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Advanced Inverter Functionality to Support Grid Reliability & Related Interconnection Requirements Part 2

Daniel Brooks, Aminul Huque, & Jeff Smith

PC Enhanced Inverters Stakeholder Meeting

2014 April 28

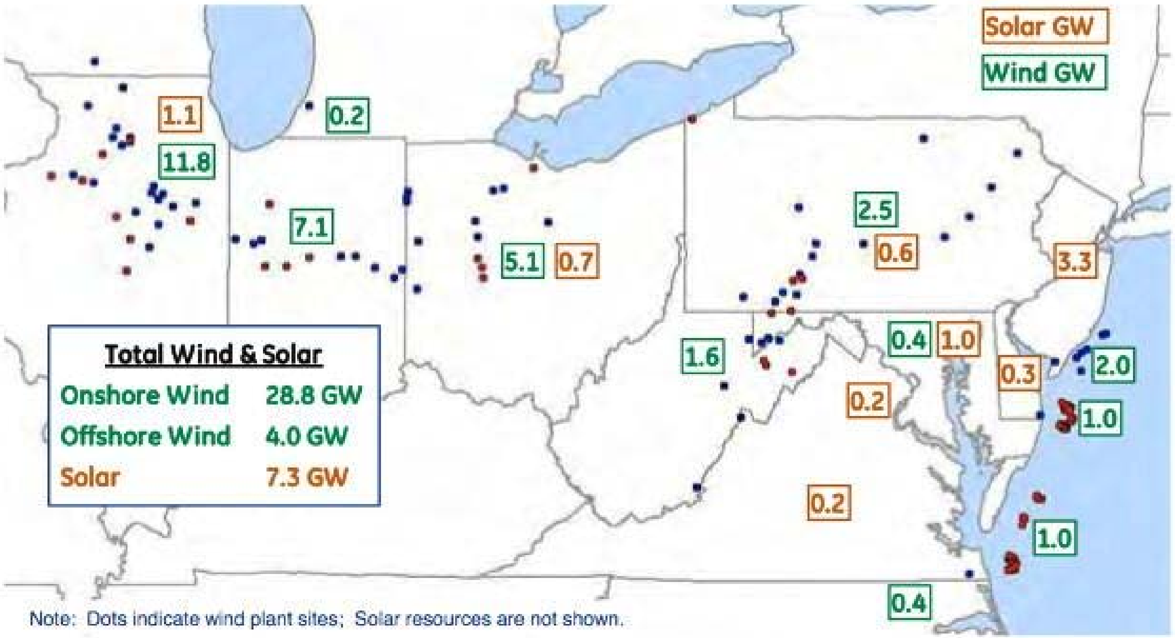
Objectives & Agenda

Agenda:

- Bulk System reliability impacts & needed inverter-based generation functionality
- Overview of Distribution System impacts
- Advanced inverter cost considerations
- Key take-aways from Apr 23-24 IEEE 1547 Mtg
- Q&A

Basic Understanding of Need for Advanced Reliability Services from Inverter-Based Generation

PJM Renewable Integration Study Scenario



14% RPS Scenario

- **Onshore Wind: 28.8 GW**
- **Offshore Wind: 4.0 GW**
- **Central Solar: 3.2 GW**
- **Distributed Solar: 4.1 GW**

30% High PV Scenario

- **Onshore Wind: 47.1 GW**
- **Offshore Wind: 5.4 GW**
- **Central Solar: 27.3 GW**
- **Distributed Solar: 33.8 GW**

Recently reported study included scenarios ranging from 2% (BAU) to 30% energy from renewables

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Bulk System Reliability Impacts and Benefits of Inverter Generation Support

April 28, 2014

General Reliability Concerns

Reliability Functions

- Reactive power/voltage control
- Active power control
  - inertia/primary freq response
- Disturbance performance
  - voltage & frequency ride through

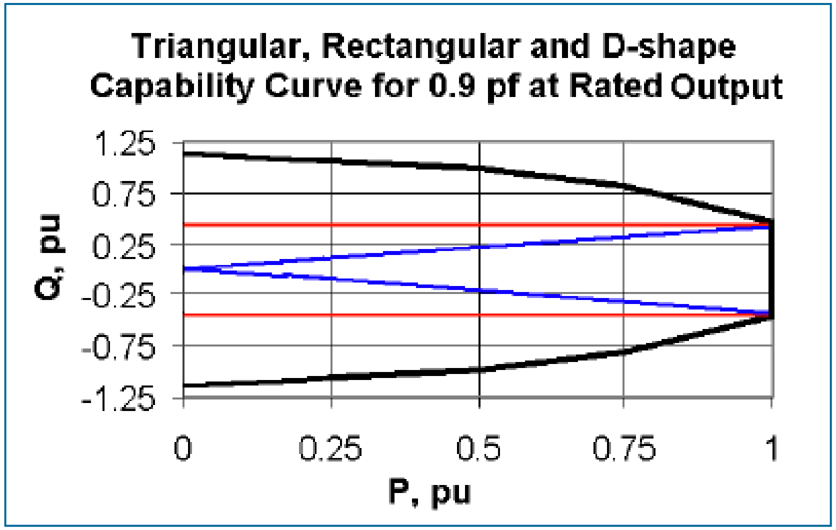
Other Considerations

- Inverter capabilities
- Available headroom for wind/PV
- Distribute

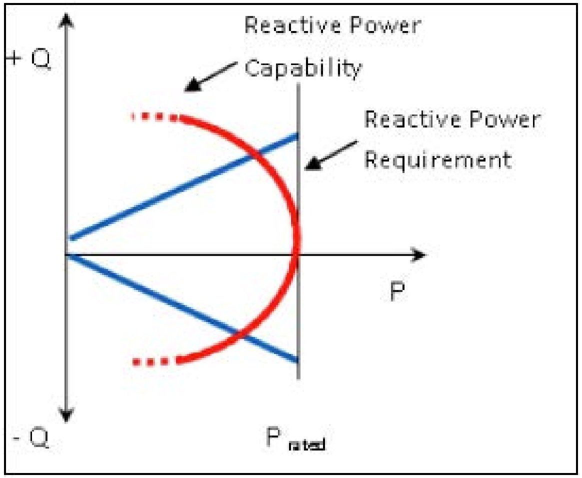
Inverter-Based Generators must supply Reliability Services as they Displace Conventional Sources of those reliability services!

Wind/PV Reactive Support Range

Typical Type 3/4 WTG VAR Capability Options

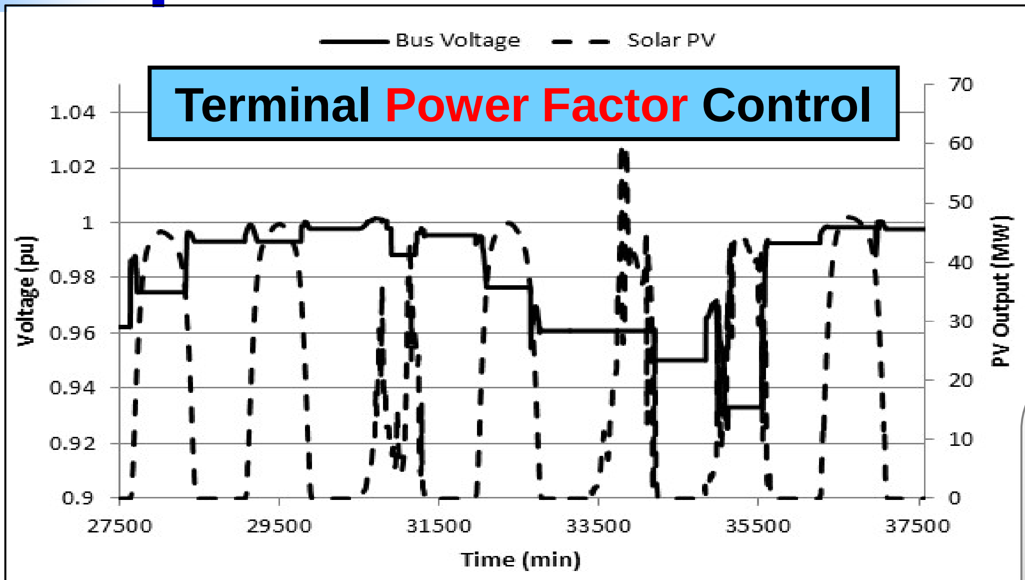


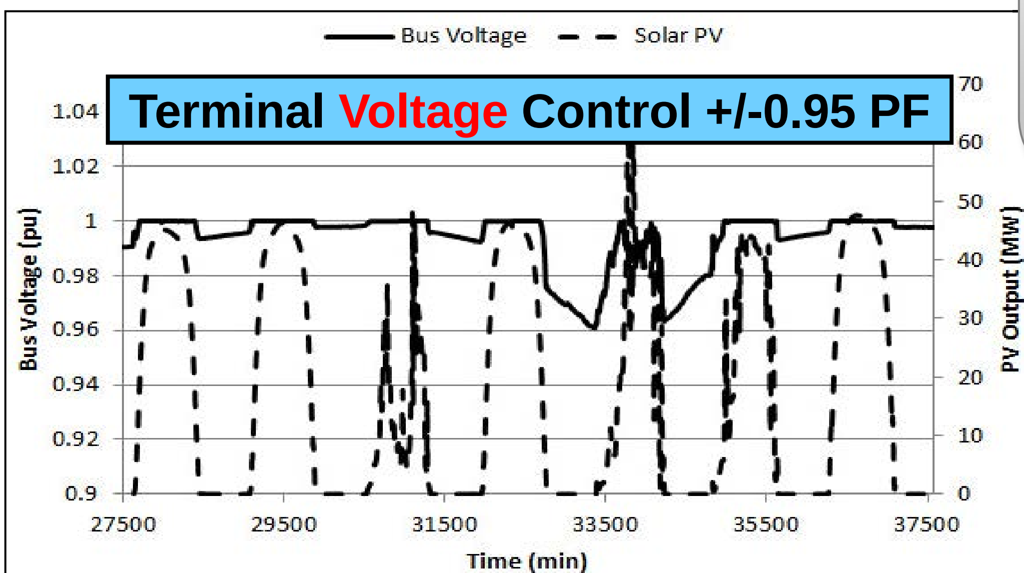
PV Capability (I limits) Vs. Triangle Require.



- Plant requirements can differ
  - Reduced range at low wind/PV levels
- Solar PV inverters over-sized for full range at max power output
  - historically distribution w/unity PF control
- Dynamic vs. static capability
  - switched shunts often included for static range
  - SVC/STATCOM may be used for additional dynamic range

EPRI PV Voltage Control Project** Results
Impact of PV Reactive Power Control



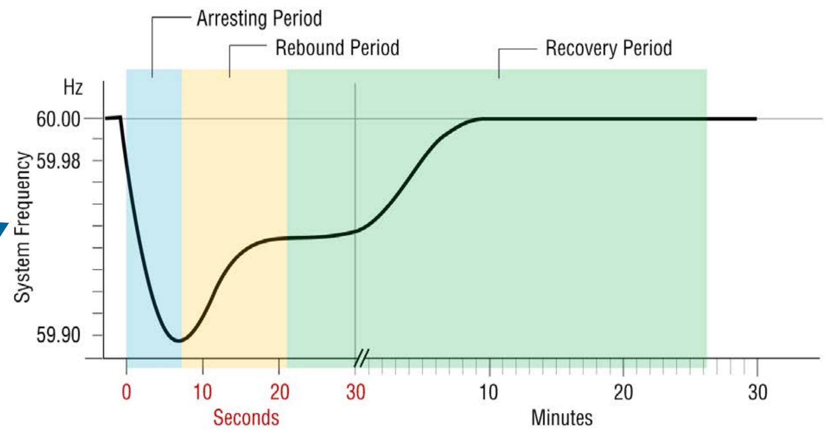


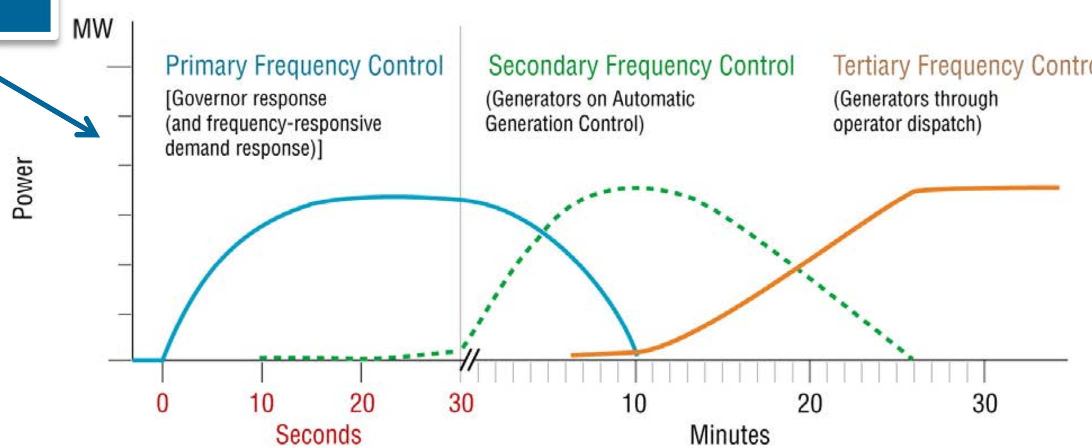
***Bulk Electricity System Impacts of Distributed and Transmission System Connected Solar PV,* EPRI, Palo Alto, CA: 2012. 1024349.**

- **Selected Bus Voltage -- July**
- **High solar PV output**
- **PF Control → Lower Voltages**
- **Voltage Control → More Robust Voltages**

High Levels of Inverter-Based Generation Can Impact Frequency Stability

Sudden Generation Loss



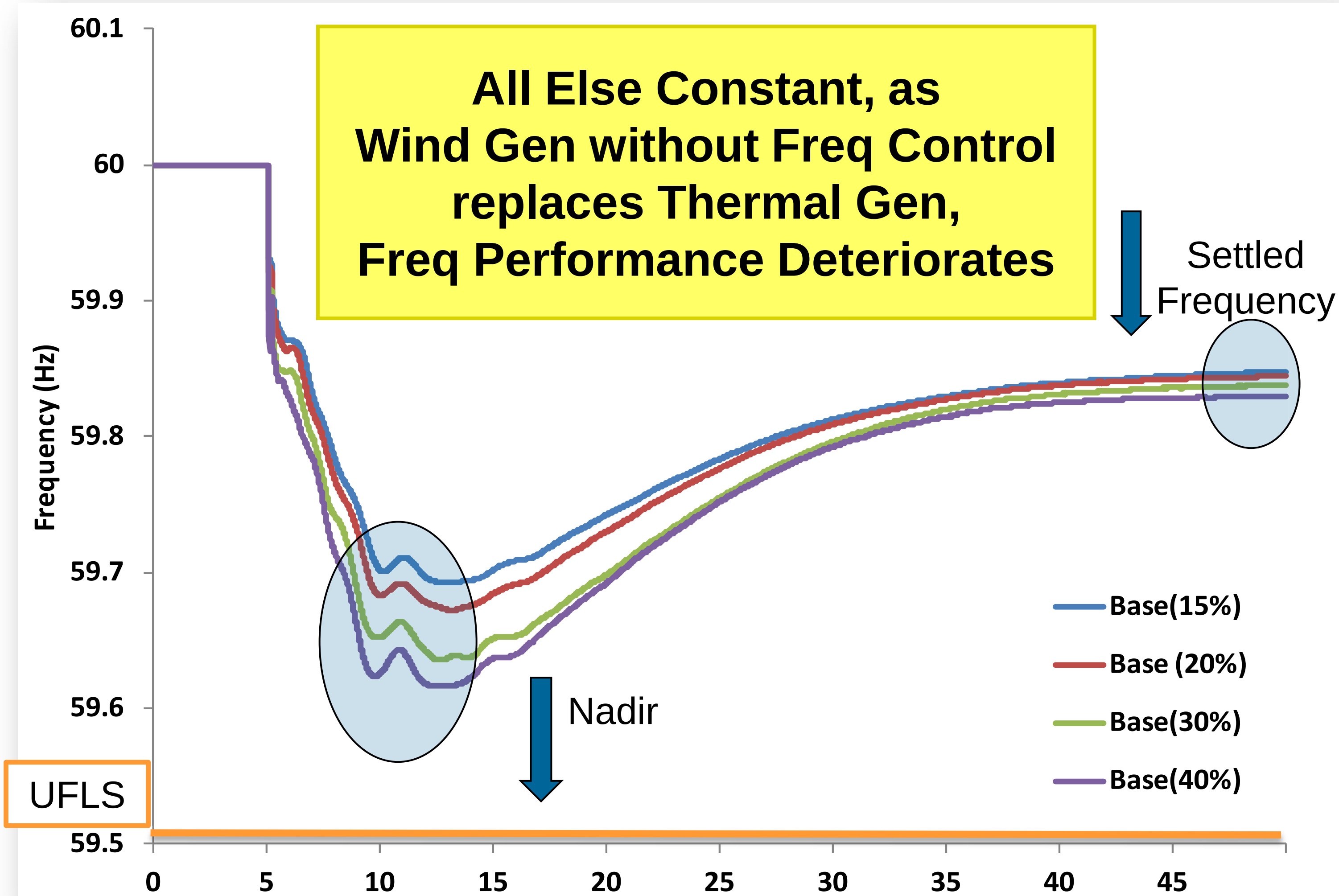


VG may displace conventional units & reduce system inertia & primary frequency response

Non-synchronous VG may provide inertia & primary frequency response through power electronics

*Graphics Source: LBNL-4142E **Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation,** Prepared for Office of Electric Reliability Federal Energy Regulatory Commission, Dec 2010*

EPRI Frequency Response Project (WECC)
Impact of Wind Without Frequency Response



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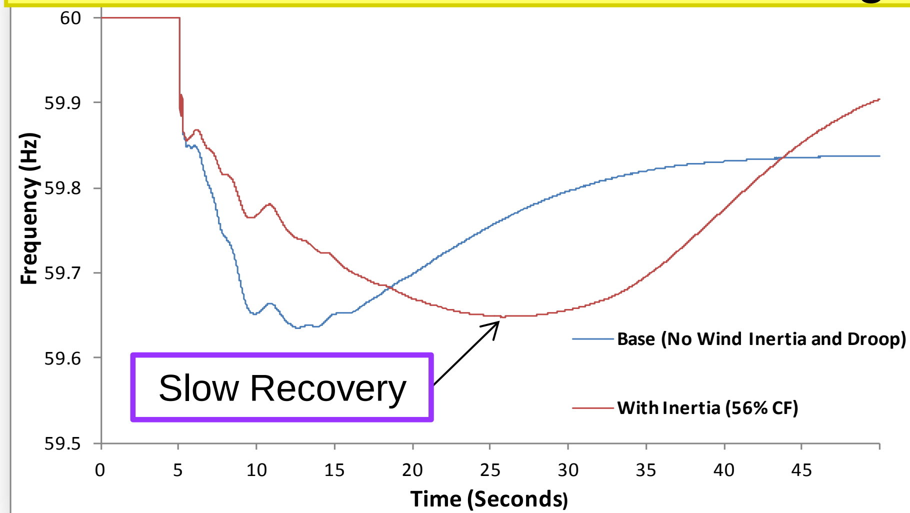
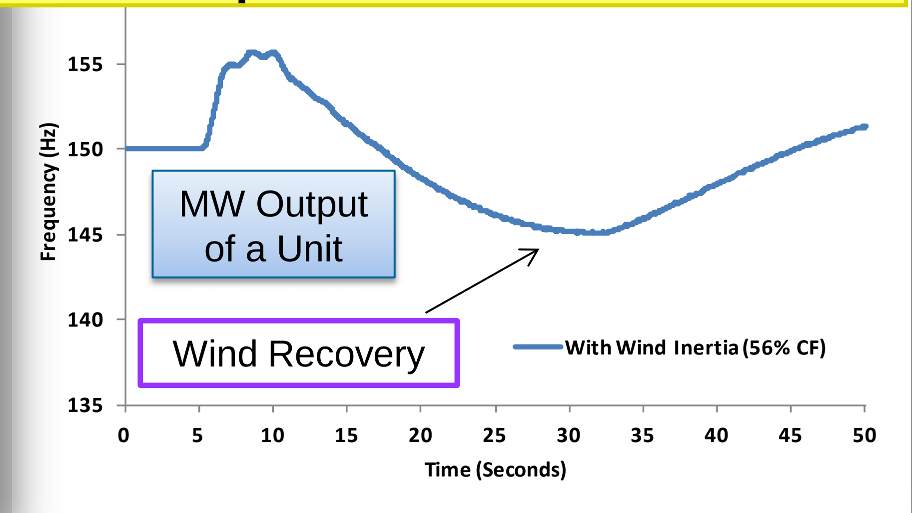
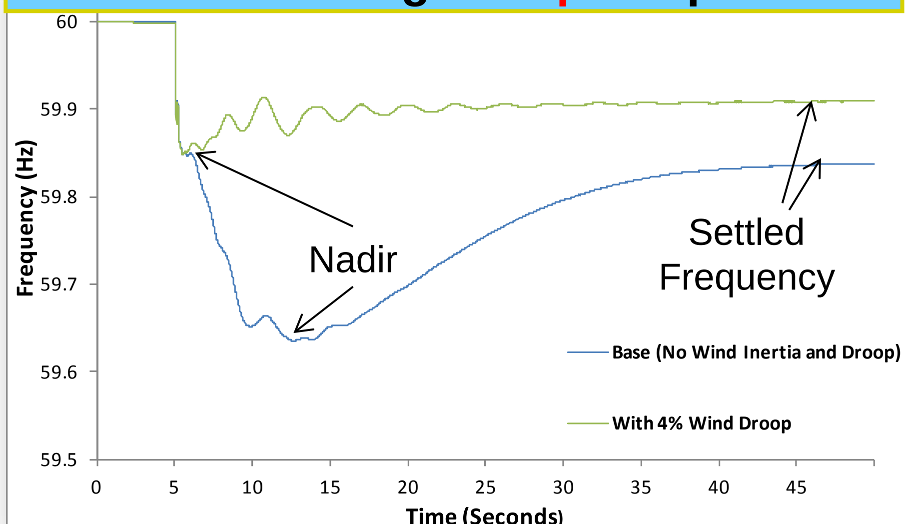
EPRI Frequency Response Project (WECC) Benefits of Wind With Frequency Response

Wind Providing **Inertial** Response





Wind Providing **Droop** Response



- **Wind Inertia & Droop Control Improve Freq Performance**
- **Controls must be tuned to ensure desired performance**

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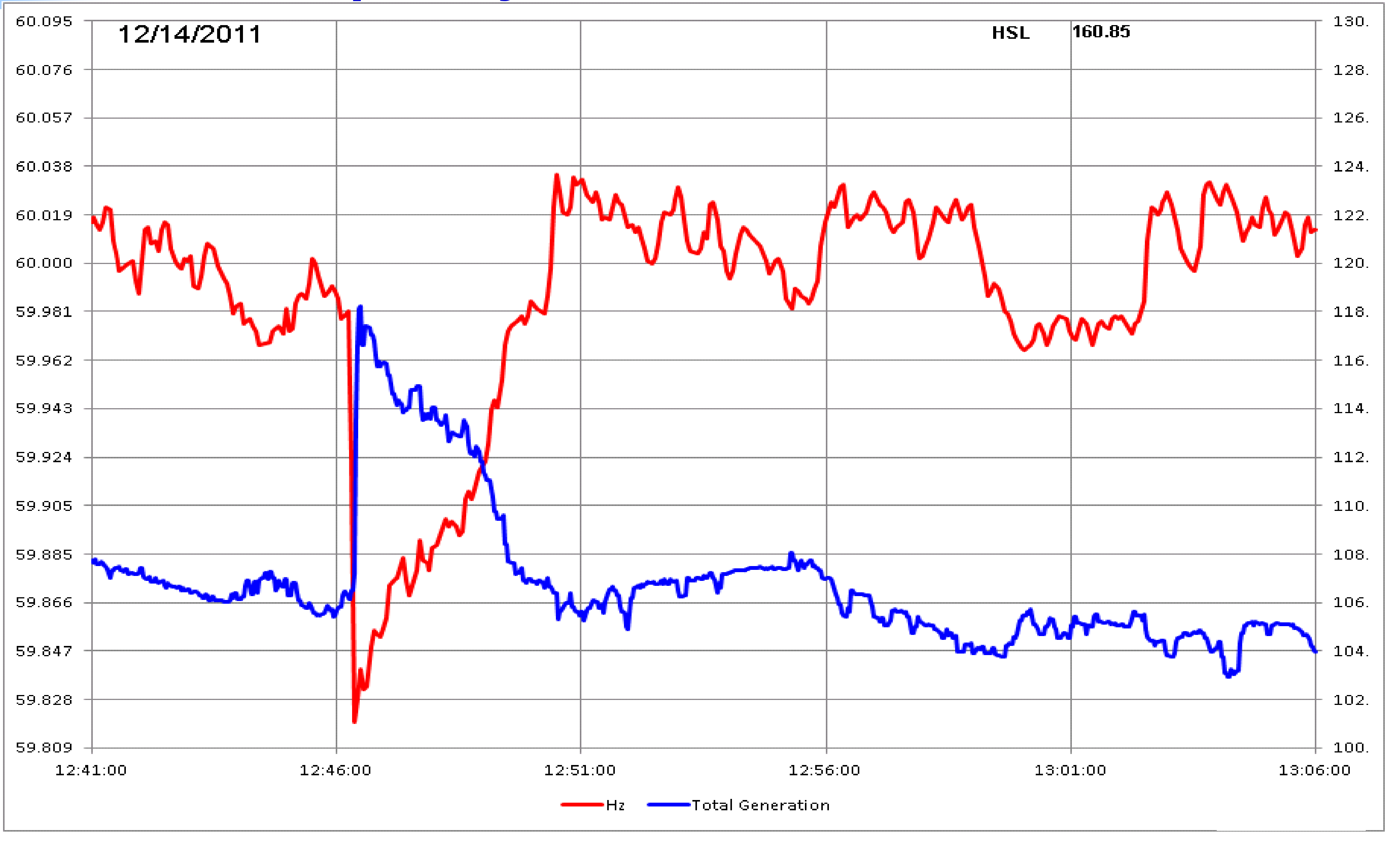
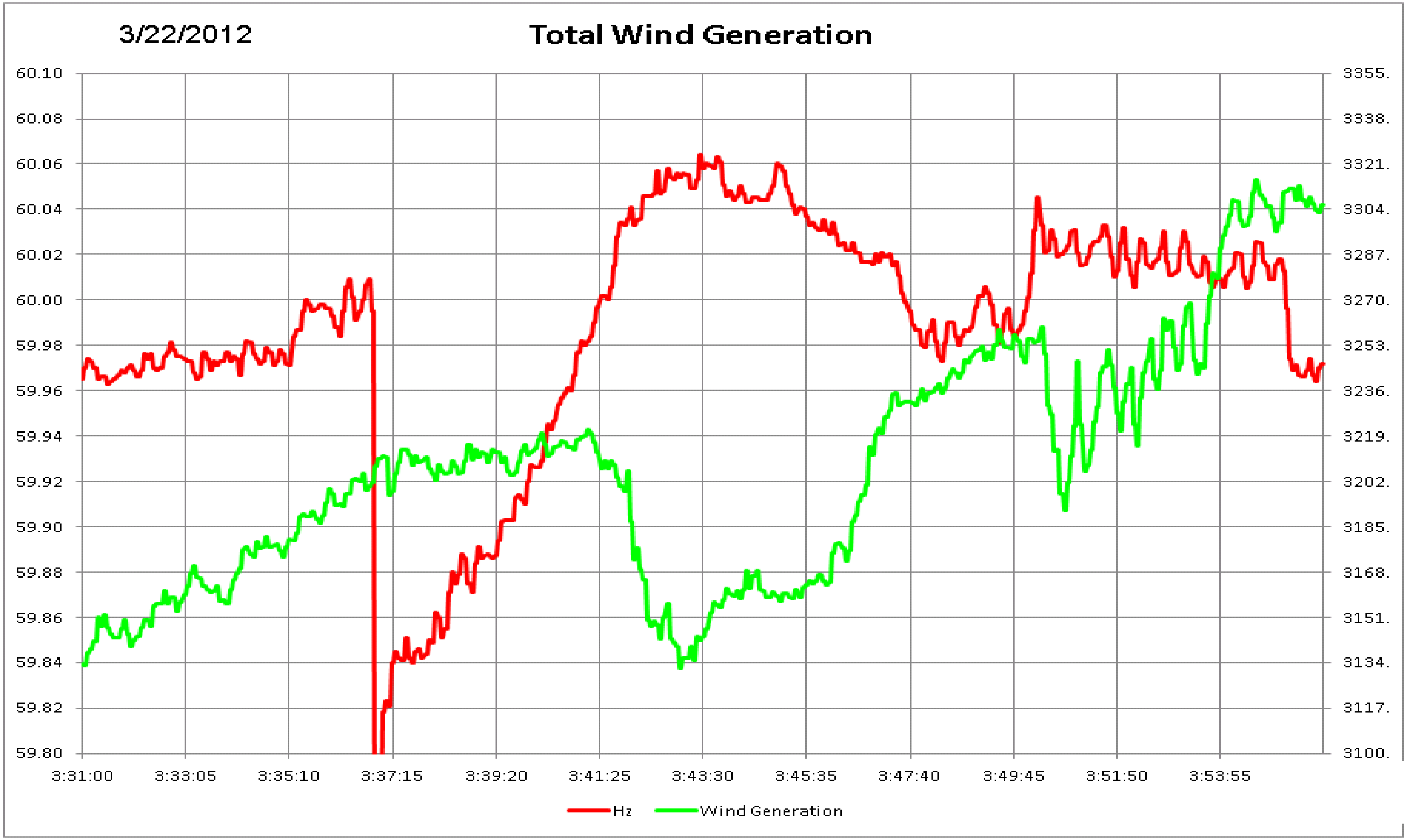
ERCOT – Measured Wind Generator's Response to Low Frequency



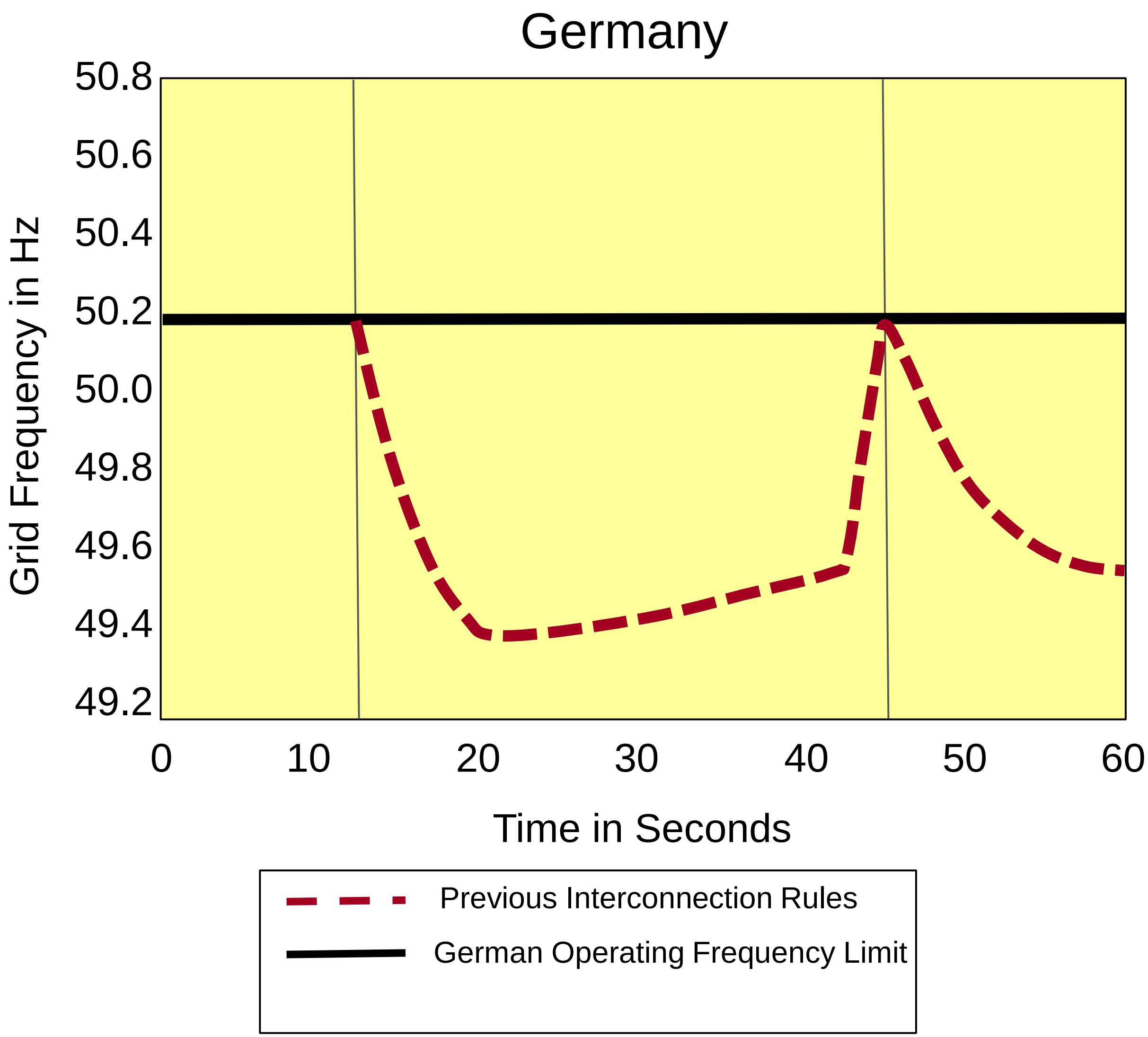
SOURCE: Sandip Sharma, ERCOT, "Frequency control requirements and performance in ERCOT ISO," presented at EPRI/NREL/PJM Inverter Generation Interconnection Workshop, Apr 11-12, 2012.

ERCOT – Measured Wind Generator's Response to High Frequency



SOURCE: Sandip Sharma, ERCOT, "Frequency control requirements and performance in ERCOT ISO," presented at EPRI/NREL/PJM Inverter Generation Interconnection Workshop, Apr 11-12, 2012.

Frequency Ride-Through: Risk of Wide-Spread PV Disconnection

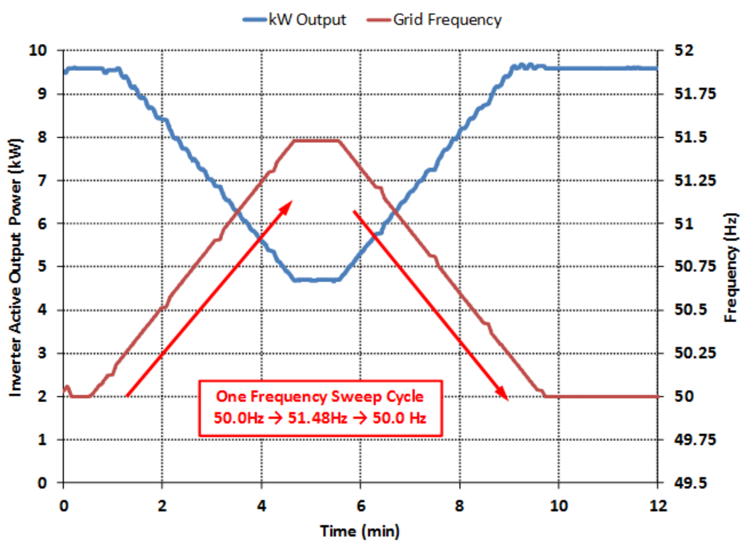


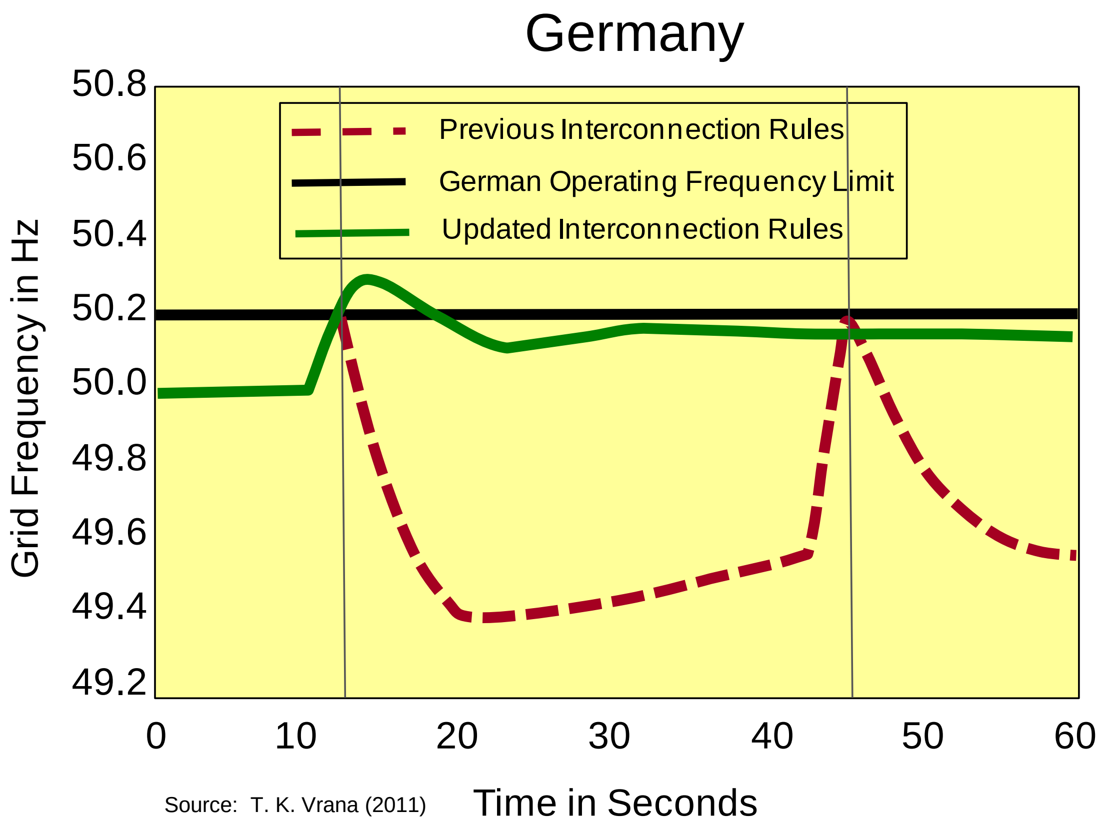
As of 2012 PV Inverters were not required to provide frequency support and disconnect from the grid if the frequency reaches 50.2 Hz

This is similar to all current interconnection requirements in US as per IEEE 1547-2003

Source: T. K. Vrana (2011)

Updated Interconnection Rules Reduces Risk of Frequency Instability





Source: T. K. Vrana (2011)

German Grid Code Change

Frequency control is required of all generators

Instead of disconnecting @50.2 Hz, gradually reduce active power output (droop curve) in proportion to the frequency

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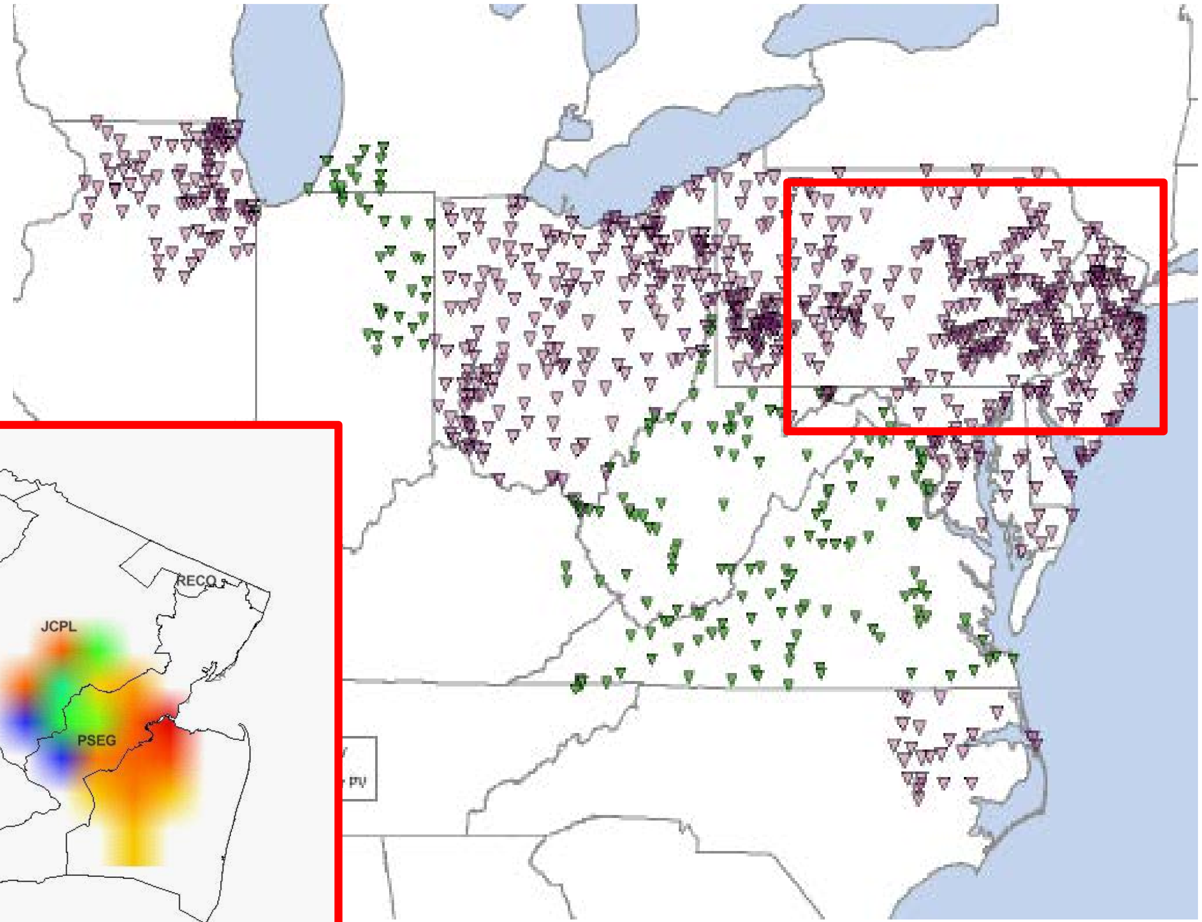
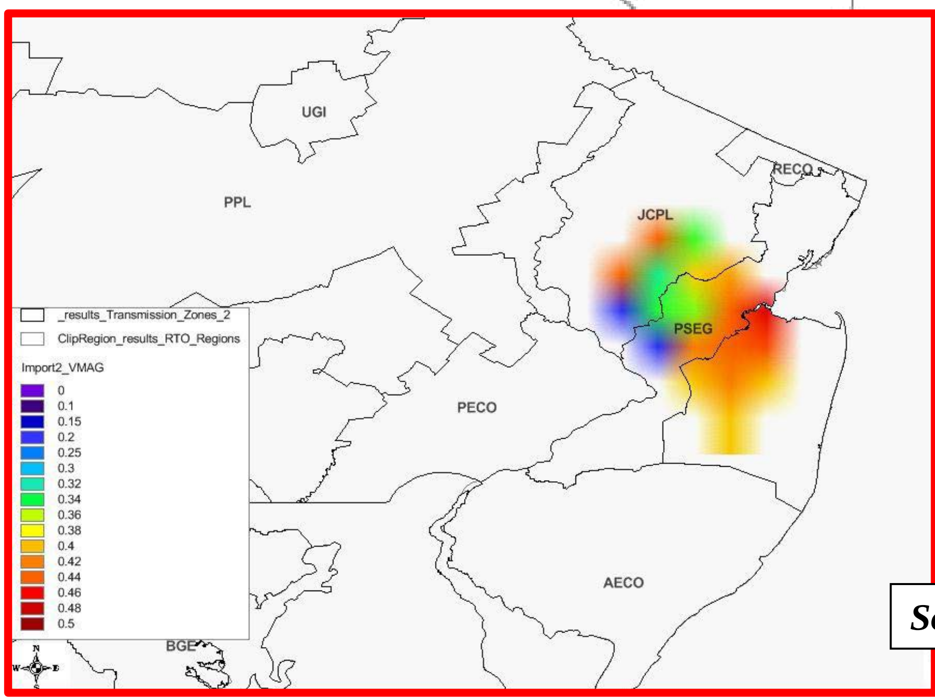
Distributed PV Low Voltage Ride-Through
PJM Example LVRT Impact

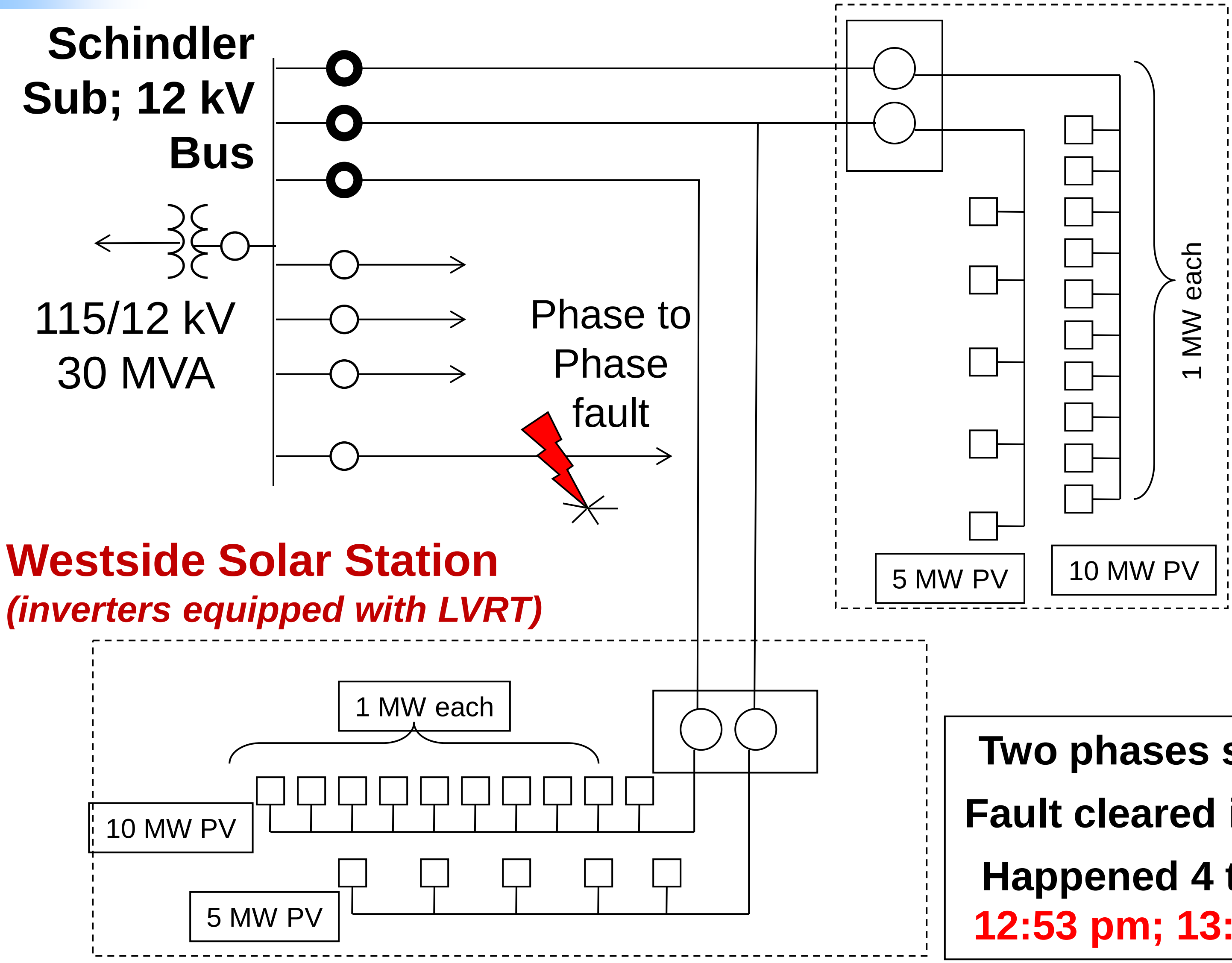




Source: Mahendra Patel, PJM.

LVRT – PG&E Experience

Pacific Gas and Electric Company



Five Points Solar Station

(inverters not equipped with LVRT)

March 17, 2012

Two phases slapped together

Fault cleared in 6 cycles (0.1 s)

Happened 4 times: 12:52 pm; 12:53 pm; 13:22 pm; 14:21 pm

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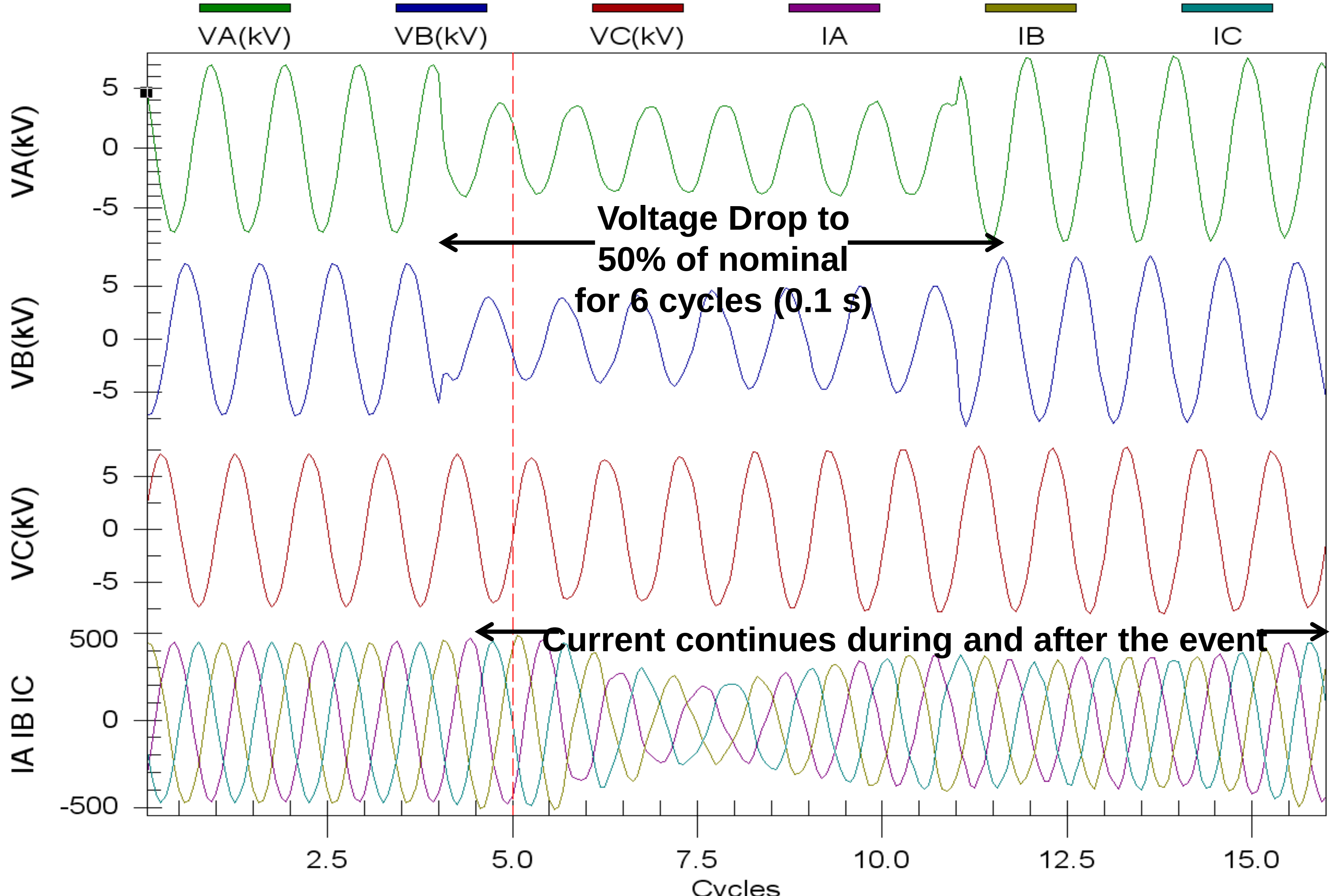
Westside Solar Station with LVRT

March 17, 2012 at 12:52pm

Pacific Gas and Electric Company



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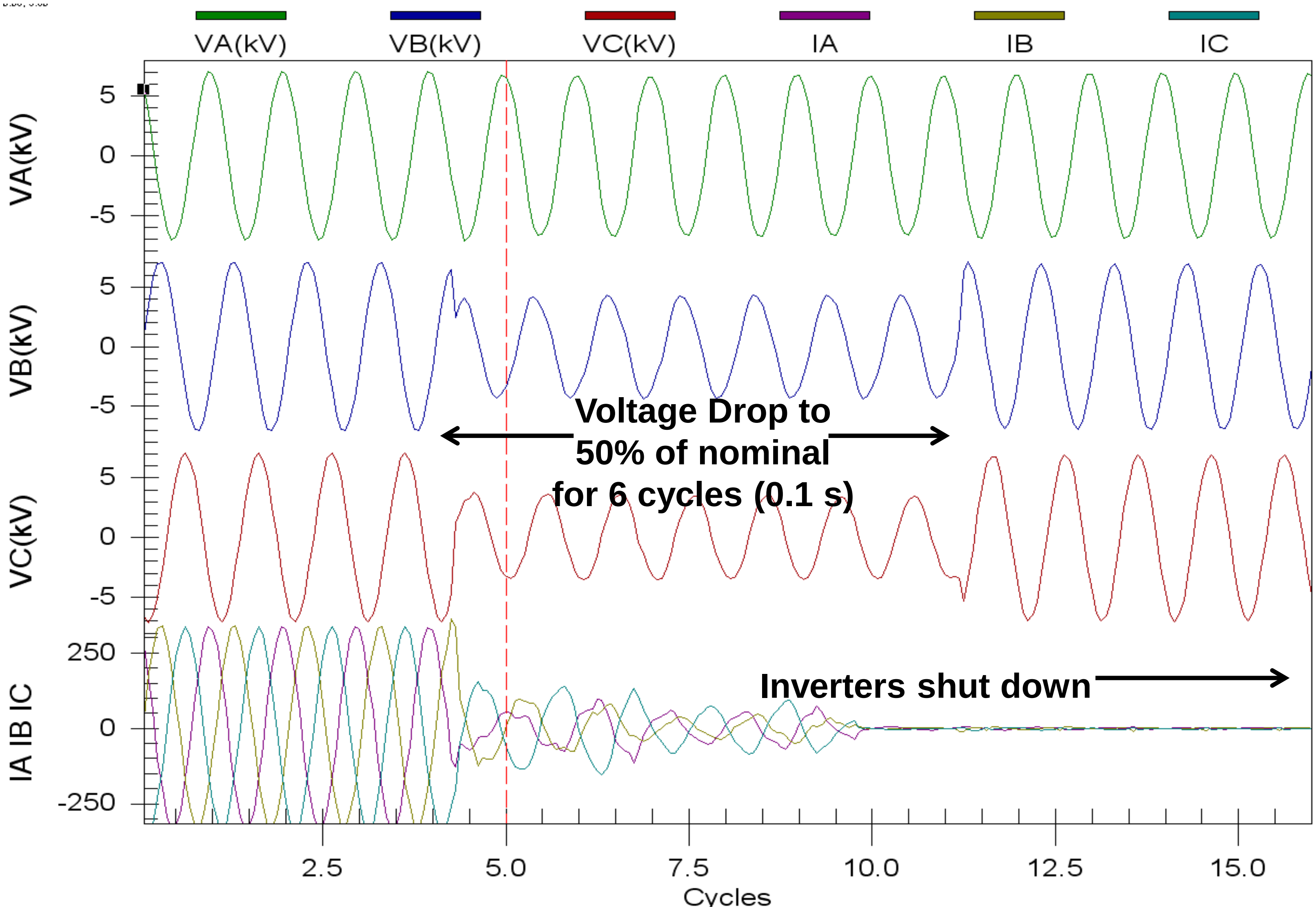
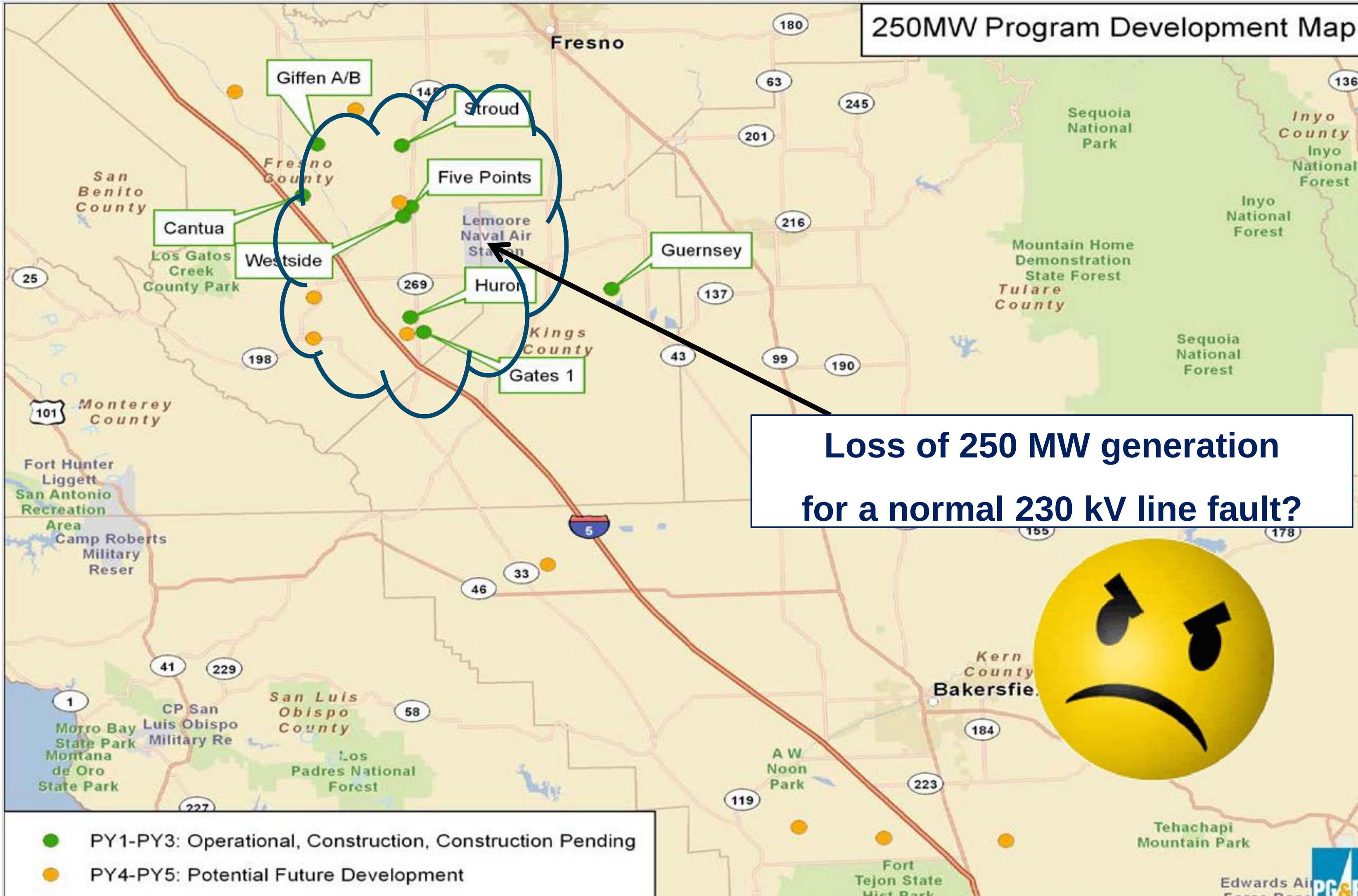
Five Points Solar Station w/o LVRT

March 17, 2012 at 12:52pm



Transmission Line Fault

Pacific Gas and Electric Company™



Loss of 250 MW generation

for a normal 230 kV line fault?

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Distribution Feeder Impacts and Inverter Support Benefits

March 31, 2014

Distribution System Impacts

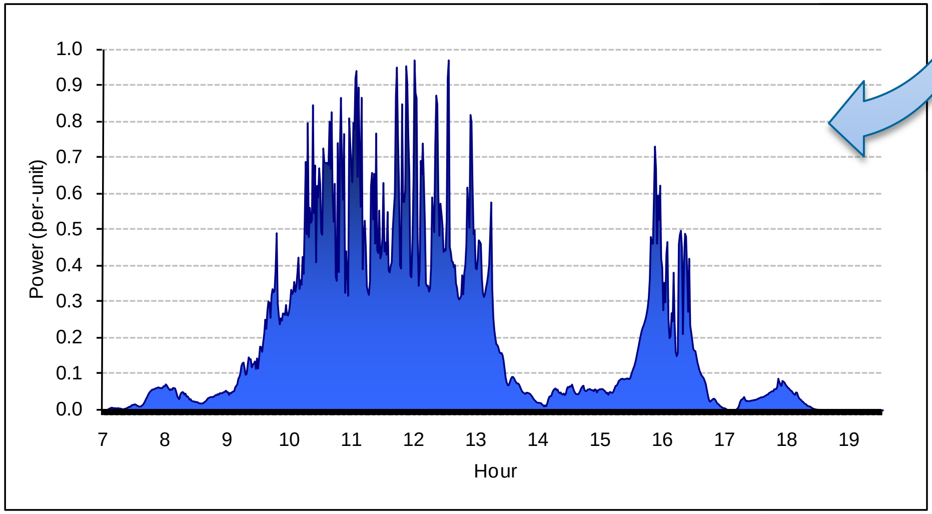
Voltage
- Overvoltage
- Voltage variations

Equipment Operation
- Feeder regulators
- Load tap changers
- Switched capacitor banks

Demand
- “Masking” peak demand
- Reducing power factor

System Protection
- Relay desensitization
- Unintentional islanding

Power Quality
- Harmonics

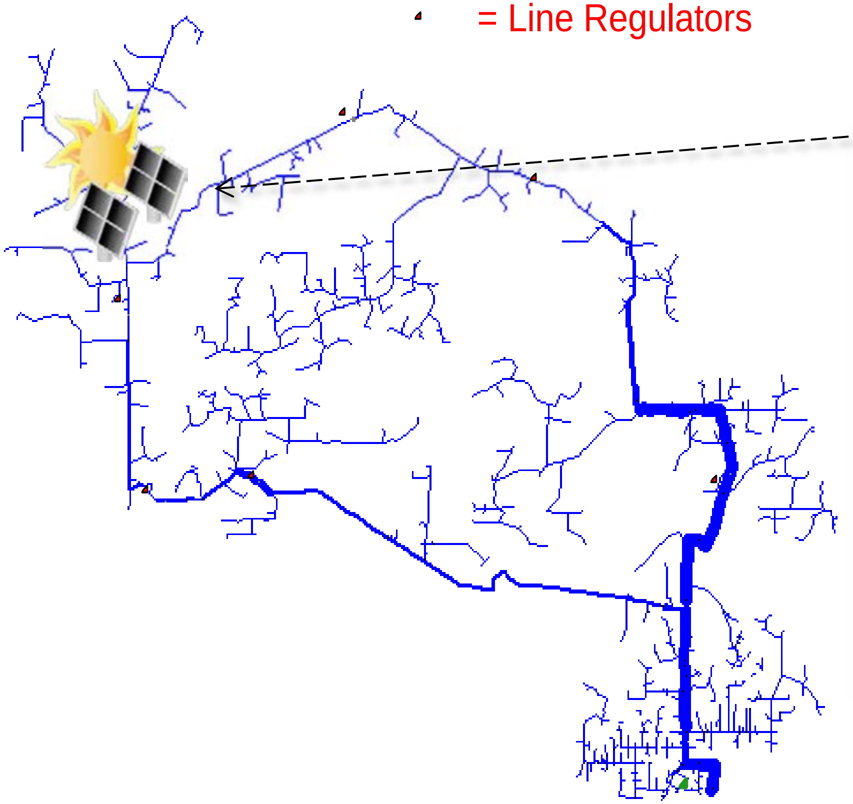


Why are Smart Inverters Important?

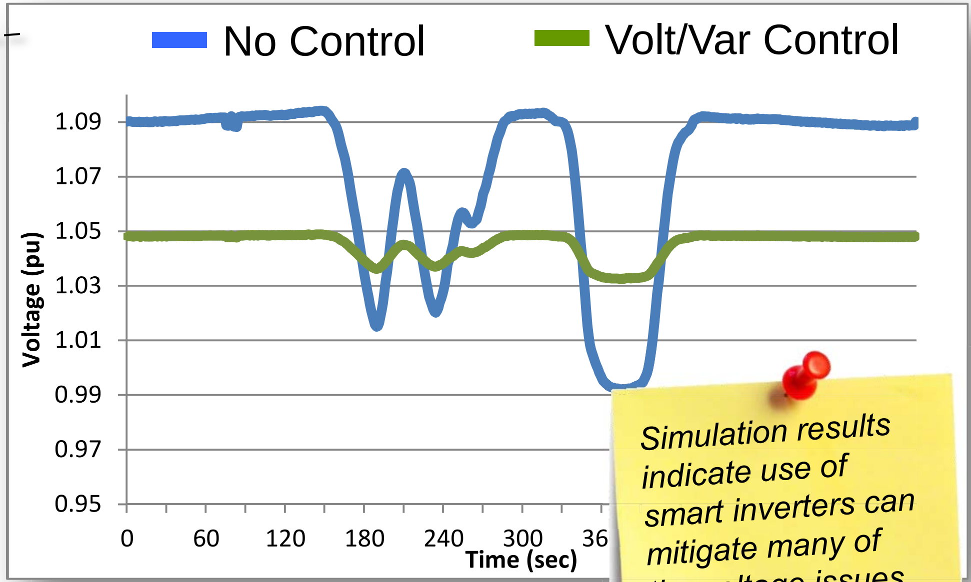
Smart Inverters Mitigating Voltage Issues

= Substation

= Line Regulators



Voltage at END of feeder



Simulation results indicate use of smart inverters can mitigate many of the voltage issues resulting from PV

*Simulated in OpenDSS

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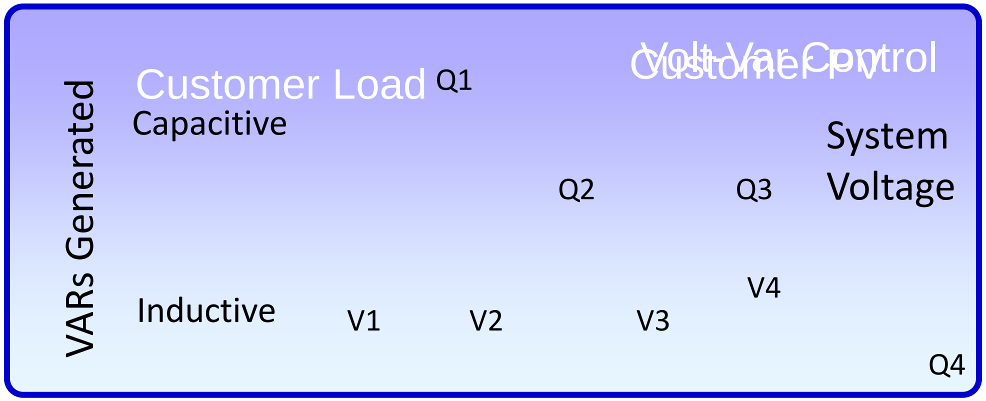
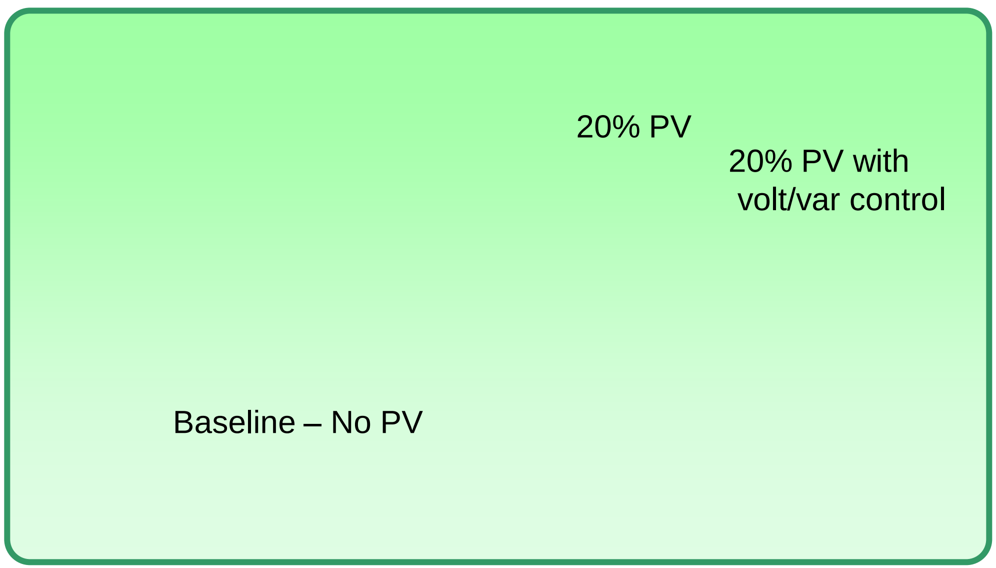
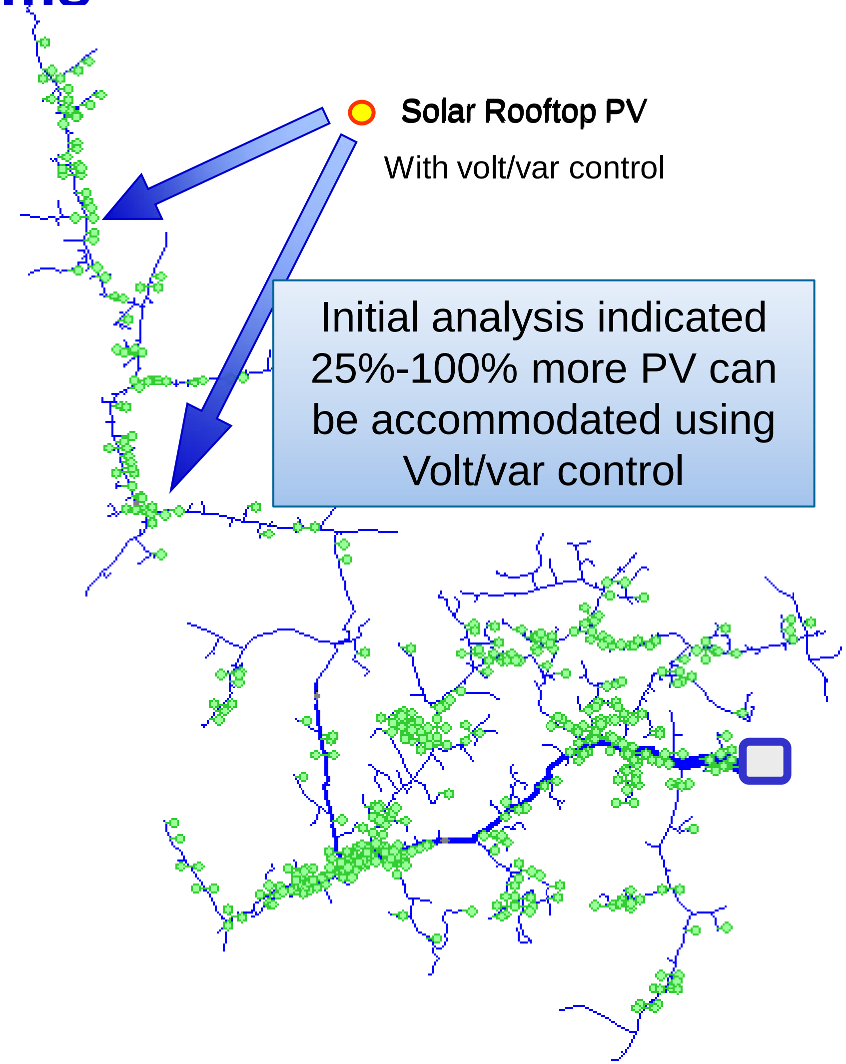
Use of Smart Inverters for Accommodating Large Number of Distributed PV Systems





24 Hour Simulation



Initial analysis indicated 25%-100% more PV can be accommodated using Volt/var control

Source: J. Smith, T. Key "High-Penetration PV Impact Analysis on Distribution Systems," Solar Power International, Oct 2011

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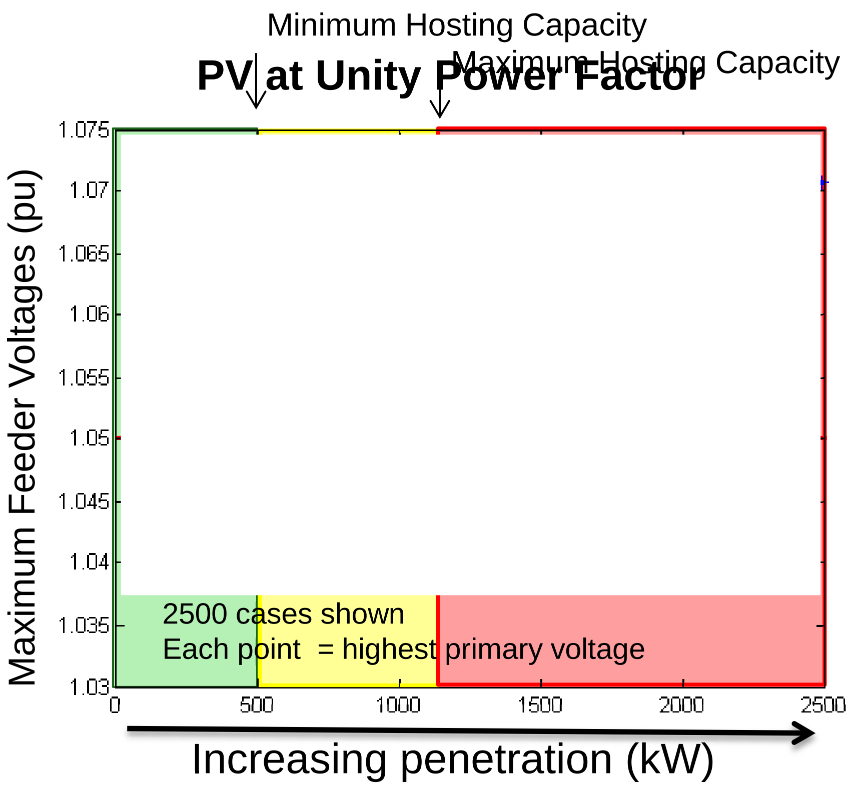
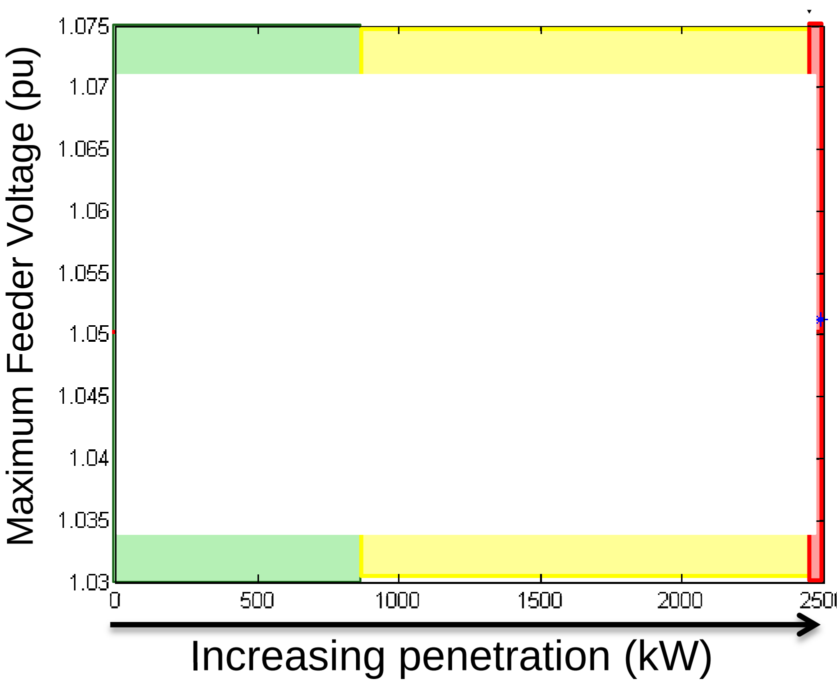
Smart Inverters for Increasing Hosting Capacity of Distributed PV





No observable violations regardless of PV size/location

Possible violations based upon PV size/location

Observable violations occur regardless of size/location

For voltage-constrained feeders, results indicate use of smart inverters can increase feeder hosting capacity for PV

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Cost Considerations for Advanced Inverter Functionality

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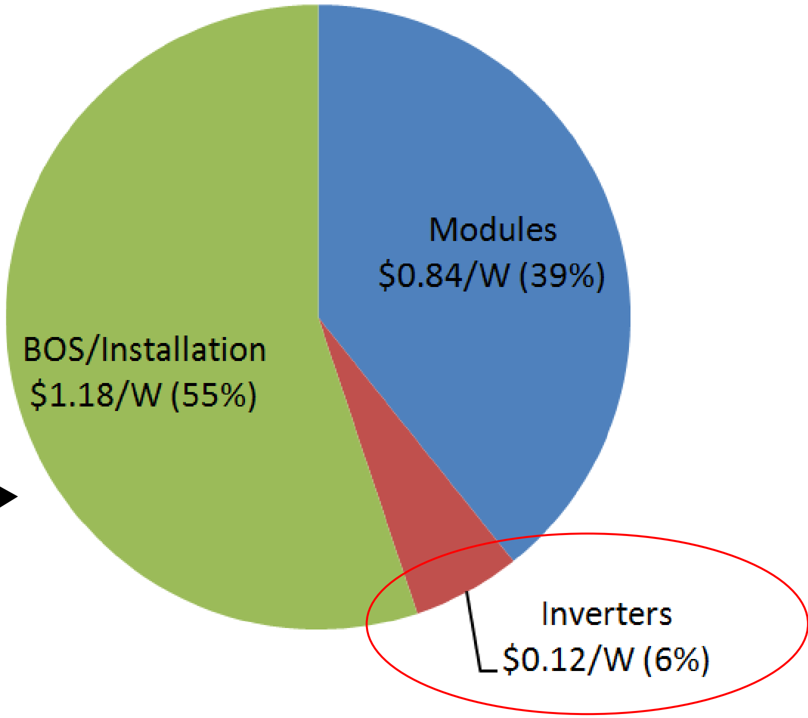
Inverter Cost and Reliability Impacts PV System Performance

- Inverter cost is a small percentage of the total plant cost/installed cost
- Inverters with grid support functions are not expected cost any higher than current price once the interconnection requirements start incorporating the functional capabilities
- Communication (where needed!) cost will be additional

Average U.S. Utility-Scale PV Price Breakdown (May 2013)



Q1 2013 US PV System Cost

Residential - $4.93/W

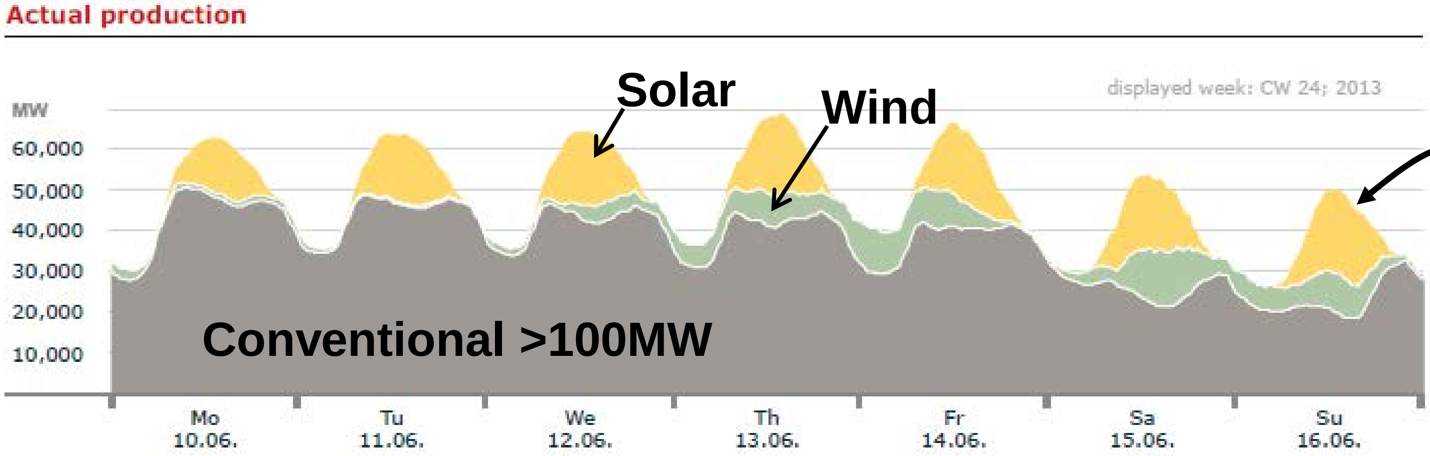
Commercial-scale - $3.92/W

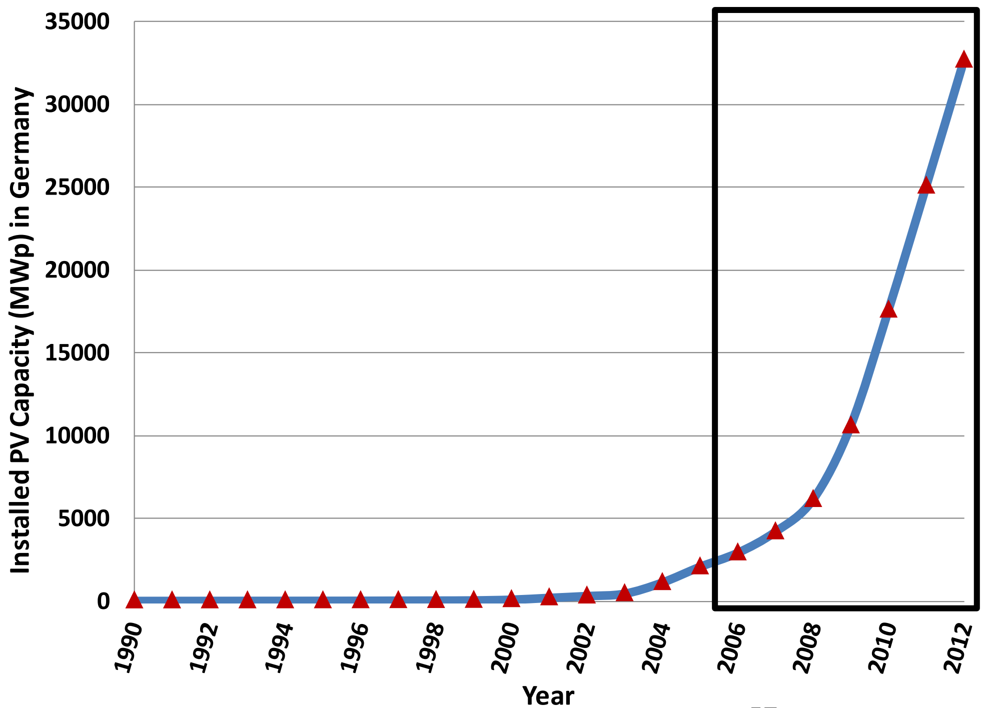
Utility-scale - $2.14/W

National average - $3.37/W

Sources: *Sources: GTM Research/SEIA, NREL, Lawrence Berkeley National Lab, BNEF, European Photovoltaic Industry Assn (EPIA), BSW Solar*

German Experience of High Penetration of PV





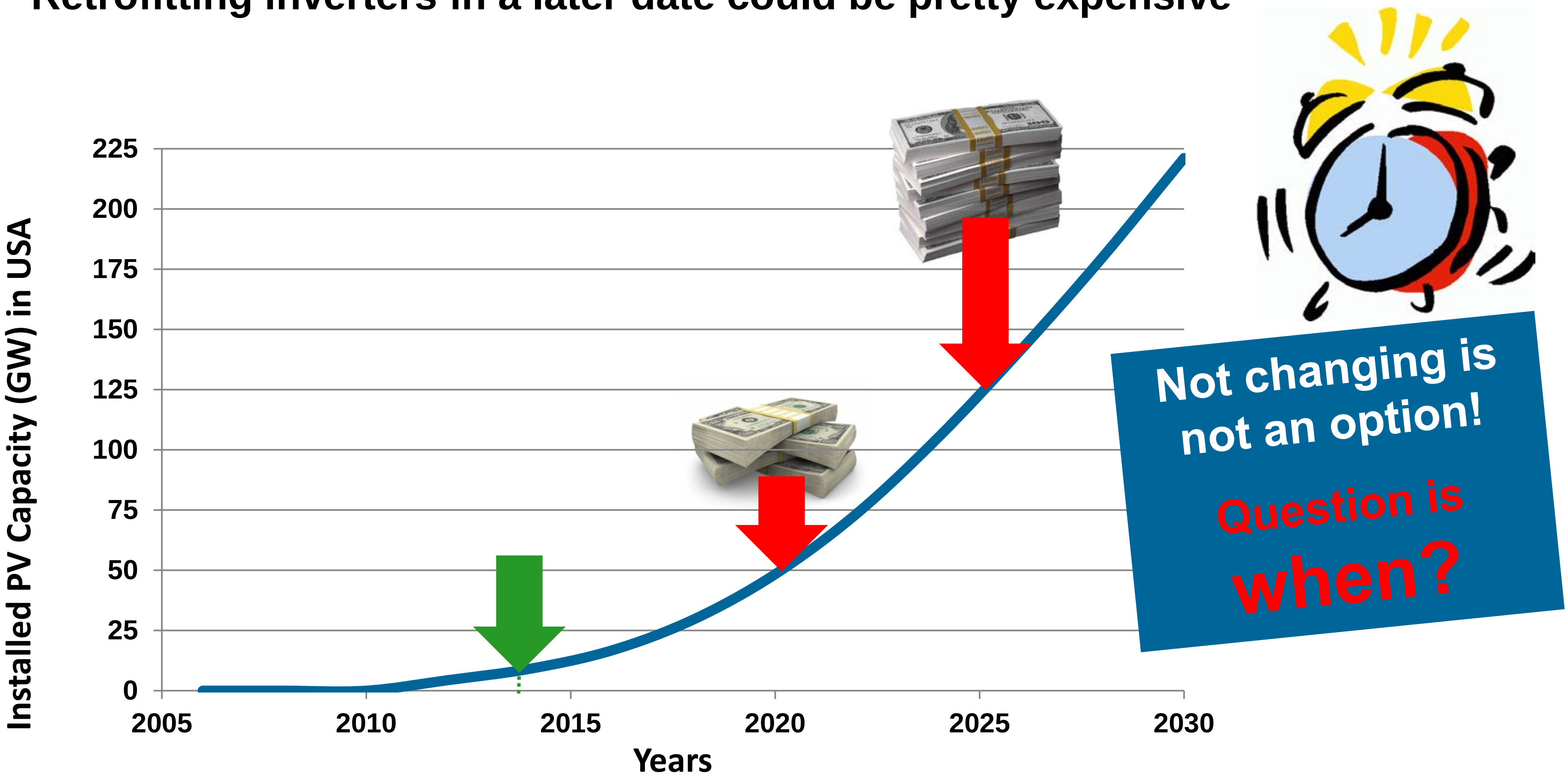
Bright, breezy Sunday between 2pm to 3pm

Grid at that time could take up to 45GW

PV and wind supplied 28.9 GW – more than half the total!

What if Standards are not Changed?

Retrofitting inverters in a later date could be pretty expensive



Source: DOE SunShot Vision Study (Total PV Capacity in U.S. 2008 – 2030)

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IEEE Standard 1547 Revision Apr 23-24 Meeting Overview

March 31, 2014

IEEE 1547 Full Revision – 1st WG Meeting Highlights

- Around 90 stakeholders joined the meeting
  - 50% plus were from utilities including NERC and FERC
  - 25% were from manufacturers
  - Remaining were testing labs, national labs, and consultants
- Need for inclusion of abnormal voltage and frequency must ride thru in the standard was clearly expressed by majority – *off course there were few exceptions*
- Different ride thru requirements for inverter and rotating machines?
- Remove or increase the standard's existing limitation to aggregate capacity of 10 MVA or less?
- Need for control, in addition to monitoring provision (for 250MVA and larger), beyond certain size (yet to be discussed) ?
- Revision is considering inclusion to two type tests – Short circuit & loss of load behavior test
- Next meeting (tentative) – June 24-25: 1547.1a & 26-27: Full rev. of 1547

  – Most likely again in Las Vegas

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