Successful Integration Of Distributed PV

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SunPower 2011

- 2010: Revenue $2.23B
- 5,500+ Employees
- 550+ MW 2010 production
- >1.5 GW solar PV deployed
- World-leading solar conversion efficiency
- Diversified portfolio: roofs to power plants
- 1,500 dealer partners, #1 R&C USA
- 5 GW power plant pipeline

Residential

Commercial

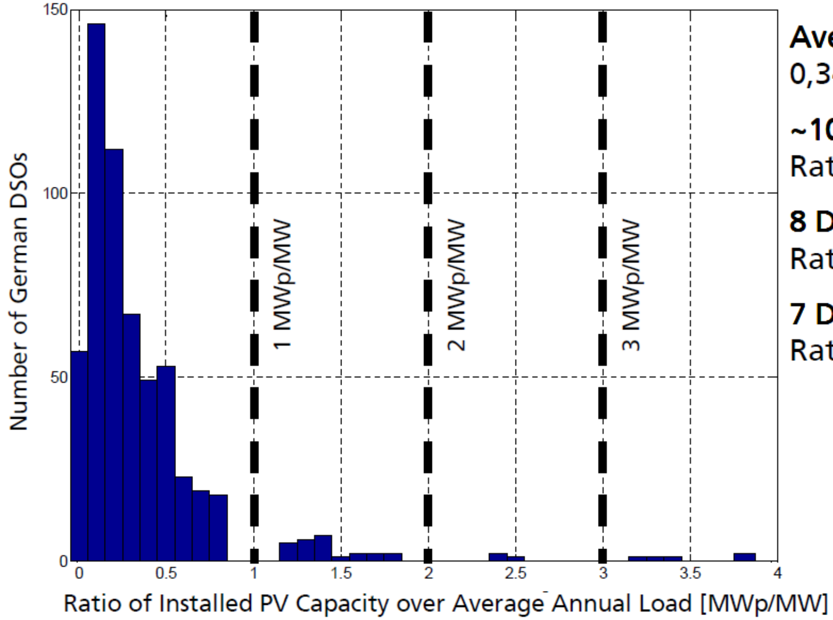
Power Plants

Case Study: High Penetration In Europe

- **Germany:** 15.5 GW PV, <u>99% DG</u>, ~70% in S. Germany
- **Spain:** 3.4 GW PV, <u>98% DG</u>
- **Italy:** 5.8 GW PV in 2010?

<u>No significant issues reported at these levels of penetration</u>

Ratio of Installed PV Capacity over Average Annual Load [MWp/MW]

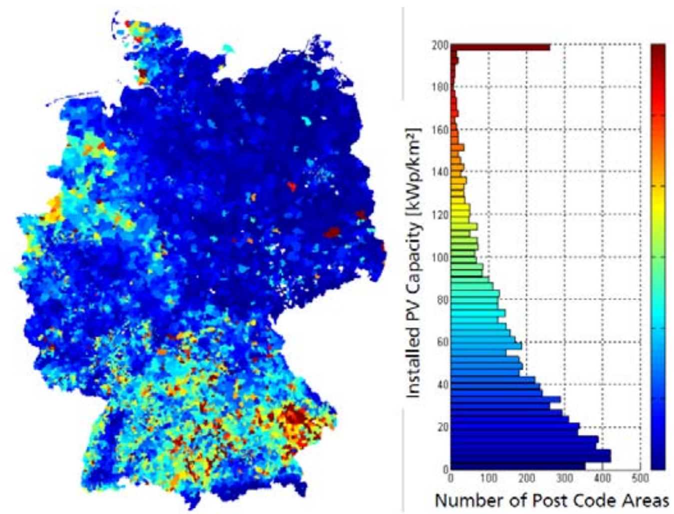


Average Ratio:
0,34 MWp/MW

~10% of the DSOs:
Ratio > 1 MWp/MW

8 DSOs:
Ratio 2-3 MWp/MW

7 DSOs:
Ratio 3-4 MWp/MW



Source: Y.-M. Saint-Drenan 2010 (IWES)

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Sources: Braun 2010, IEA PVPS Task 14 Workshop

KEMA Memos – No Reported Issues Due To:

- PV output variability

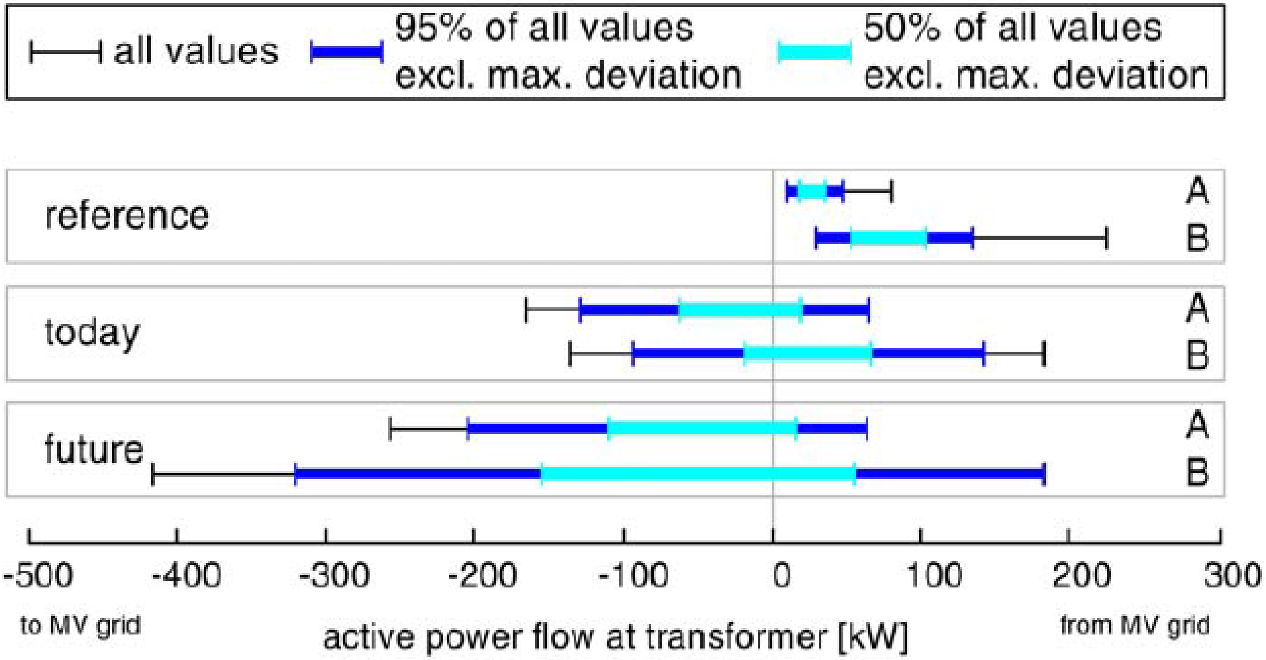
- Harmonics

- DC current injection

- Anti-islanding failure or protection coordination issues (despite routine German penetration levels in excess of 100% of minimum load)

→ **These issues are often cited as potential barriers to high penetration**

Reverse Power Flow – Common In Germany



K. Budenbender, M. Braun *et. al.* 2010 EUPVSEC proceedings

The “today” scenarios shown here represent two *actual* German distribution grids, operating without issue. Grid “A” is at 88% penetration*, Grid “B” at 37% penetration.

* Peak PV capacity (kW) divided by transformer rating (kVA)

German Grid Codes (BDEW)

- Updated requirements came into full force in **July 2010**

- In anticipation of 12% EU electricity from PV – 60 GW in Germany alone.

- Note that when proposed in 2009, already **9 GW PV** installed.

- MV code addresses **only ~ 20% of German installs**. LV updates in development to address other 80%, but currently these systems are similar to US.

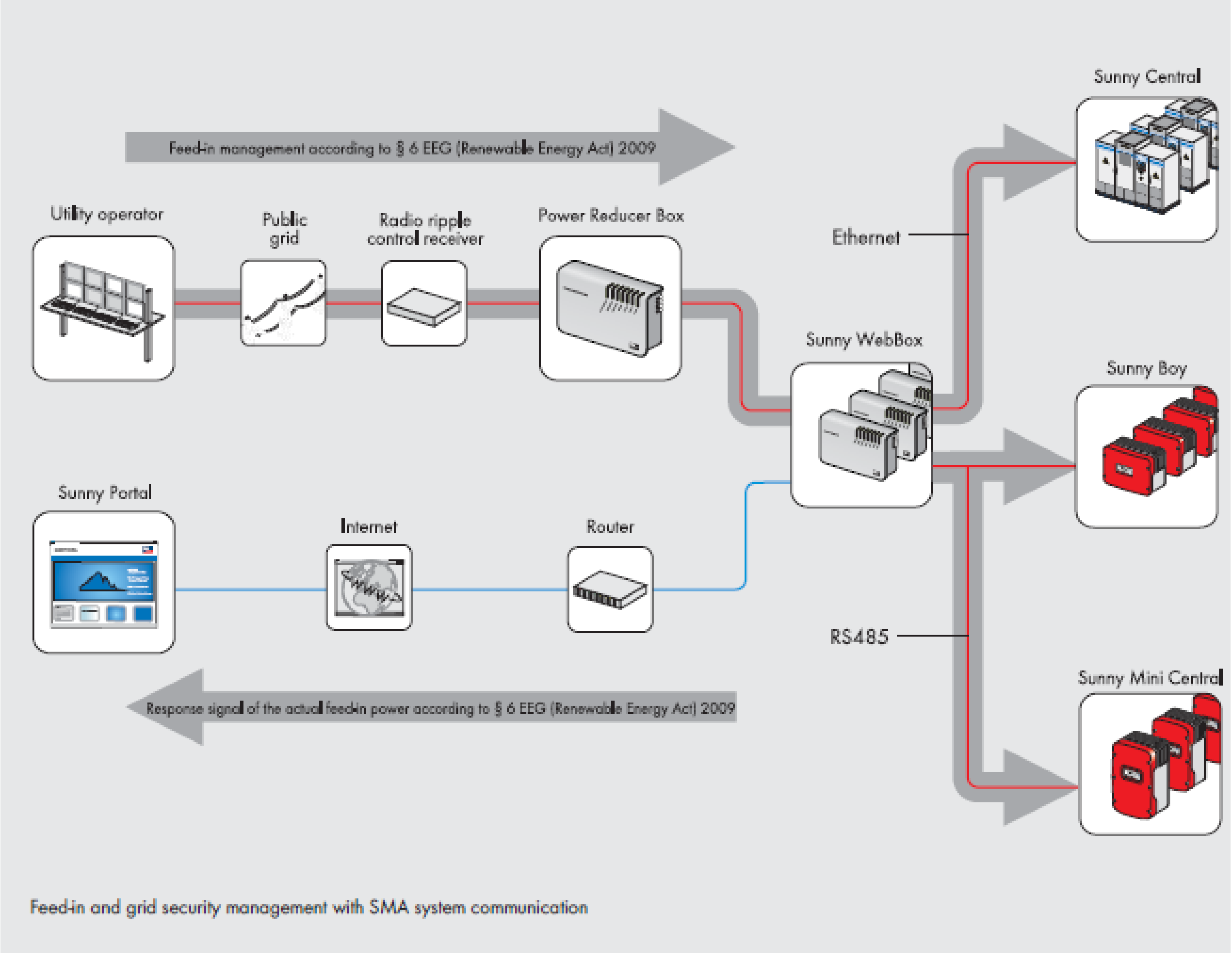
- Code includes: Curtailment control, PF setpoint or volt/VAR droop, over-frequency droop, LVRT w/ reactive contribution in fault recovery.

- Does not address variability (i.e. ramp rate limits) - has not been an issue.

- Does not require utility SCADA or other dedicated utility monitoring. Control is via low cost radio-based “ripple control”, used in Germany for over 20 years to achieve customer demand response.

Germany – Communications & Monitoring

Example: Operation of SMA "Power Reducer Box" For 100+ kW Systems



Courtesy of SMA

- Communication from utility to PV system is <u>unidirectional</u> via radio ripple control
- Monitoring is typically provided, but to PV system owner / operator, not directly to utility; monitoring is via public broadband.
- Transmission system operators contract for PV output estimates and forecasts provided by 3rd parties – modeling based .

Anti-Islanding Considerations

- A commonly expressed concern in the US is that anti-islanding may not be effective at high penetration. This is the primary driver of the "15% penetration study trigger" in the SGIP screens. **IREC recently looked closely at this and found the following:**

- An IEA study* found that the risk of islanding (exact match of load and generation for a meaningful period of time) is "virtually zero for low, medium, and high penetrations of PV systems". This is essentially because the probability that load and PV generation will be matched for more than a few seconds is extremely low.

- There is no equivalent study trigger or limit in Europe, and islanding has not been found to be an issue in practice.

- More study is needed to confirm if European findings hold in the US, and to determine how potential future capabilities – low voltage ride through (LVRT) and reactive power control – will interact with protection coordination and change the risk of unintentional islanding.

*IEA-PVPS T5-07: 2002

Other High Penetration Circuit Examples

Empirical data has not revealed any significant barriers to integrating high penetrations of PV onto distribution circuits.

Location	Description	Penetration	Notes
Ota City, Japan (2003)	550 Sites / 2 MW residential, one circuit	Not Reported	Residential energy storage evaluated and removed; no issues reported post-removal.
Freiburg, Germany (2006)	70 Sites / 440 kW multi-unit residential	110% on capacity (400 kVA XFR)	Minimal, correctable issues reported (phase imbalance)
Kona, HI (2009)	700 kWac commercial	35% on capacity (2 MVA feeder), backfeed up to 30% in low load	No issues reported
Lanai, HI (2009)	600 kWac commercial (1.2 MW system, brought online incrementally)	~12% on capacity, ~25% in low load, weak island system	No issues reported.
Anatolia, CA (2009)	115 Sites / 238 kW residential	4% on capacity, 13% low load	No issues reported, PV variability less than AC cycling variability.
Las Vegas, NV (2008)	> 10 MW commercial, 35 kV interconnection	~ 50% on capacity, ~100% low load	No issues reported
Atlantic City, NJ (2009)	1.9 MW commercial, 23 kV interconnection	~24% on capacity, ~63% low load	No issues reported

High Penetration Case Study – Lanai, HI

- Currently operating at 600 kW - up to 24% of island's power in low load conditions.
- Tied to 12.47 kV feeder, routinely back feeds (>100% penetration).
- PF is remotely adjustable by MECO, typically operates at 0.98 leading (inductive)
- No discernable impact on voltage (or frequency) under highly variable conditions.

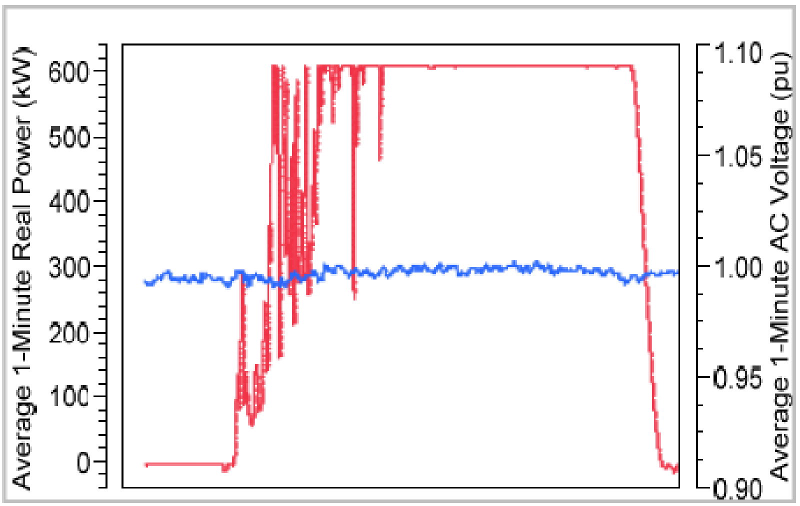
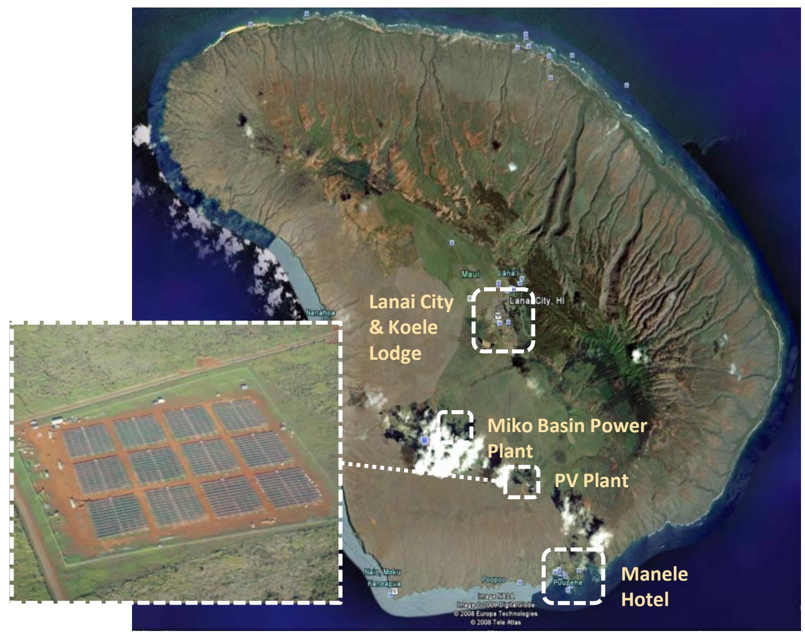


Figure 5. PV plant power output (red) and grid voltage (blue) on April 11, 2010

Johnson *et. al.* IEEE PVSC 2010



Does PV Variability Present A Barrier To Adoption?

Some have used the following argument:

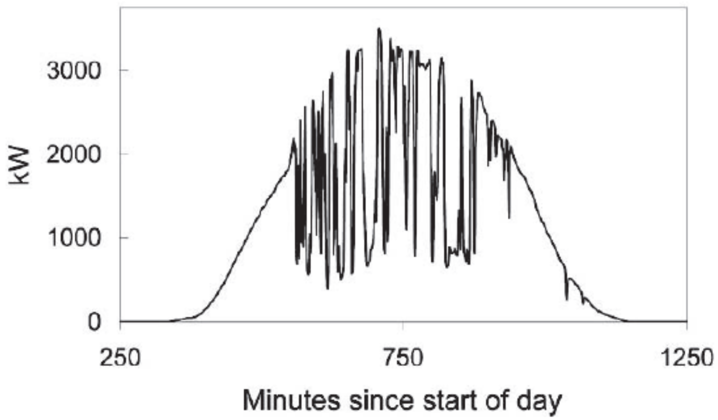


Figure 6-1
Output on June 3, 2004 for Tucson Electric Power's Springerville PV Plant. Data is Based on One Minute Increments

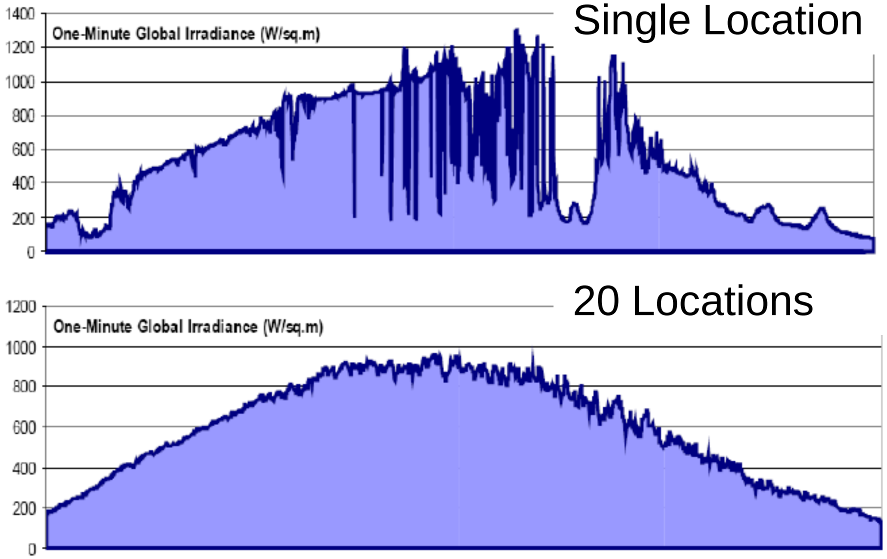
→ **BAD**

However, this *does* beg a few important questions, such as:

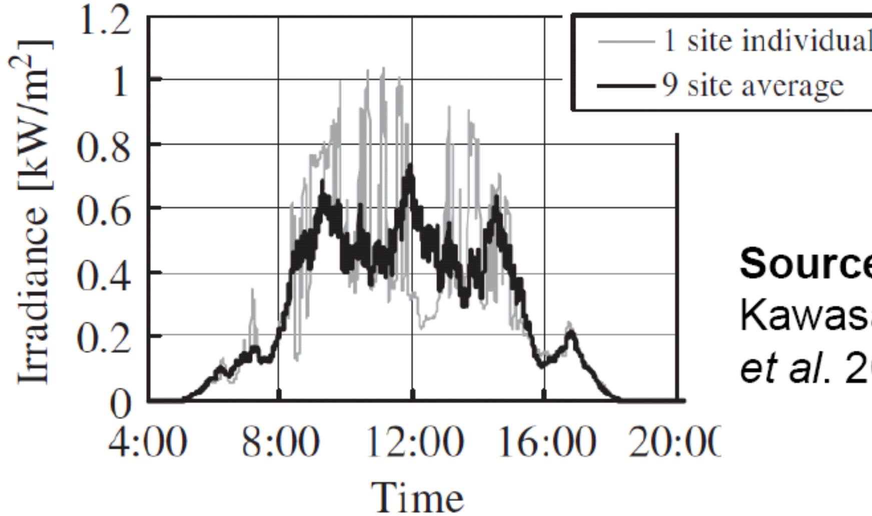
- How rapid are these changes, and how often do they occur?
- Does the observed behavior of a single system scale? If so, how?
- What are the impacts of variability on the utility infrastructure and the customer?
- How do these impacts change as penetration increases?
- What mitigations are available for these impacts? What are the best solutions?

Geographical Diversity Is A Crucial Factor

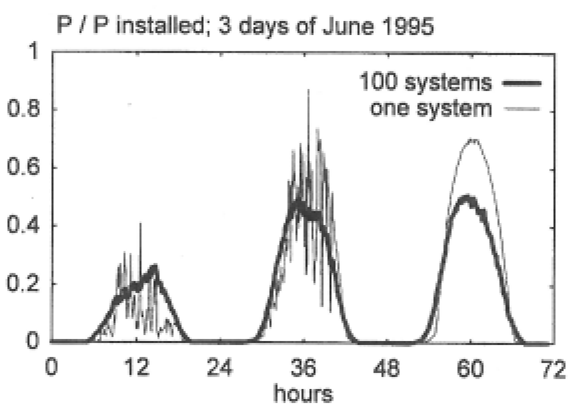
High Irradiance Variability At Single Sites Is Reduced With A Portfolio Of Sites



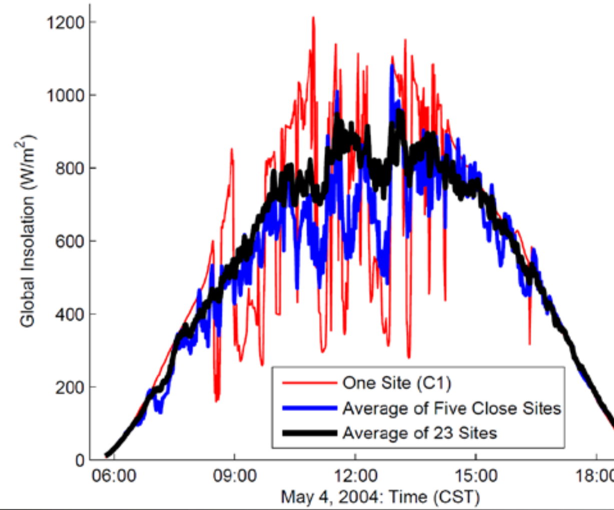
Source: Hoff et al. 2008



Source:
Kawasaki
et al. 2006.



Source:
Weimken
et. al.
2001



Source:
Mills *et. al.* 2010

Diversity Is Very Powerful Over Large Areas

- Tom Hoff (Clean Power Research) recently analyzed variability of a 5400 MW fleet of PV plants (5 MW – 500 MW in size) across CA.

- On a moderately variable day, for 1 location (equivalent to a ~5 MW or smaller system), the standard deviation of 1-minute variability was **~10%**.

- For all locations, the standard deviation of 1-minute variability was **~0.3%.**

- **That is, a 97% reduction in variability was found in this analysis**.

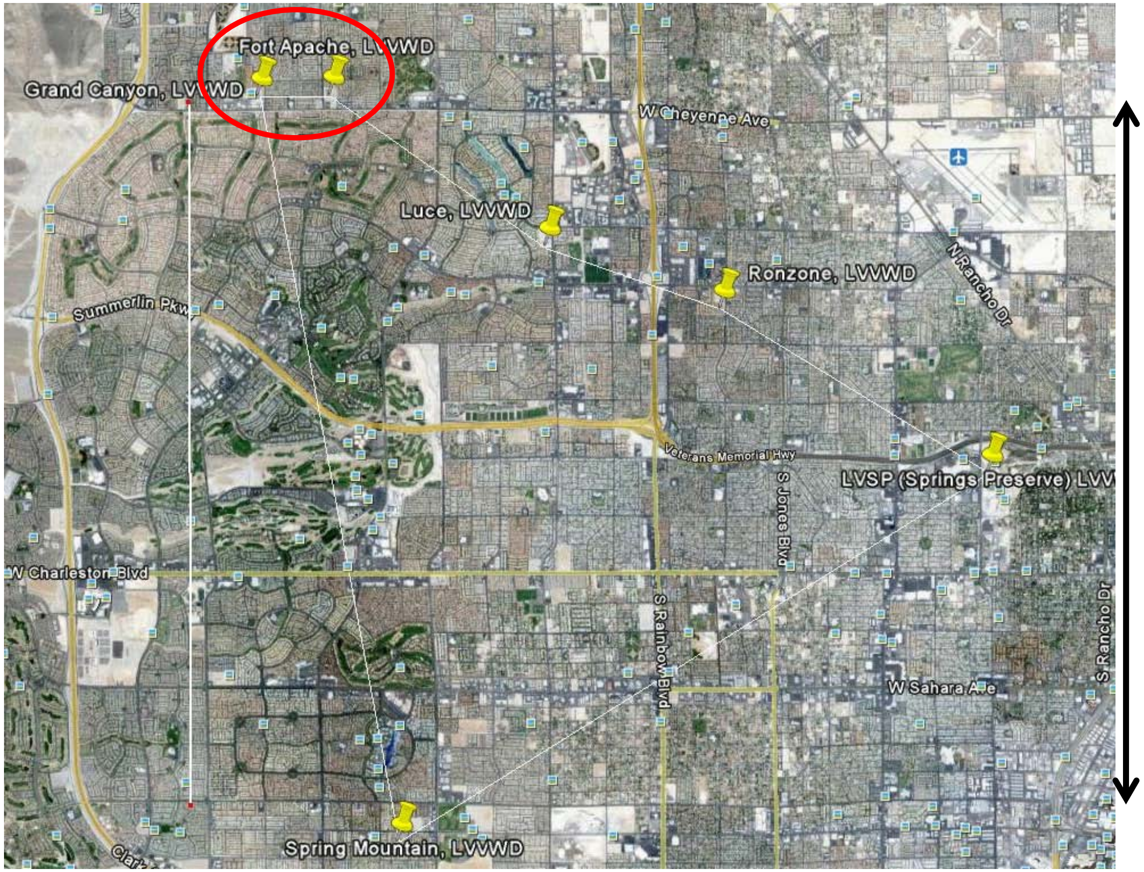
- **Controlling (or "backing up") the output of individual plants would require at least 33 times** the installed regulation capacity than controlling the variability of the fleet in aggregate.

- Combining aggregate solar variability with other uncorrelated variability, from load and wind, would further reduce the total regulation required compared to that required to manage each taken individually.

What About Over Short Distances?

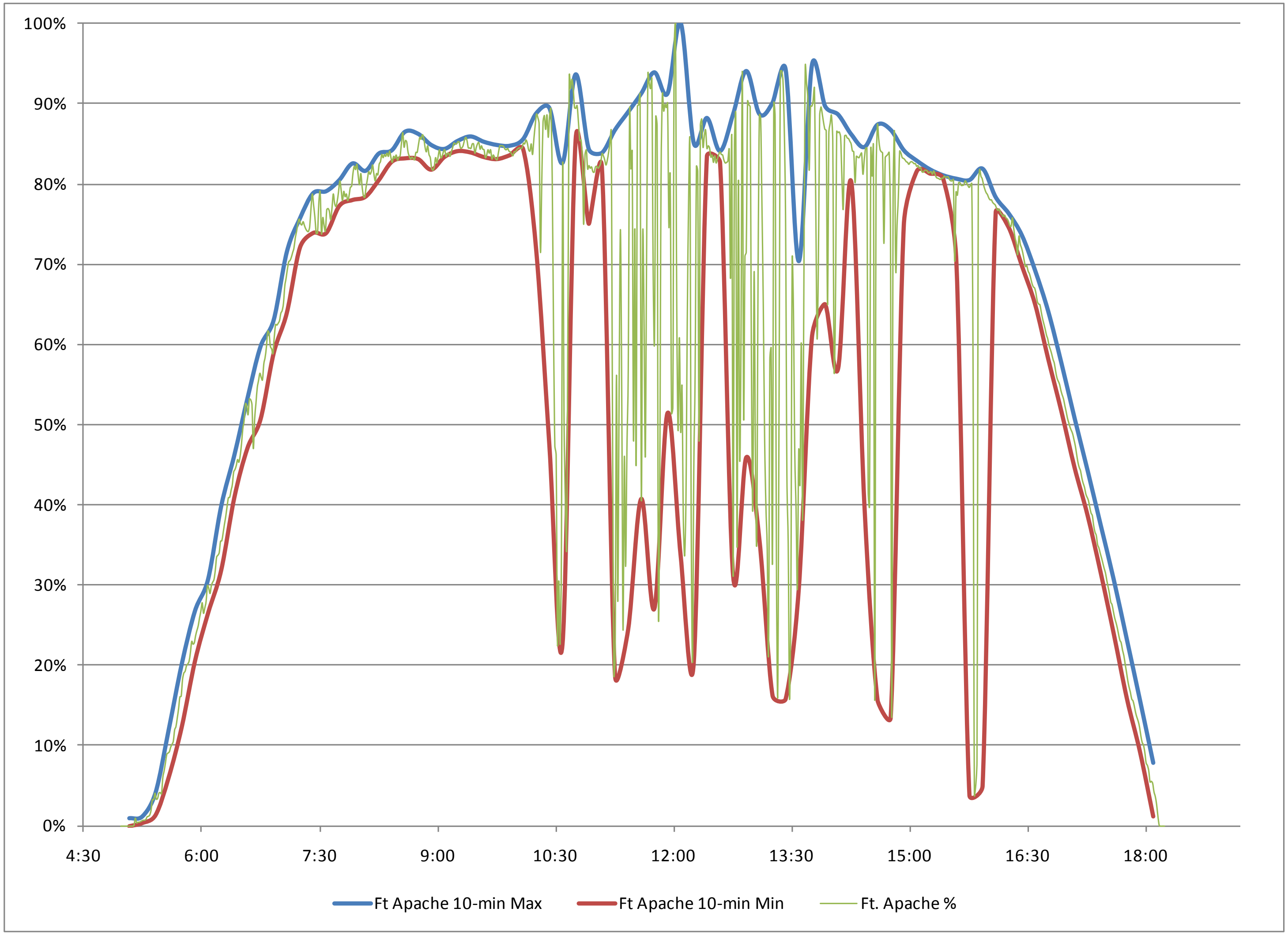
Case Study: Los Vegas Valley Water District

Six Distributed Sites. Minimum Distance: Grand Canyon – Ft. Apache = 1 km



Top – Grand Canyon
Bottom - Ronzone

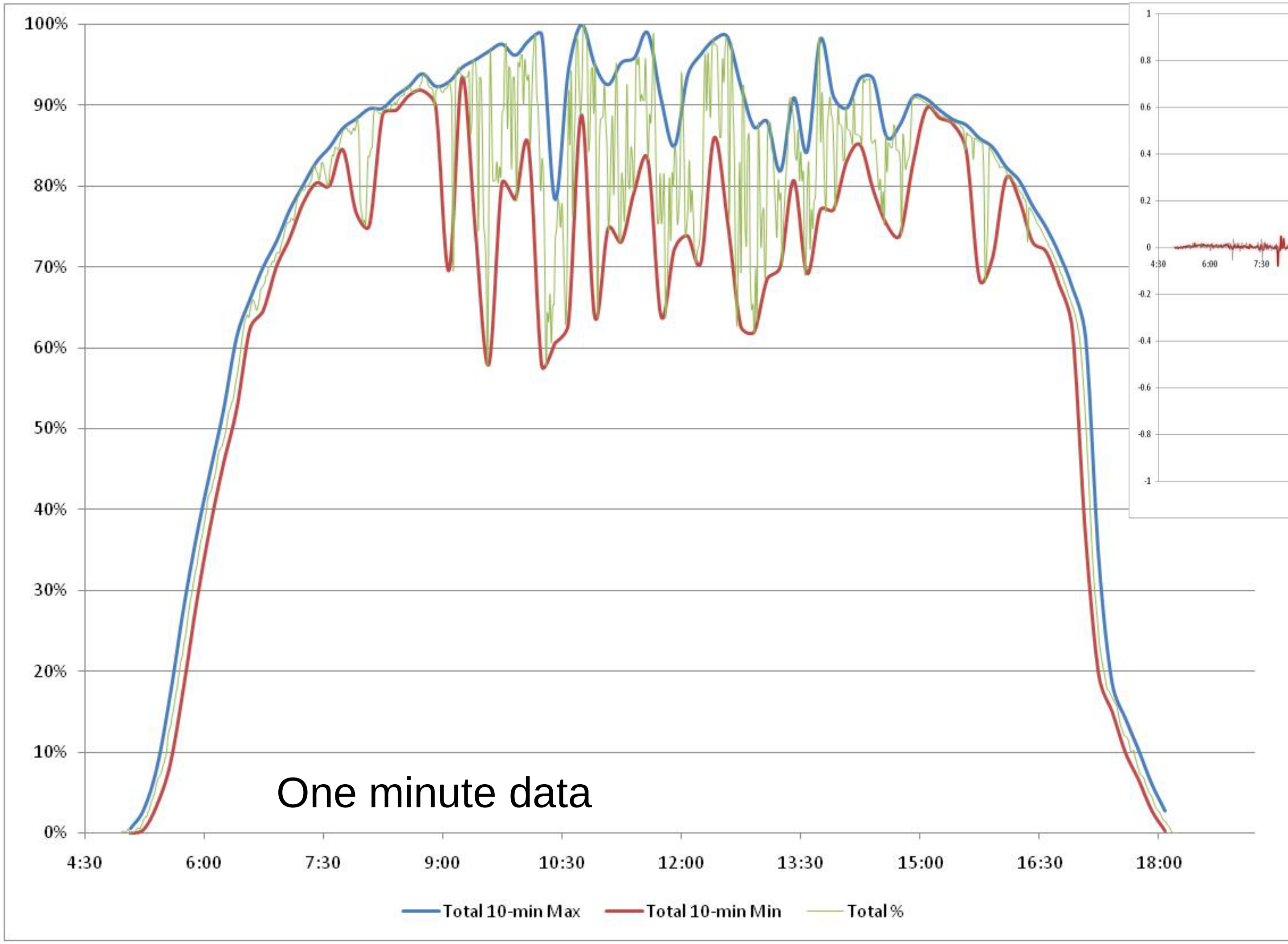
Single Site – Highly Variable Day

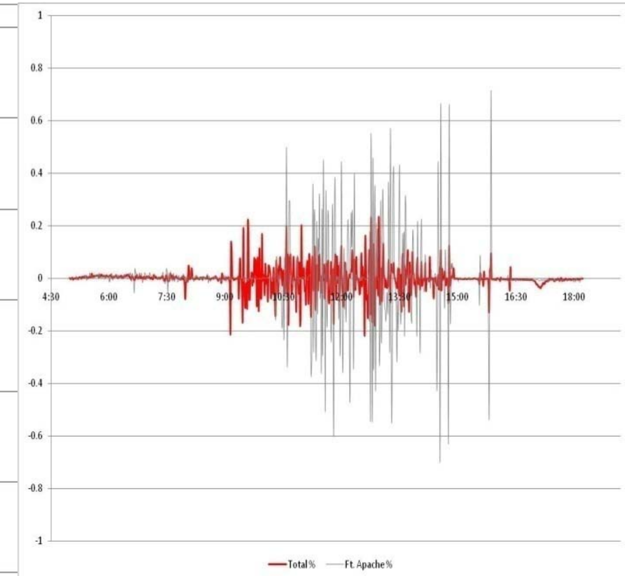


One minute data (Ft. Apache)

Partly cloudy day, highly variable conditions.

All 6 LVVWD Sites (same day)





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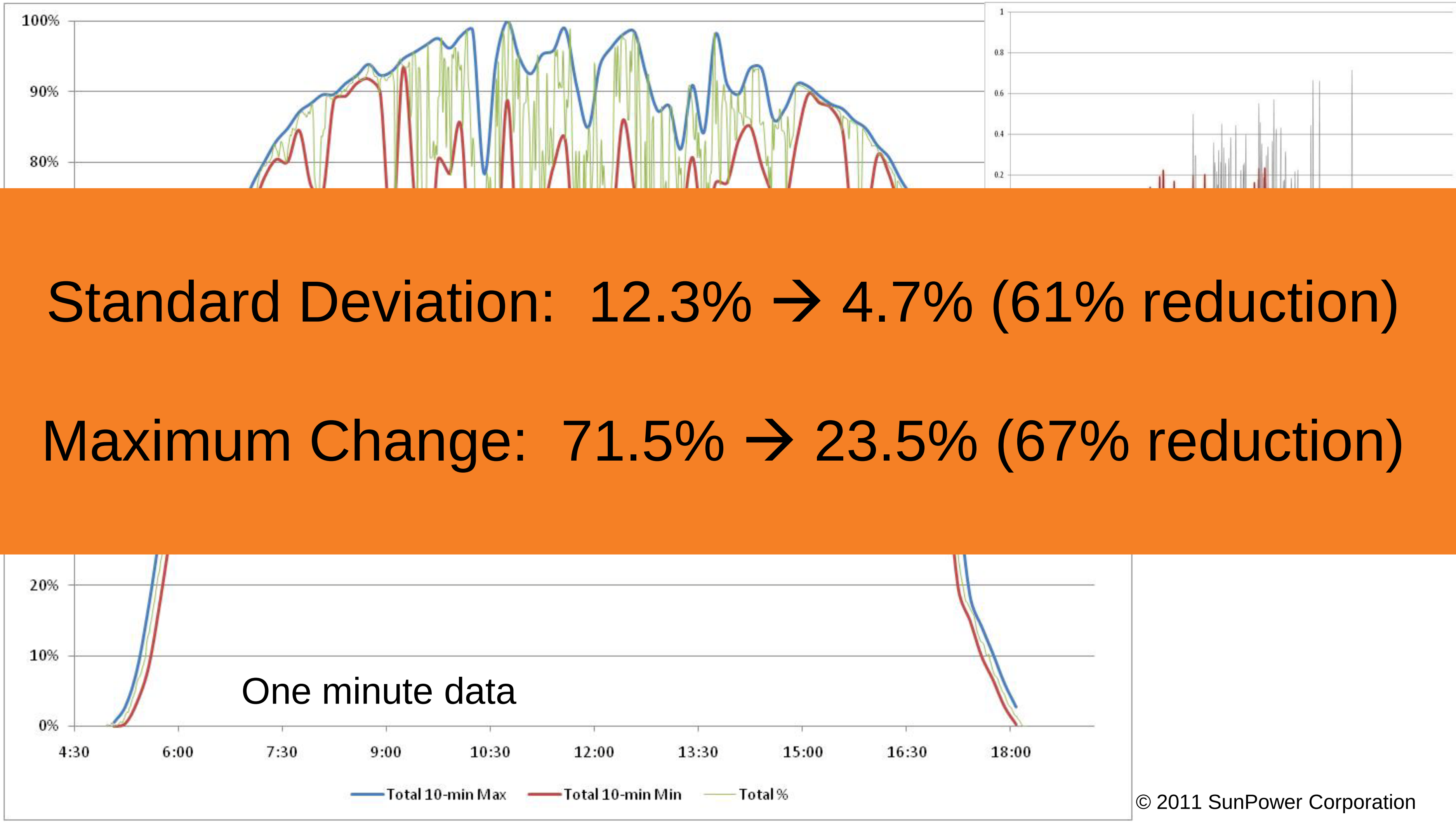
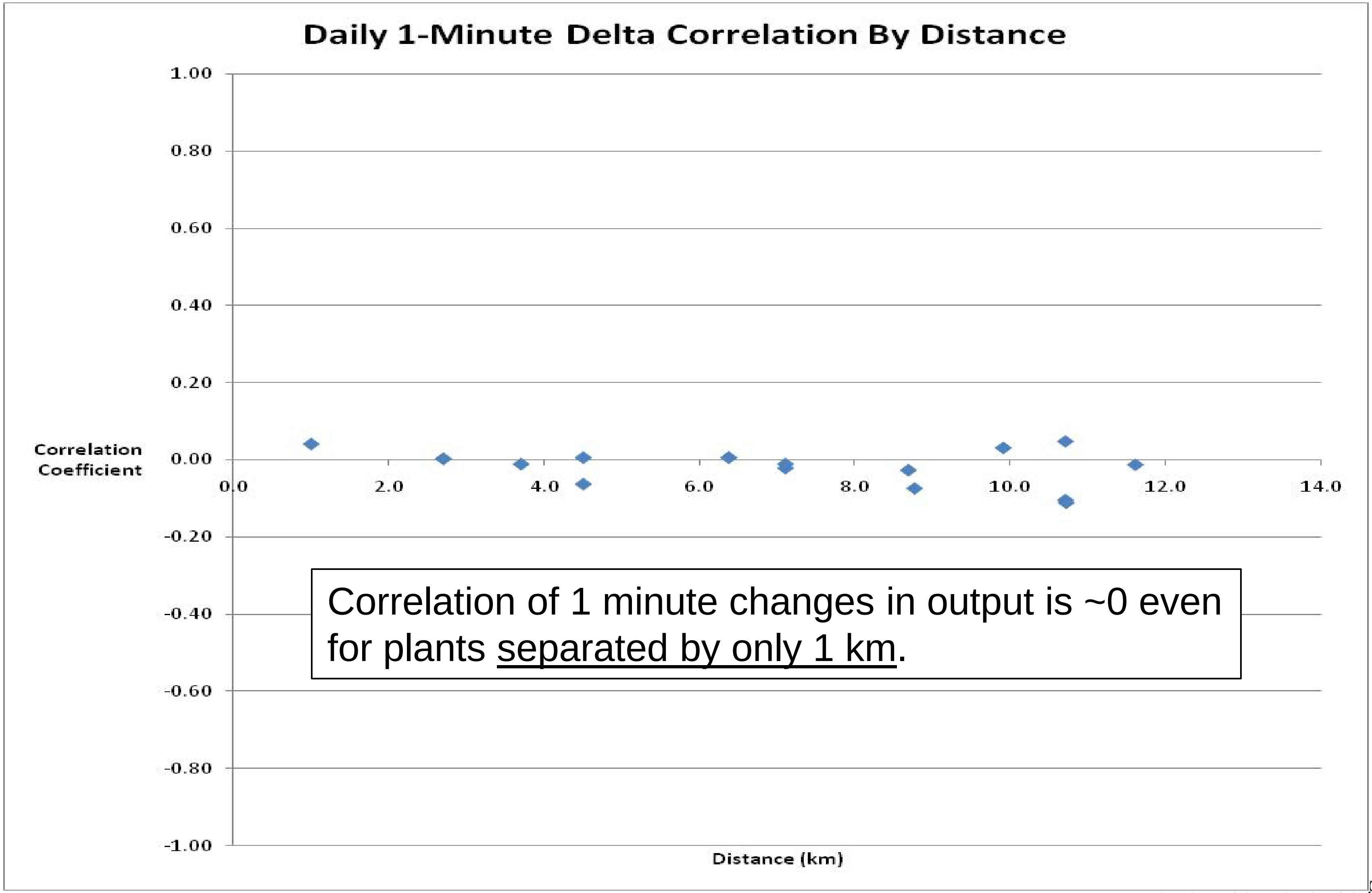
All 6 LVVWD Sites (same day)



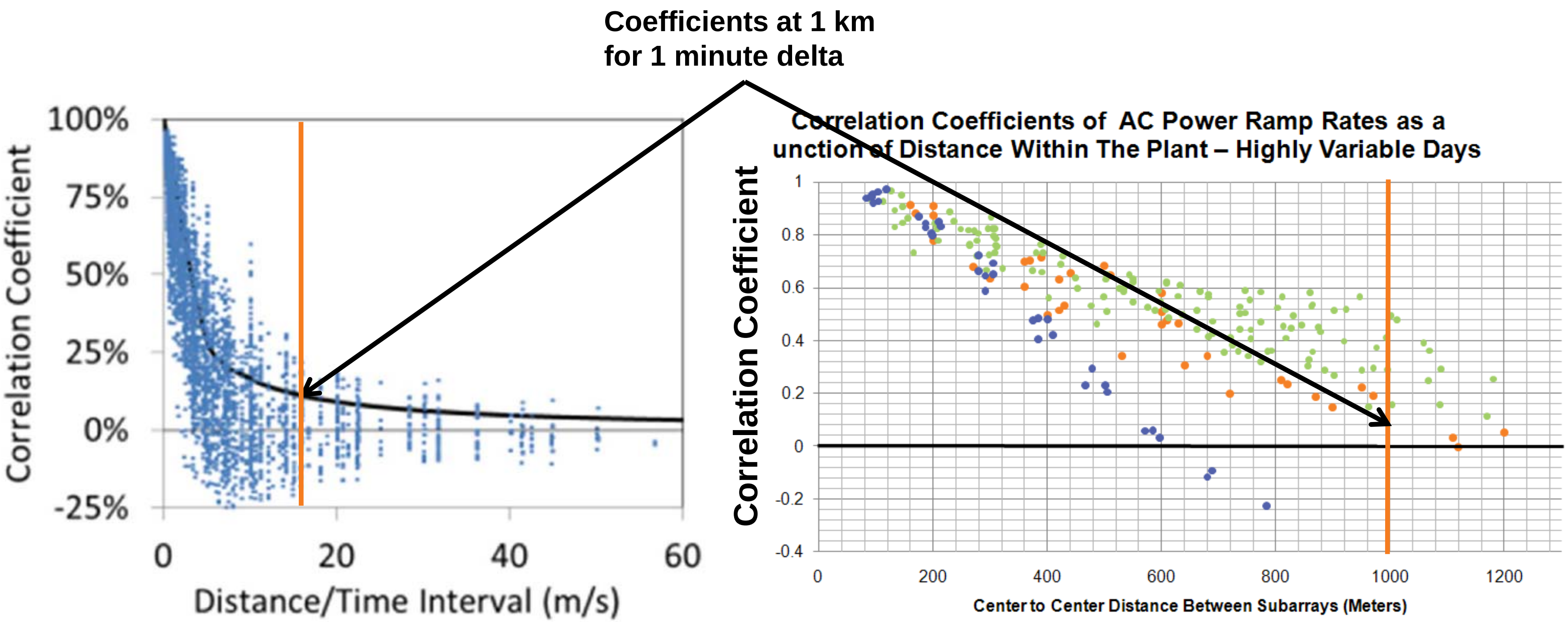
Standard Deviation: 12.3% → 4.7% (61% reduction)

Maximum Change: 71.5% → 23.5% (67% reduction)

Why? 1-Minute Changes Are Uncorrelated



More Examples of Diversity Over Short Distances



Analysis by Clean Power Research based on 25 node irradiance sensor network on 4 km^2 footprint (Napa CA), high variability day

Analysis of 1-minute deltas on high variability days from 3 operating mid-size plants (10 MW – 25 MW) in desert, tropical, and midwestern climates

- Consistently, **correlations of 1-minute deltas approach zero at ~1 km (+/- 500 m?).**
- **Zero-correlation distance for 1-second deltas could be as small as 20 meters.**
- **Geographical diversity likely mitigates voltage impacts on distribution systems.**

Reactive Power Controls Voltage If Needed

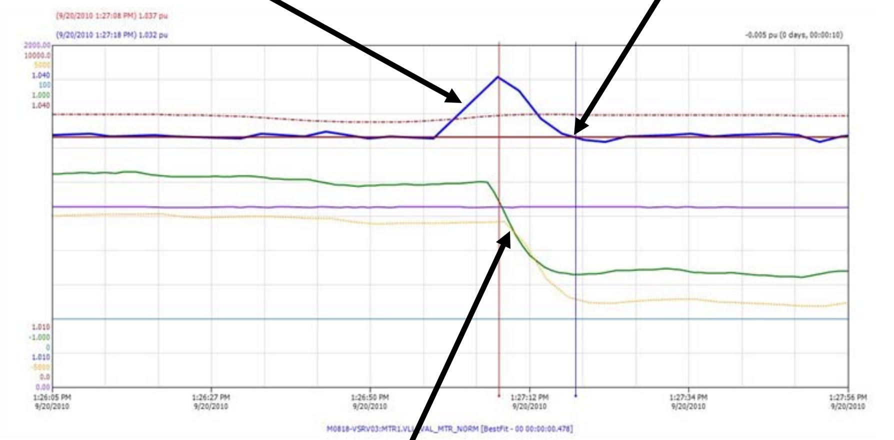
- Geographical diversity has a substantial impact in mitigating variability over small distances, even within a distribution feeder.

- Voltage fluctuations can result – particularly where a single, high penetration system is interconnected to a circuit with high impedance.

- Reactive power control can substantially reduce the impacts of output variability on voltage, as demonstrated in studies by EPRI and others.

- Active voltage regulation (AVR) is particularly effective, if mitigation is needed.

- AVR and some other reactive power control schemes not currently allowed by IEEE 1547.



SunPower has pioneered the implementation of AVR in large-scale (10+ MW) PV plants.

Low-Voltage Ride Through

- "Sympathetic tripping" of distributed PV is a legitimate concern at high total system penetration – studies indicate issues where penetration reaches 20% of total annual energy served by the interconnected transmission system.

- Nearly all PV on German system today (17+ GW) is not equipped with LVRT.

- There is not a technical barrier in terms of implementation – PV inverters with LVRT are commercially available today in Europe and are used in large "behind the utility fence" US projects.

- IEEE 1547 and UL 1741 prohibit this behavior today for distributed systems → UL 1741 certification is a *de facto* requirement to pull an electrical permit in the US.

- Expect resolution by late 2013 between UL, IEEE 1547.8 working group, with cooperation of NERC Integration of Variable Generation Task Force (IVGTF) - Task 1.7.

→ "Sympathetic tripping" is not a barrier to meeting 12 GW by 2020

12 GW Distributed PV - High Penetration?

- Black & Veatch Study For Re-DEC considered 15 GW DGPV to meet 33% RPS target.

- Constrained to no more than 30% of substation peak load.

- Multiple constraints on usability of large roofs and including close proximity of substation (i.e. only considered “stiff” circuits); consideration of “warehouse clustering”.

- Found 11.5 GW potential on large roofs alone.

- **17.3 GW** potential including small roofs and 20 MW wholesale DG.

→ There is much more than 12 GW potential for DGPV in CA, at or below current European penetration levels.

Conclusions

- Significant amounts of high penetration (100%+), distributed PV generation have been successfully integrated worldwide.

- Experience in Germany and Spain suggests that 12 GW of DG in California by 2020 is readily achievable with no significant technical barriers or need for major infrastructure improvements (i.e. "smart grid").

- Geographical diversity substantially mitigates short duration variability, even within the footprint of a given feeder.

- Many often discussed concerns such as voltage fluctuation, failure of anti-islanding, and unacceptable harmonic contribution have not emerged in practice.

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