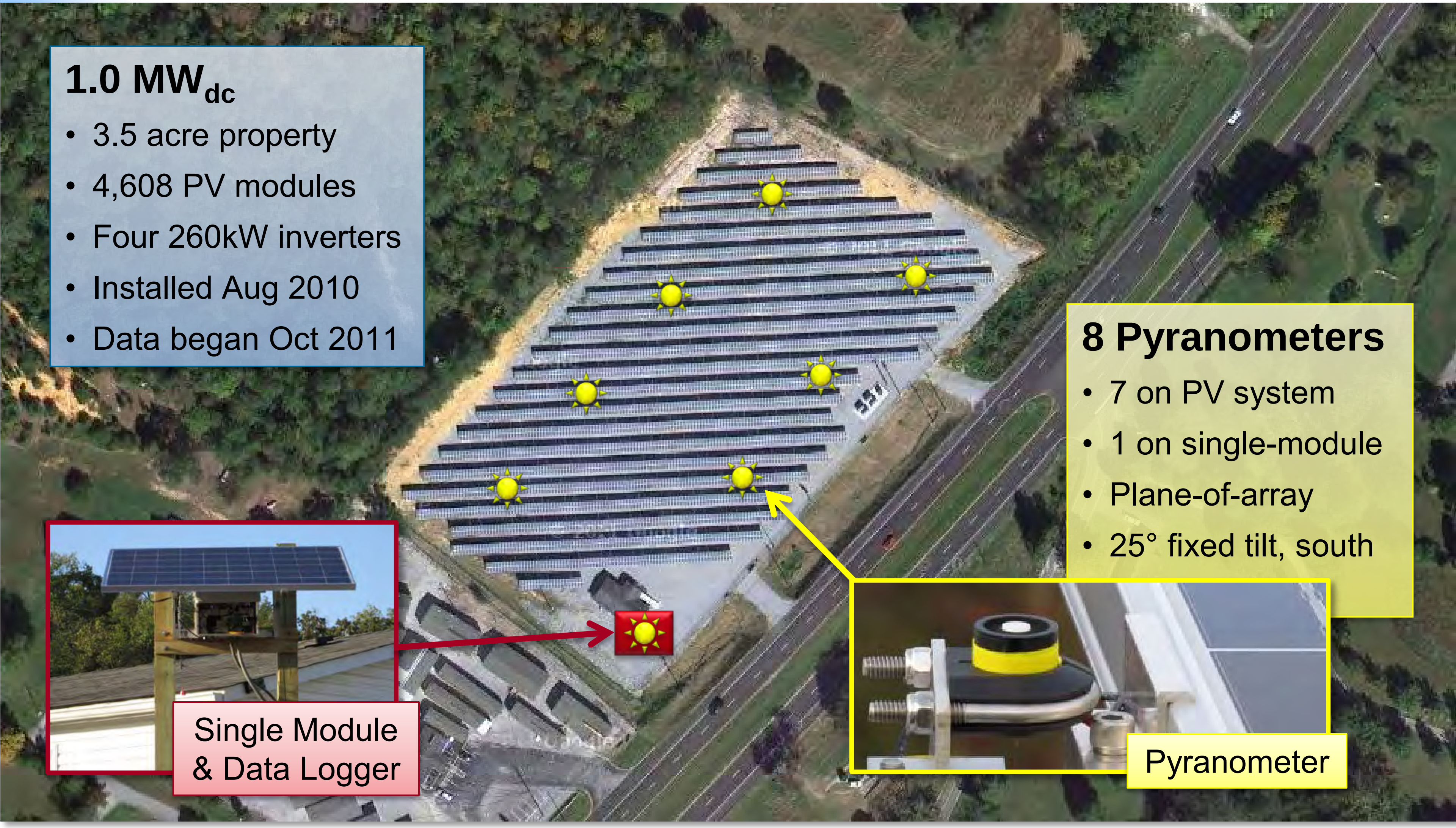
Inverter

- **Input**: dc voltage, current
- **Output**: ac power, energy totals (real & reactive), voltage, current

Instrumentation designed, assembled, configured, and tested by EPRI for field installation

1MW PV System in Tennessee

Solar resource and AC output recorded at 1-sec resolution



1.0 MW_{dc}

- 3.5 acre property
- 4,608 PV modules
- Four 260kW inverters
- Installed Aug 2010
- Data began Oct 2011

8 Pyranometers

- 7 on PV system
- 1 on single-module
- Plane-of-array
- 25° fixed tilt, south

Single Module & Data Logger

Pyranometer

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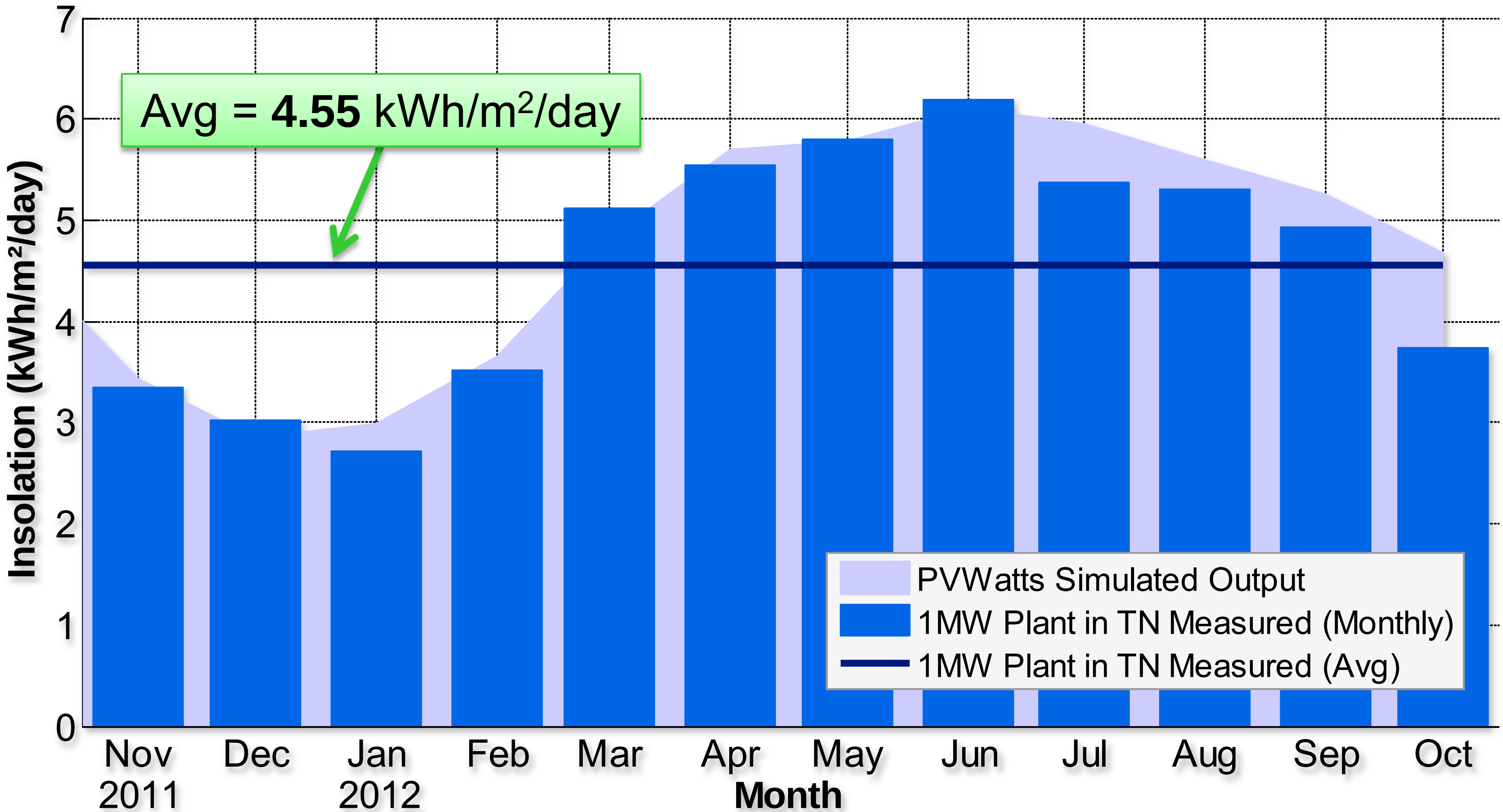
2. Solar Resource

Know your sun

Monthly Solar Insolation: Simulated & Measured

At 1MW plant in TN, measured in plane-of-array



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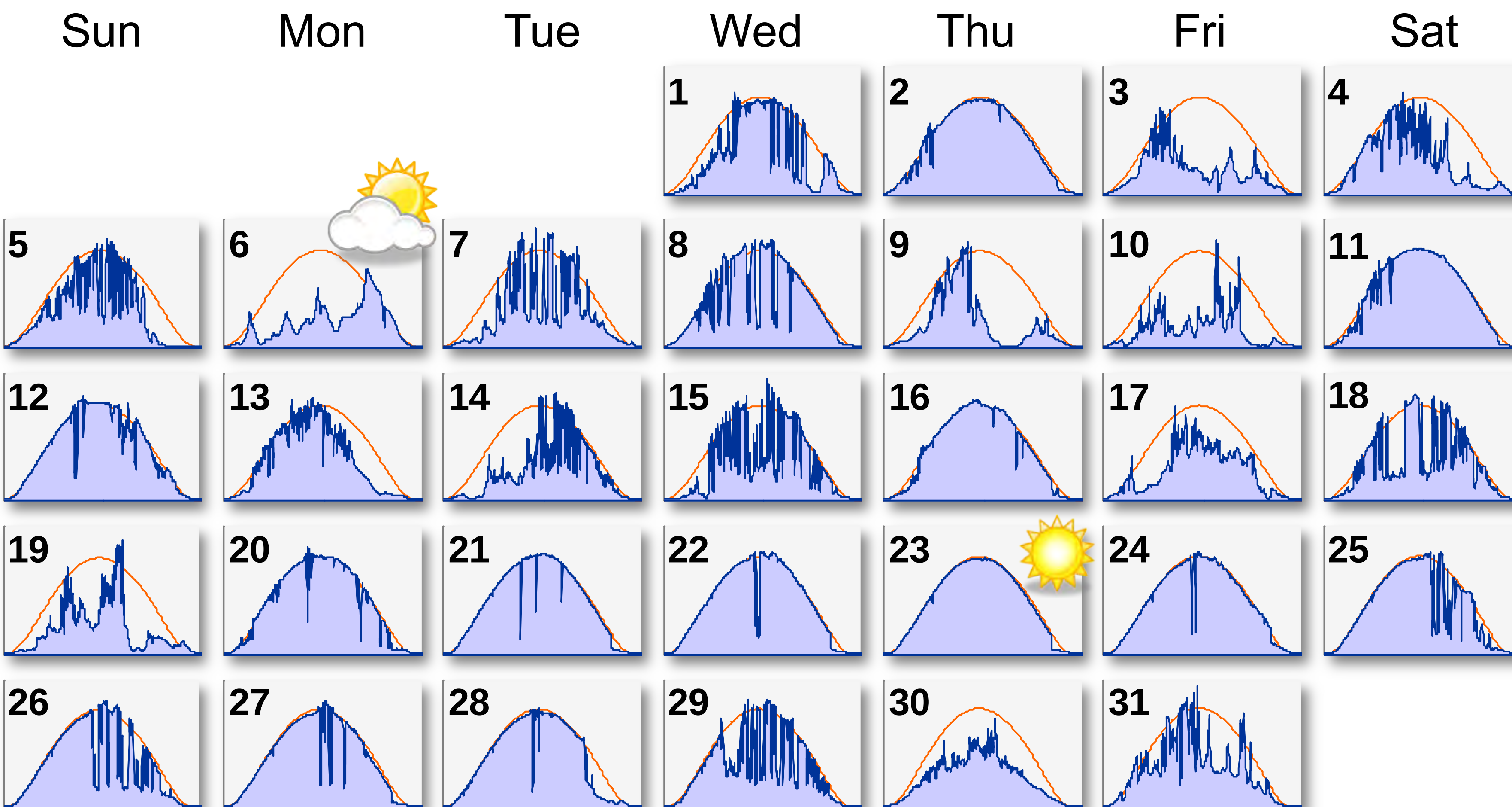
Solar Resource Calendar – August 2012

Measured plane-of-array irradiance, 1-minute averages, daytime only



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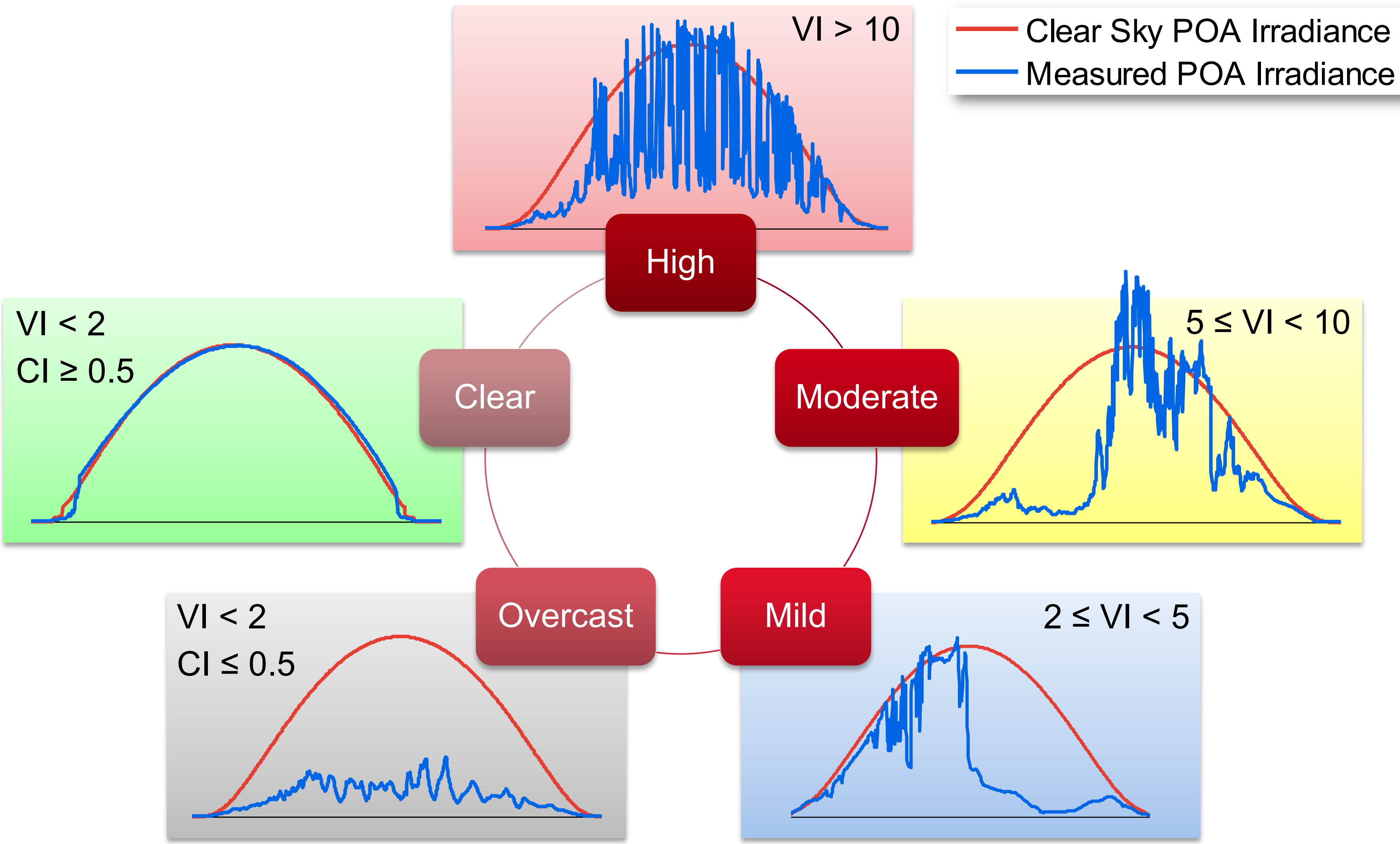
Categories for Daily Variability Conditions

Sandia's variability index (VI) and clearness index (CI) to classify days



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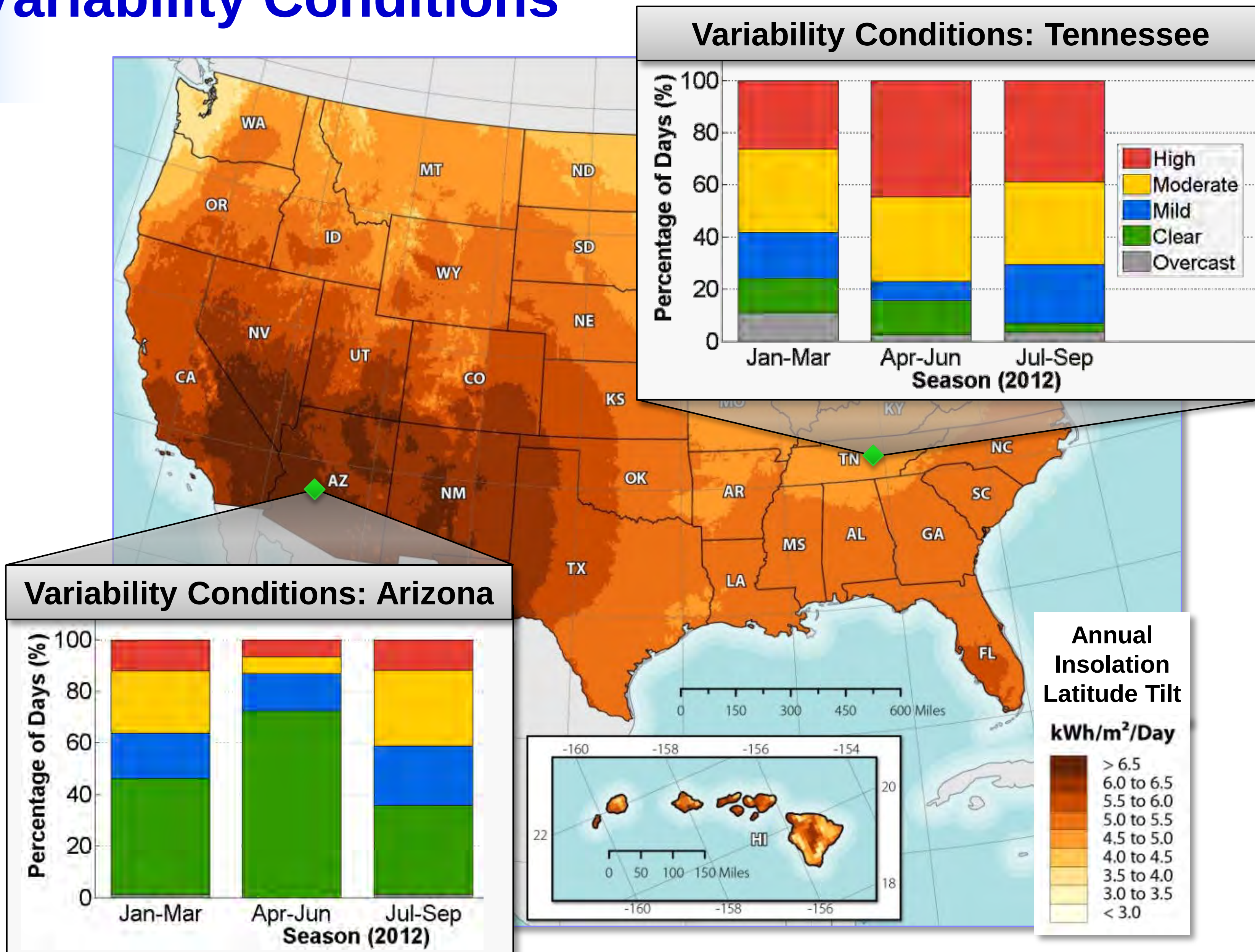
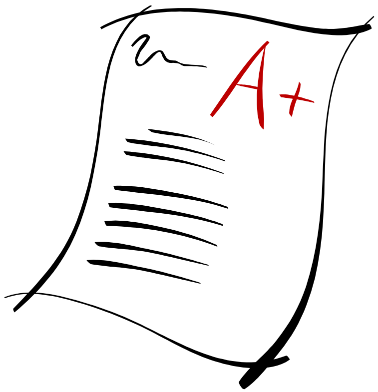
Variability Conditions



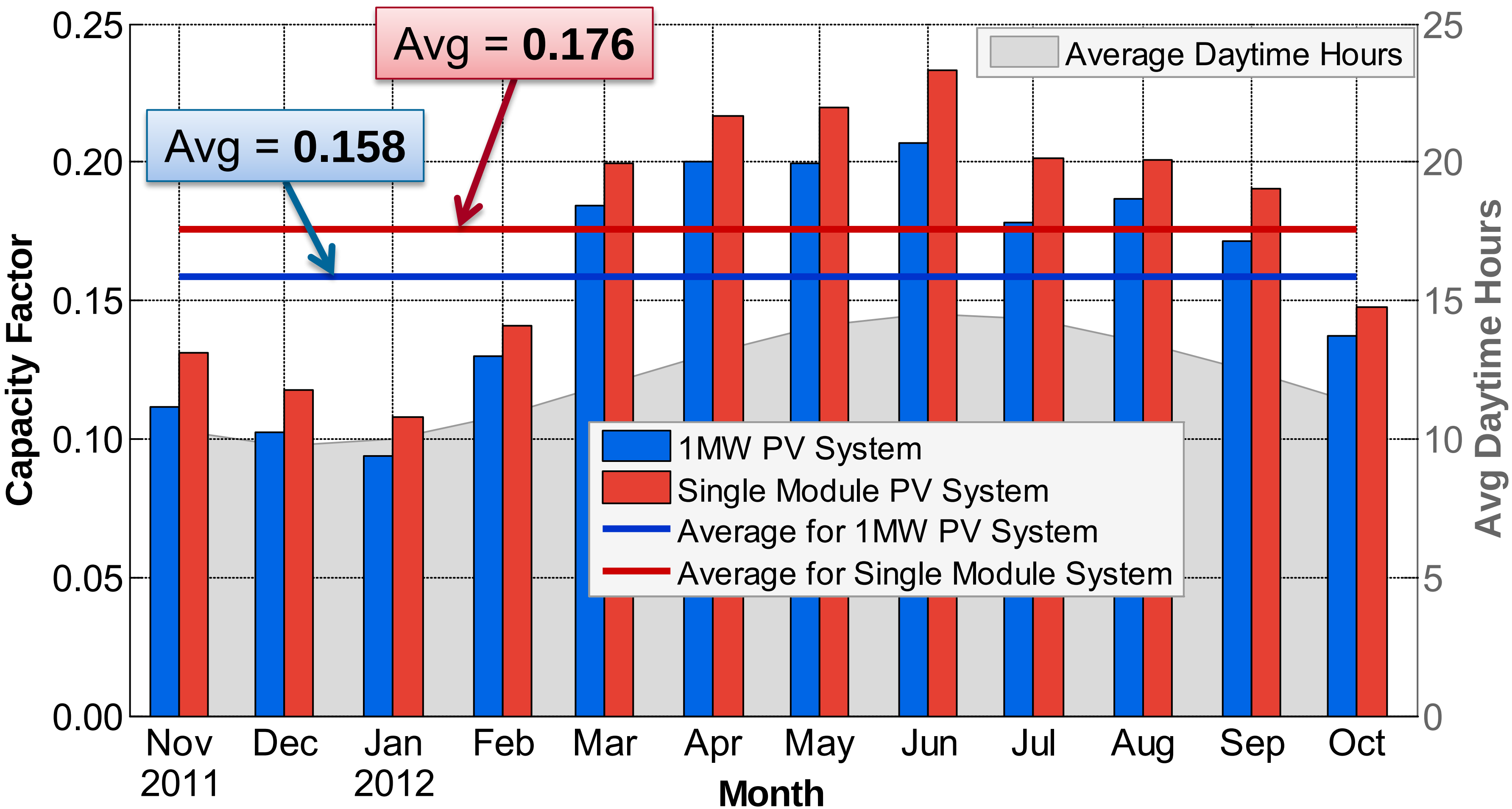
3. Energy Performance

The report card



Capacity Factor: 1MW vs. Single Module

Based on actual energy generated relative to nameplate dc rating



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Performance Factor Definition

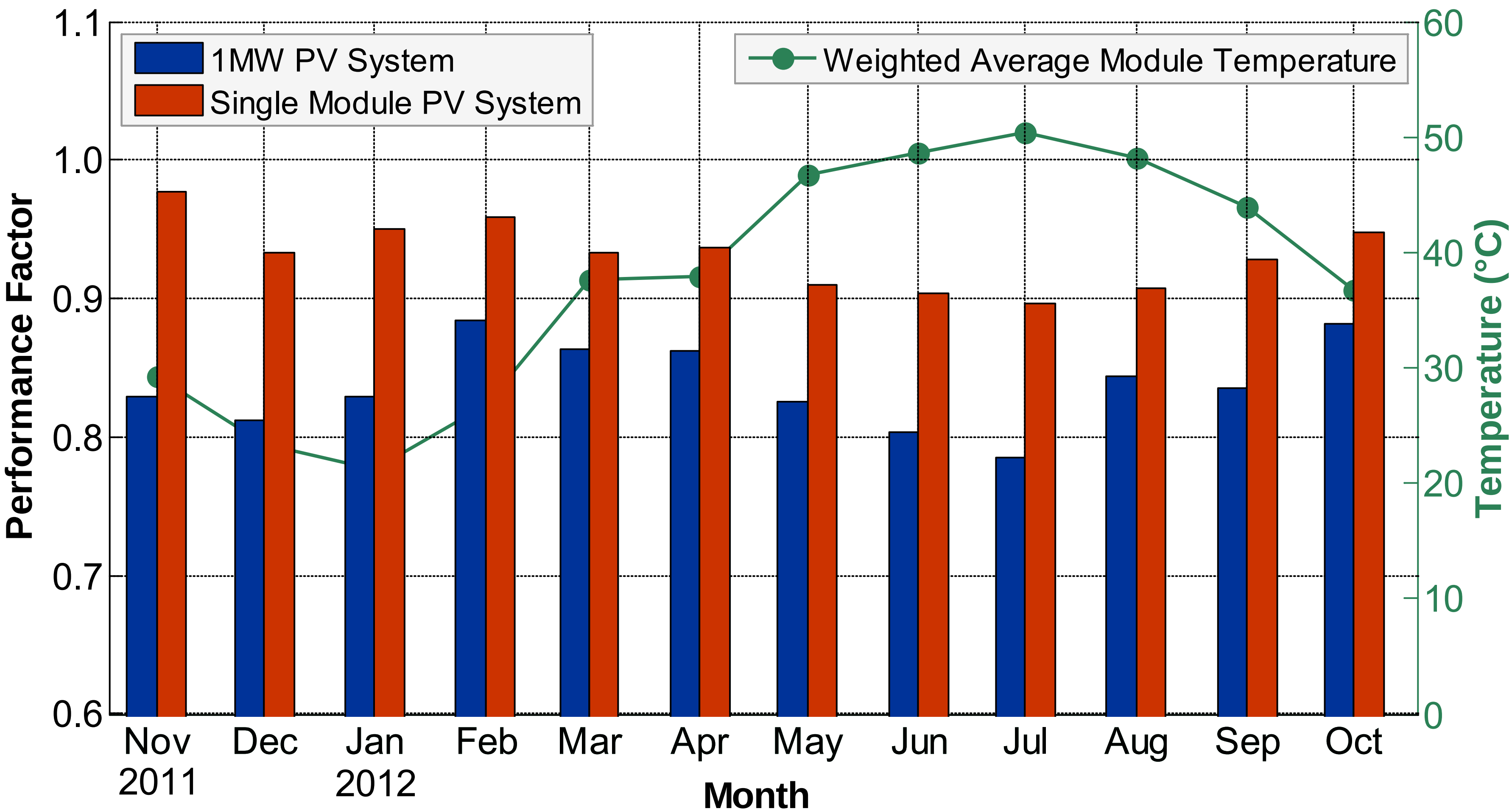
Quantifies how well a system performs given the available solar resource

$$Performance\ Factor = \frac{Energy\ Output\ (kWh) \Big/ System\ Rating\ (kW)}{Solar\ Insolation\ (Wh/m^2) \Big/ 1000\ (Wh/m^2)}$$

- Represents how well a PV system performed given the available solar resource
- Useful metric to compare the total energy output of different PV systems
- A factor of 1.0 indicates optimum PV system performance
- Typical values range between 0.7 and 1.0

Performance Factor: 1MW vs. Single Module

Offers balance-of-system insight and likely effect of module temperature



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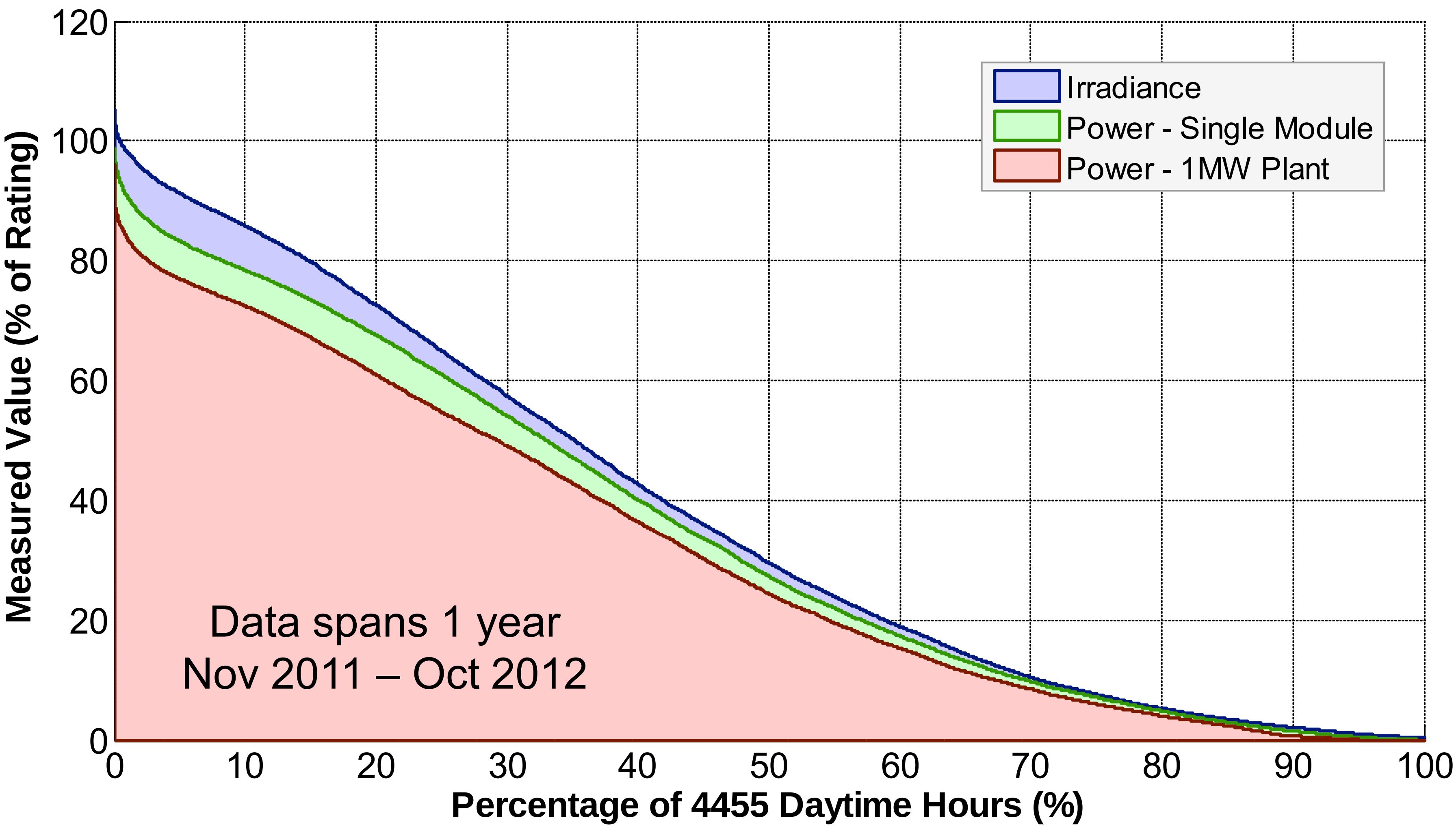
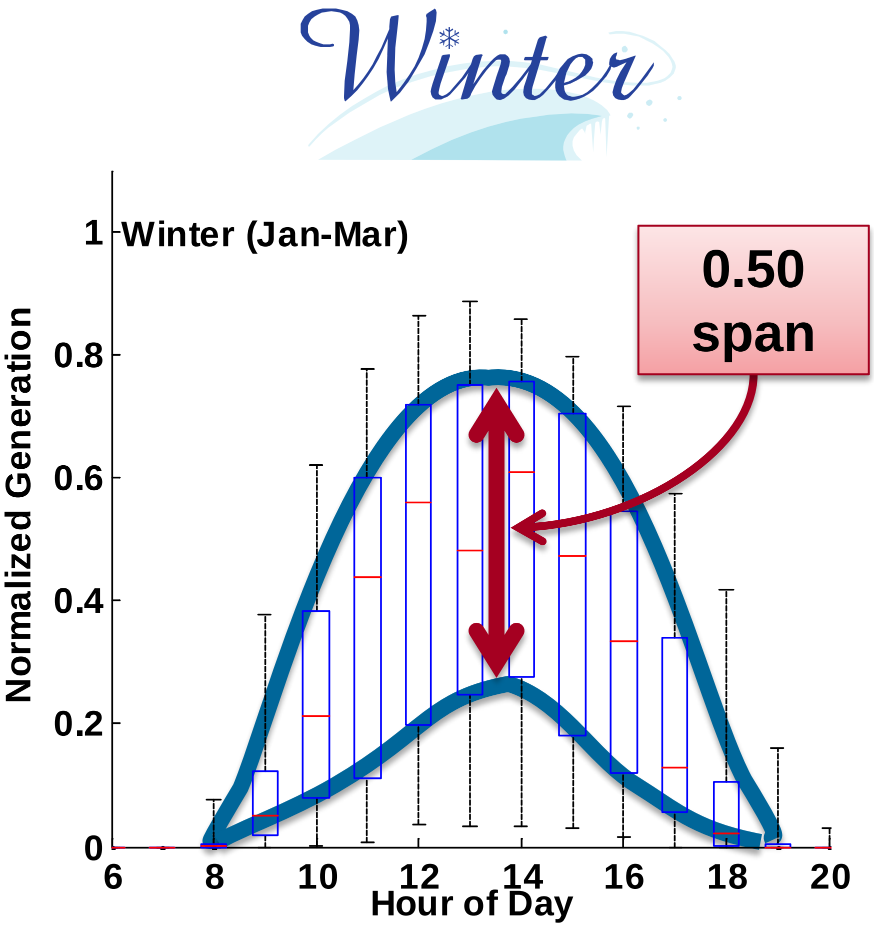
Power Duration: 1MW vs. Single Module

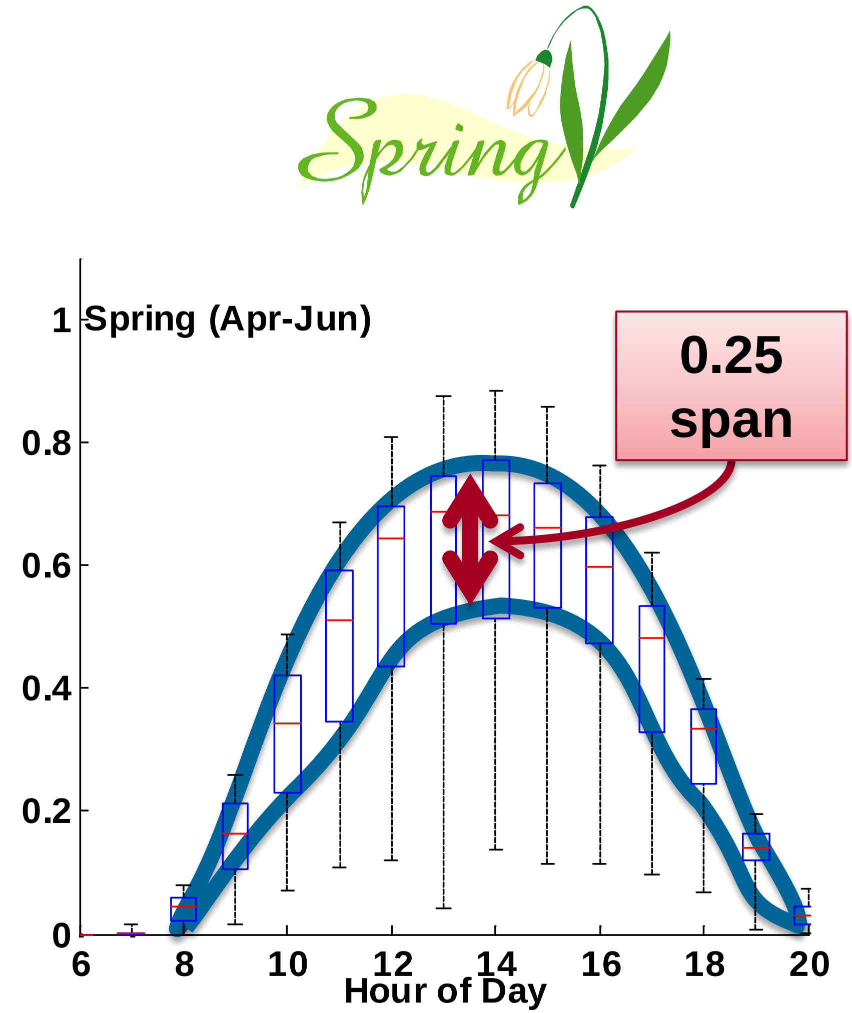
Normalized to dc nameplate rating, irradiance normalized to 1000 W/m²



Seasonal Daily Generation Profile By Hour

Shows max, min, median, and inner quartile ranges for 1MW PV system





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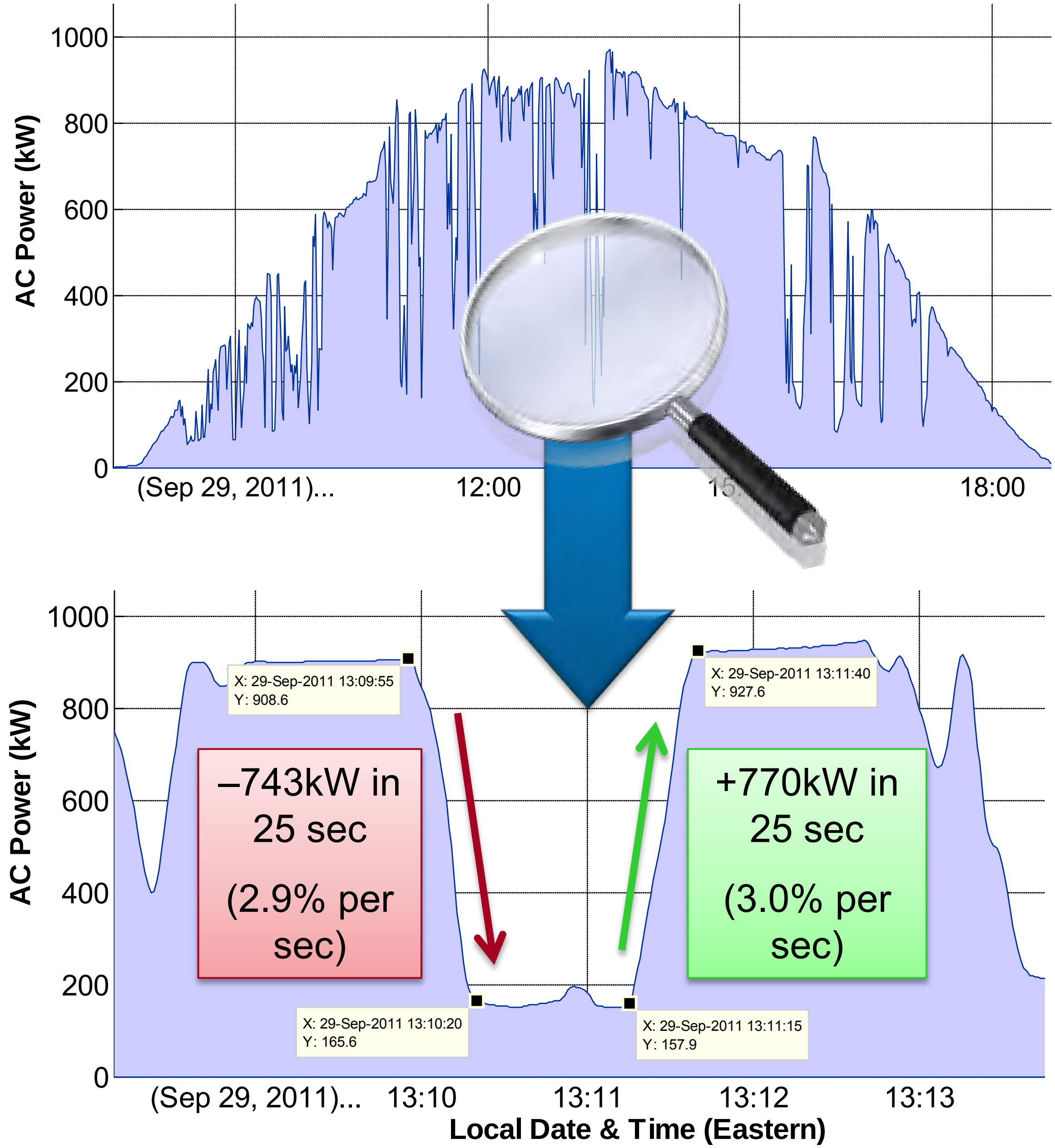
4. Output Variability

Solar is on the move…

Output Variability Analysis

- **Benefit**
  - How often and when significant ramping events occur
- **Time intervals**
  - 10 & 30 seconds
  - 1 & 10 minutes
  - 1 hour
- **Scope**
  - Single site: PV plant or representative single module
  - Aggregated single modules



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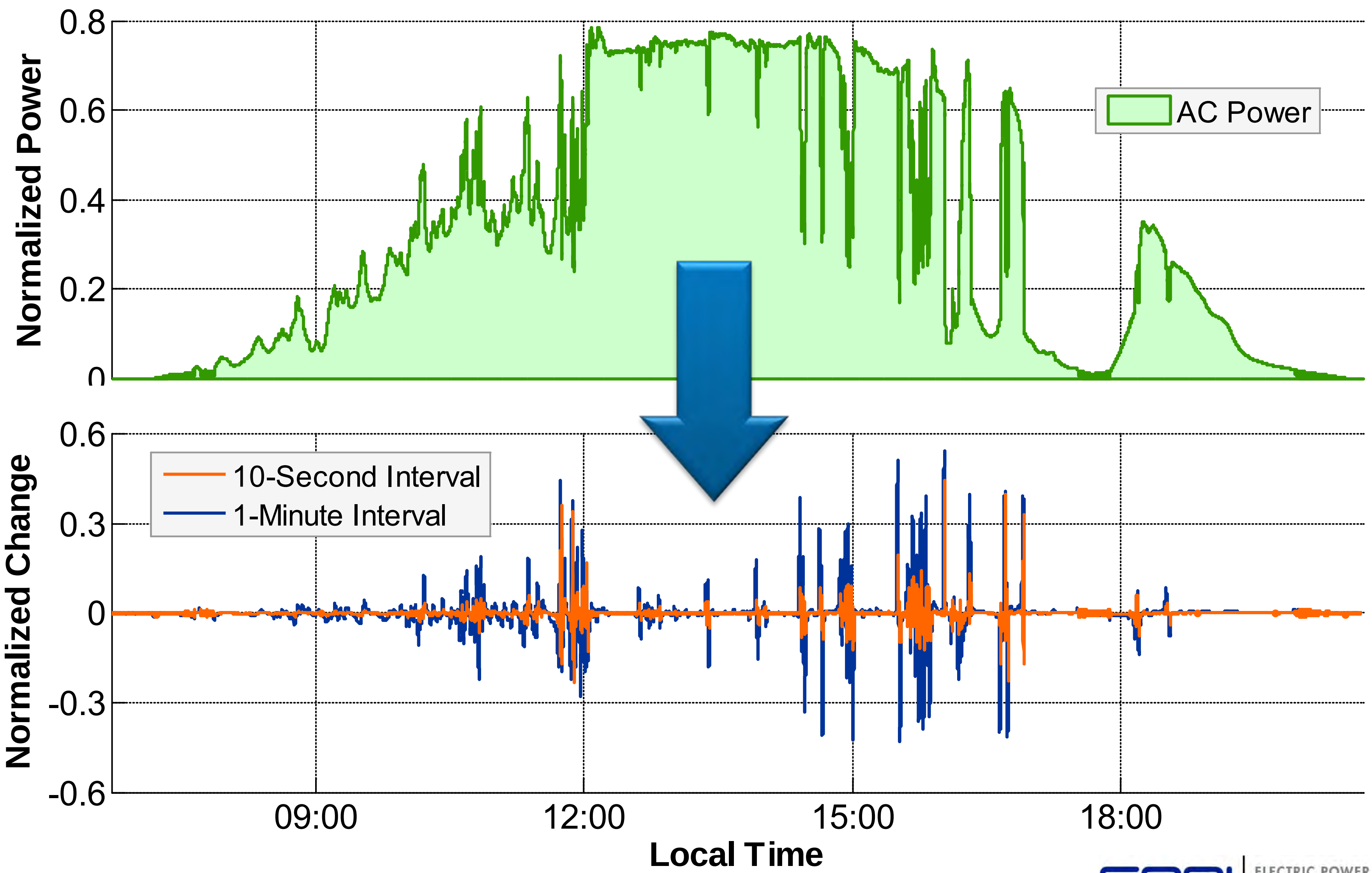
Output Variability is all about Changes in Power

Sequential differences between instantaneous or averaged measurements



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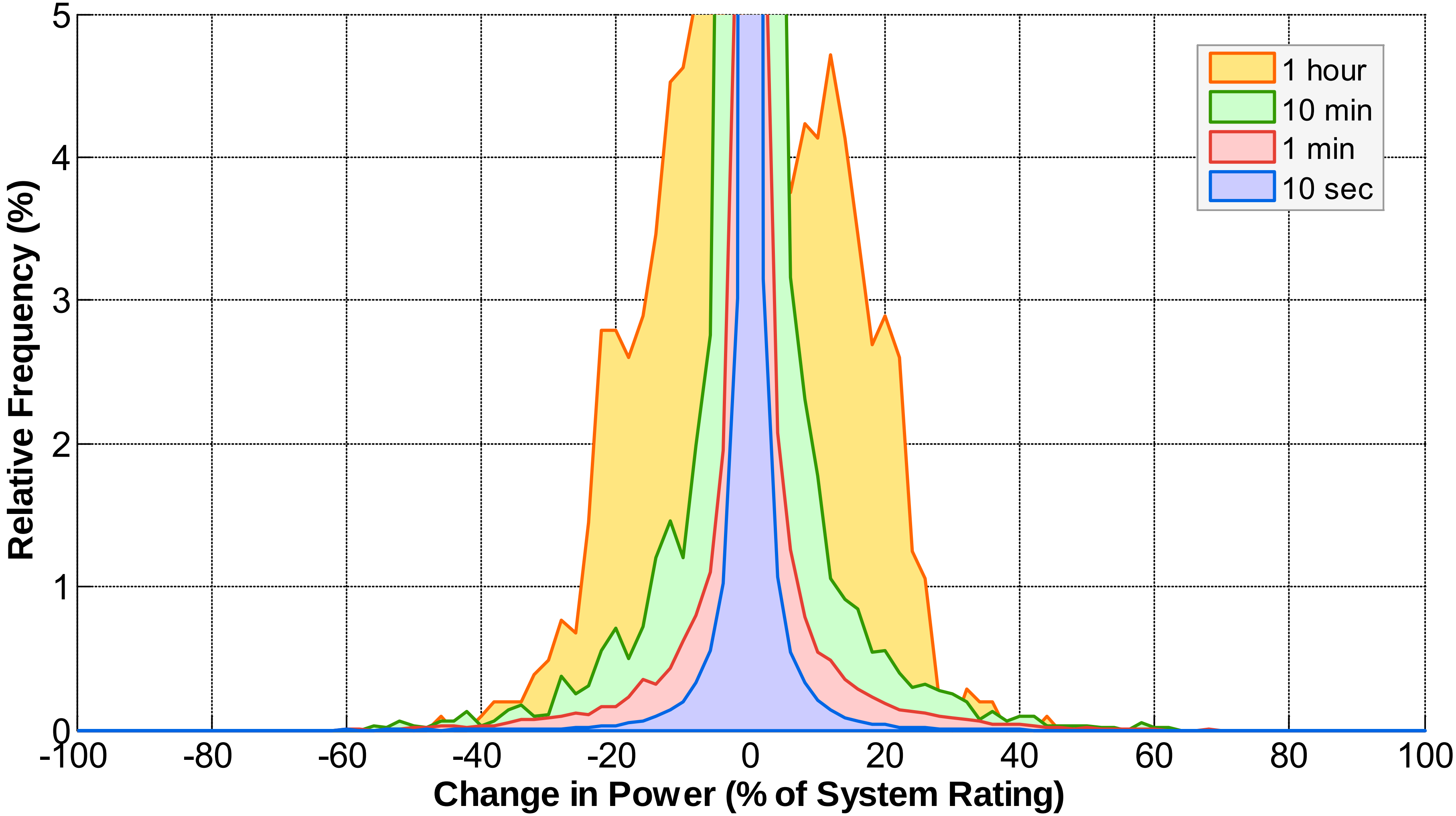
The Histogram: Changes in Power at 1MW site

Relative frequency of changes for 4 ramp rate intervals: 10s, 1m, 10m, 1h



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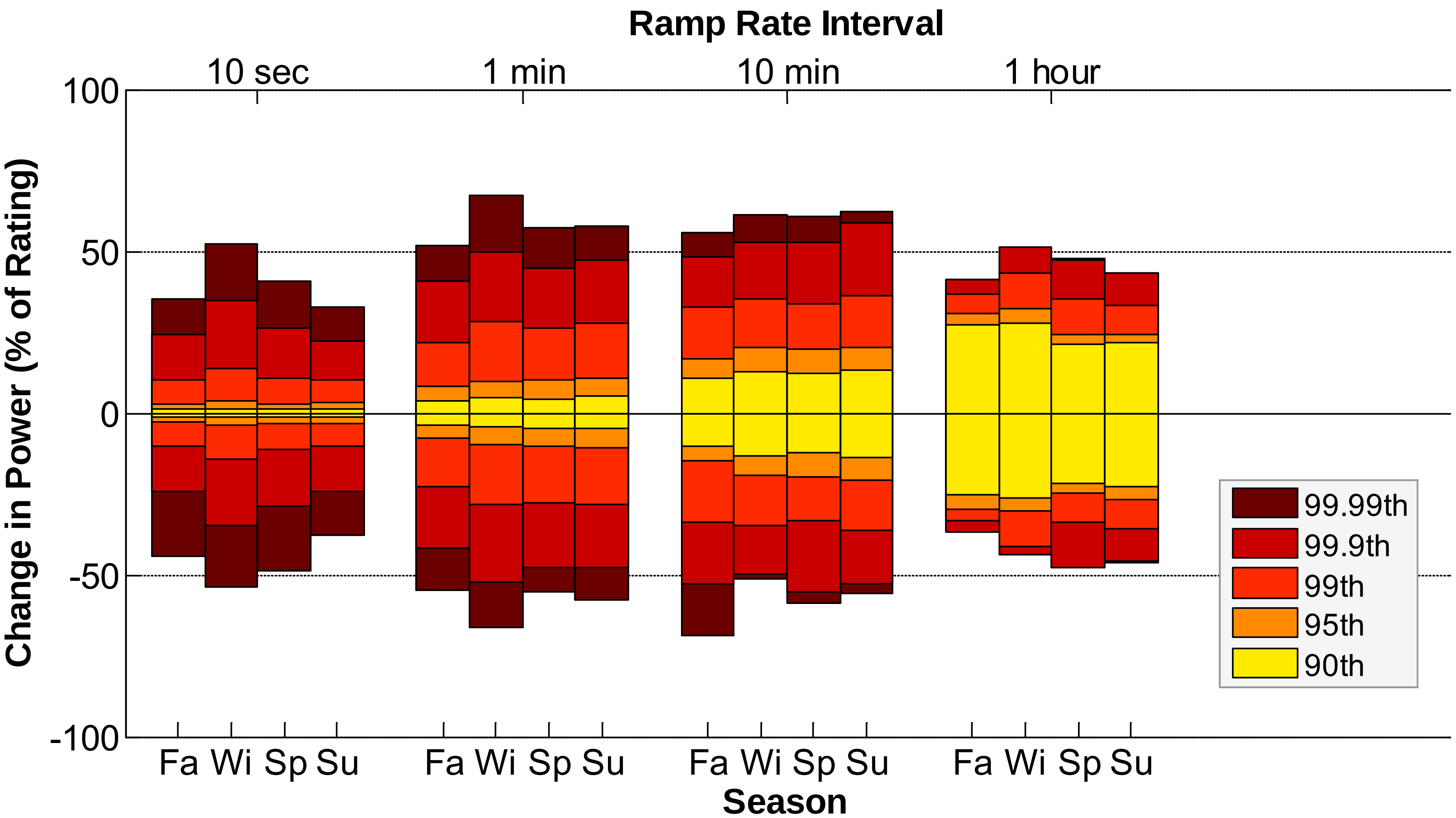
Changes in Power at Selected Percentiles

Focus is the extremes, both up and down directions (1MW PV system)



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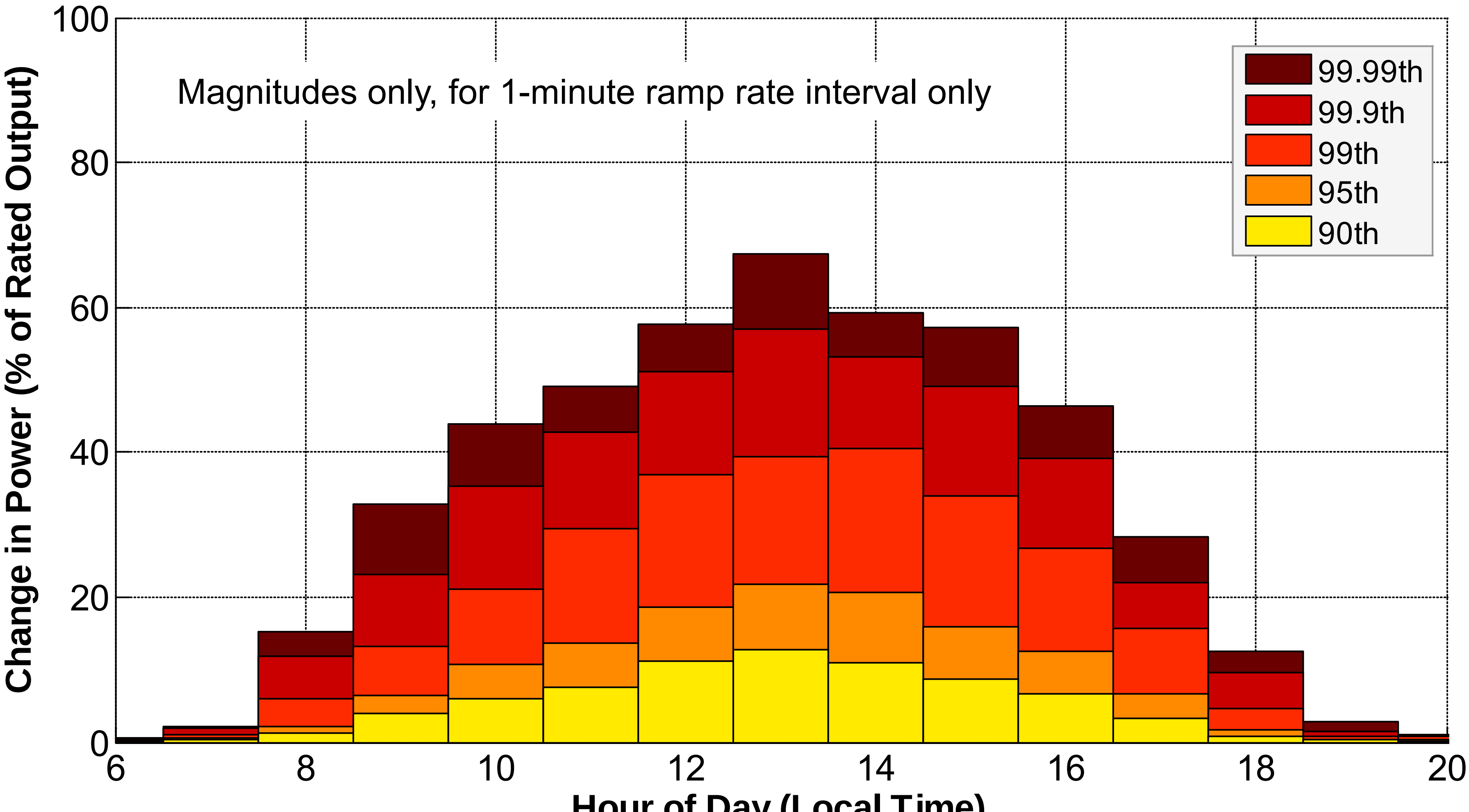
Changes in Power at Selected Percentiles

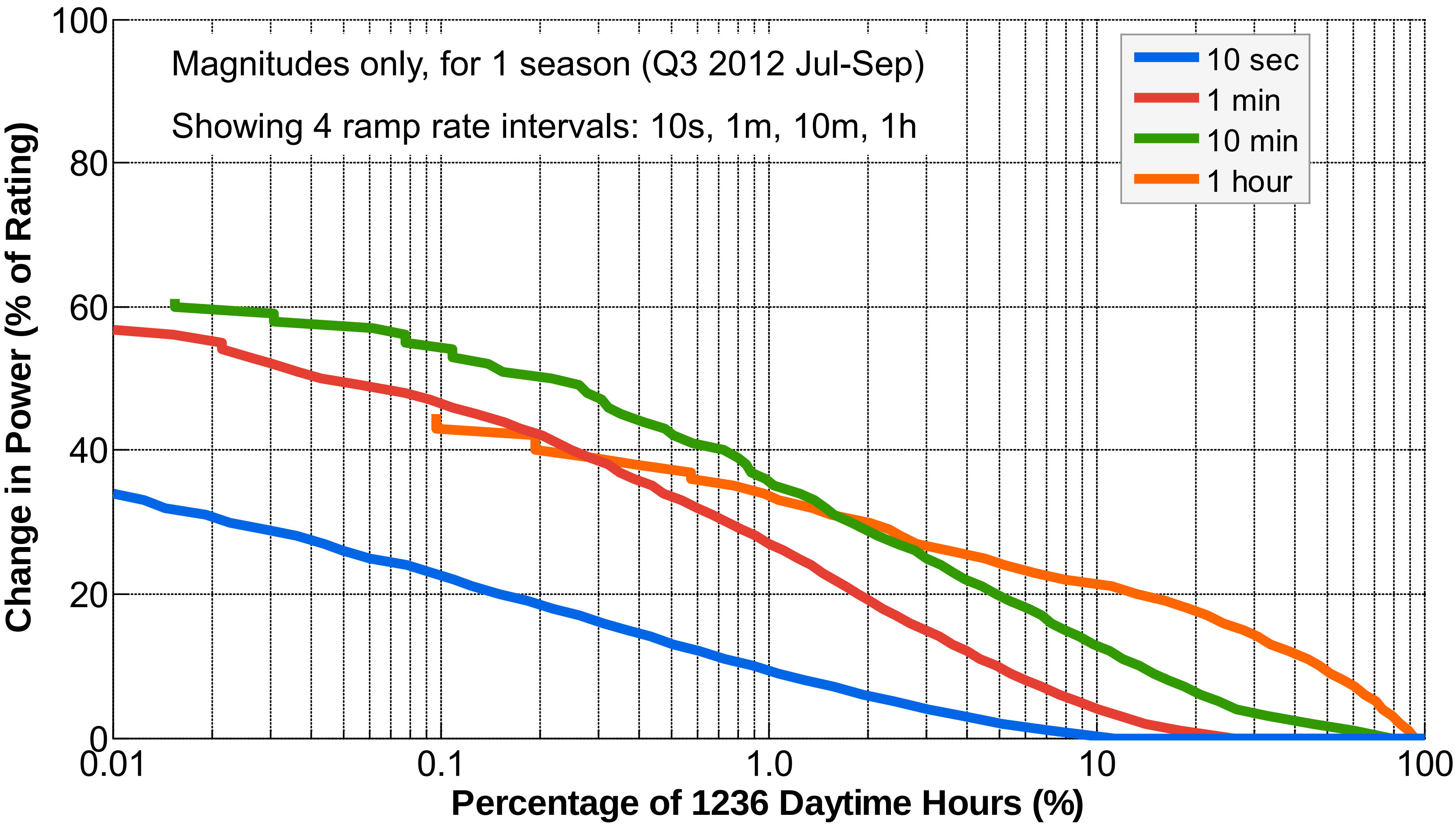
Focus is the time of day when extreme changes occur (1MW PV system)



Q3 2012 (July-September)

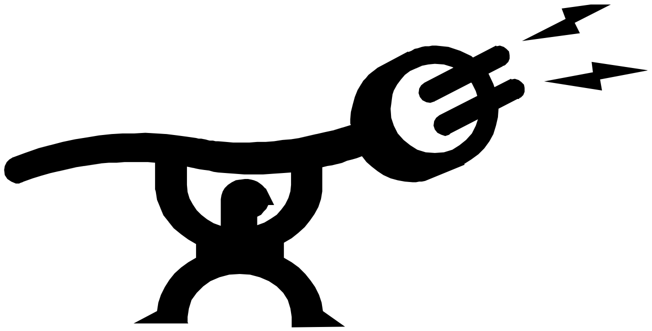
Exceedance of Change: Total Duration

Useful to visualize extreme changes and their total time of occurrence



5. Voltage Observations

What is happening to voltage?



Sample Distribution Circuits with Existing PV

J1 is in northeast, K1 is in southeast, both serve rural communities

Characteristic	J1	K1
Voltage (kV)	12.5	13.8
Peak Load, Approx (MW)	6.0	6.0
Existing PV (MW)	1.7	1.0
Substation LTC	Yes	Yes
Feeder Regulators	3	0
Capacitor Banks	2 fixed and 3 voltage controlled	1 fixed
Total Circuit Miles	58	28
Feeder "Footprint" (mi^2)	35	7

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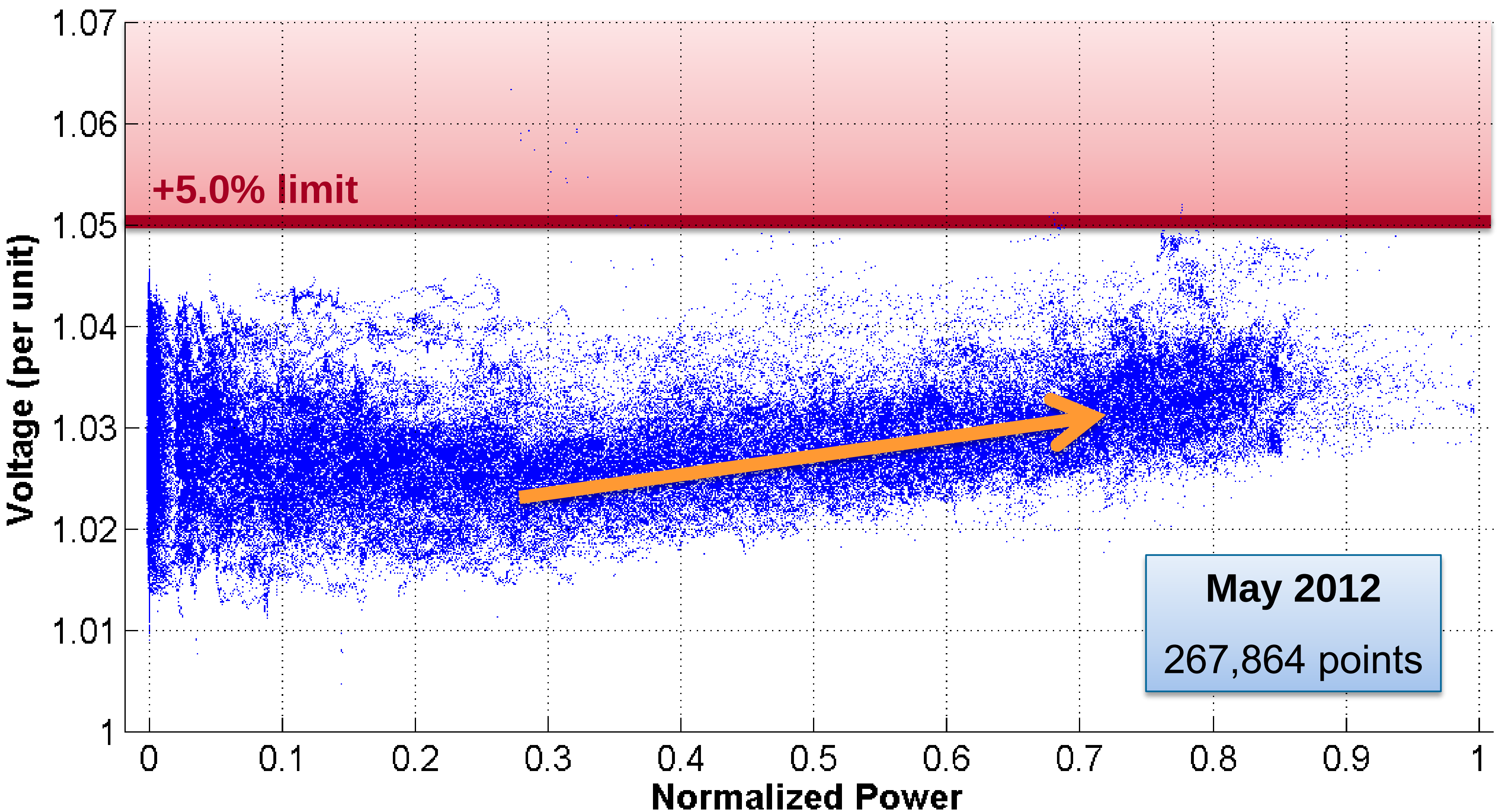
Secondary Service Voltage, 10-Second Average

1MW plant in TN (K1), May 2012 voltages plotted against ac power



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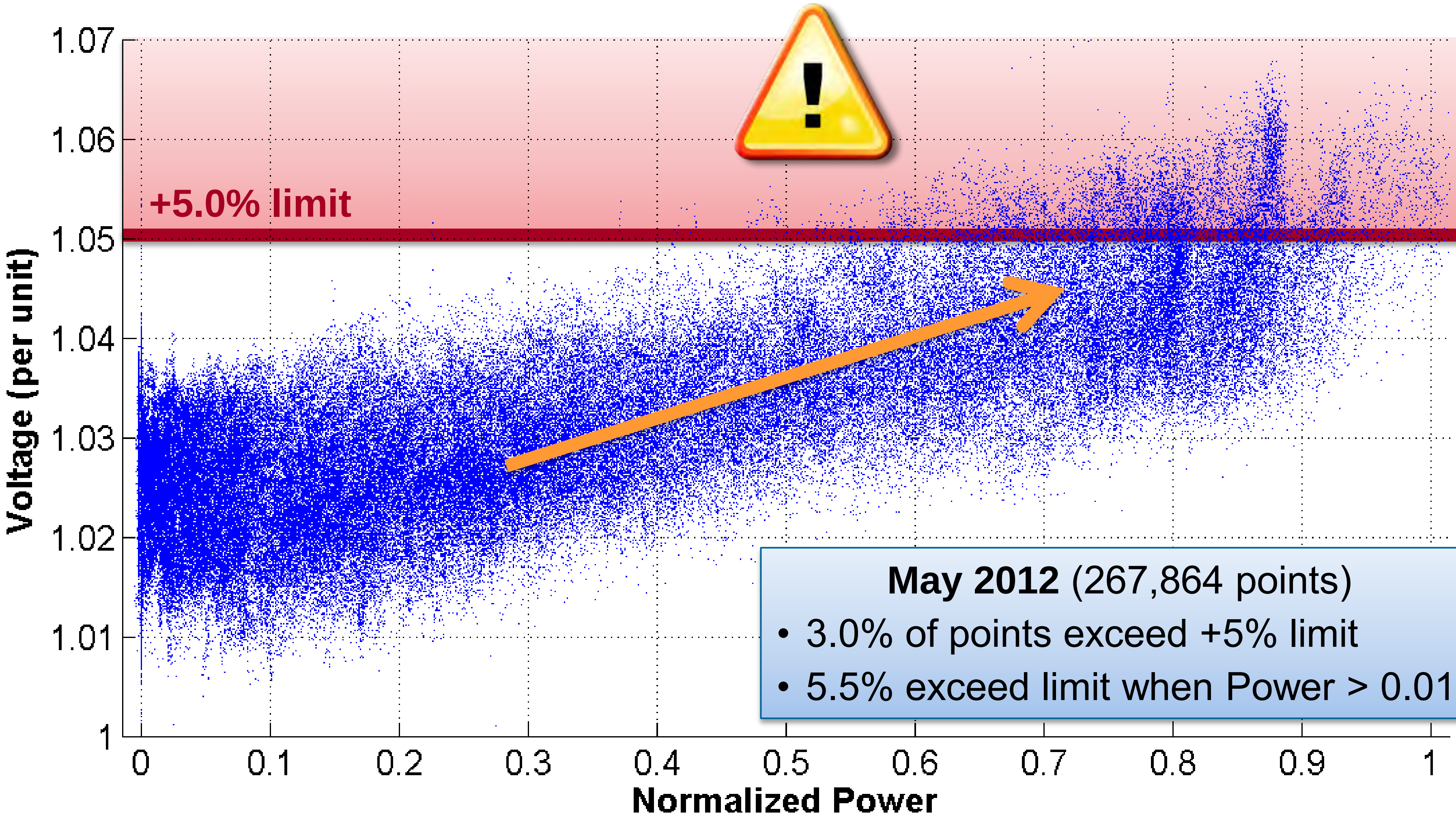
Circuit J1: Voltage Exceeds Planning Limit

10-second average PV plant service voltage often above +5% at midday



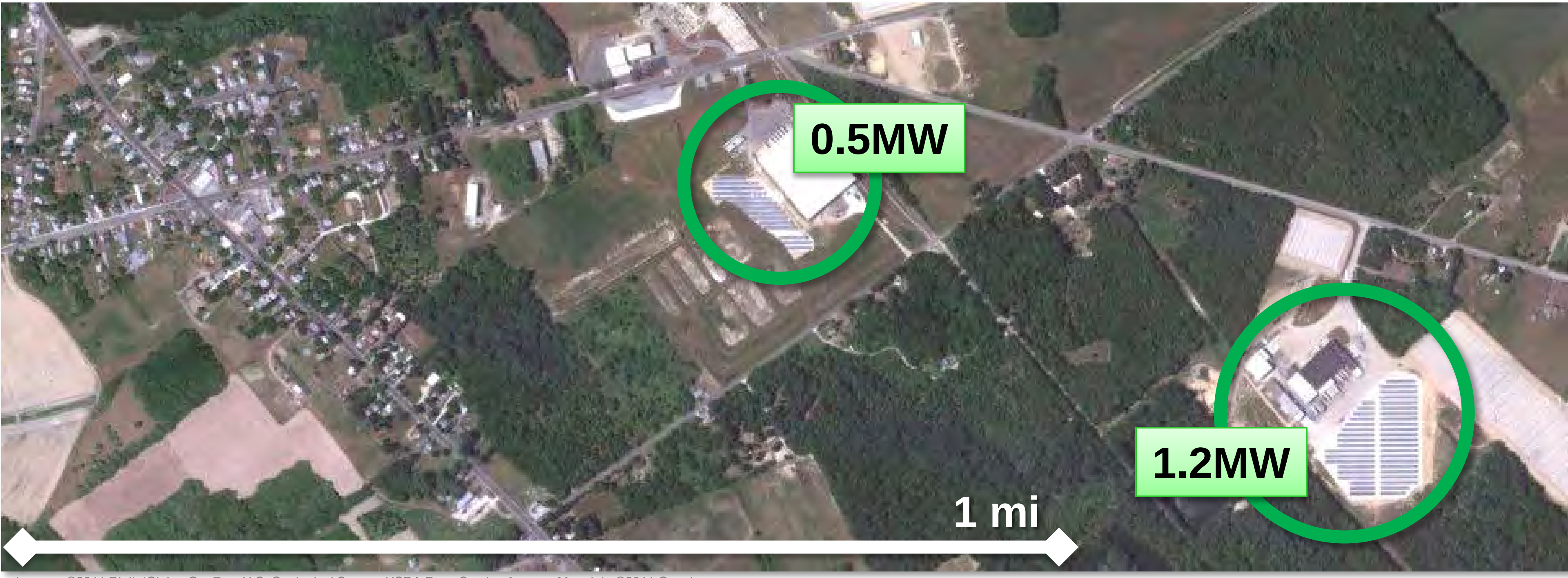
May 2012 (267,864 points)

- 3.0% of points exceed +5% limit
- 5.5% exceed limit when Power > 0.01

No More Solar Allowed

Utility has closed circuit J1 for new PV systems

- Concerns or complaints of overvoltage
- 1.7MW PV plants on rural circuit (small town + farms)
- At 6 MW max load, 28% masked by PV with full sun
- Utility asked customer to lower power factor on PV inverters



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