Results from the DOE-CPUC High Penetration Solar Forum

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DOE CPUC Forum

- First held on March 1st and 2nd, 2011
- Latest meeting February 13th and 14th, 2013
- Kevin Lynn: DOE
- Tina Eichner and Devonie McCamey: NREL
- Molly Sterkel and Melicia Charles: CPUC
- Ann Peterson: Itron
- Smita Gupta: Itron
- Format
  - Research needs from CA utilities
  - Presentation on DOE-CPUC research progress and findings
  - Discussion of remaining research gaps

Meeting Agenda

High Penetration Solar Forum 2013
Feb 13-14, San Diego, CA

A Joint CPUC - DOE Event

AGENDA

Day 1 – Wed, Feb 13, 2013

Time	Agenda/topic area	Speaker
7:30 – 8:30 am	Breakfast and Registration	
8:30 – 8:50 am	Welcome by UCSD	
8:50 - 9:10 am	Welcome by CPUC and Perspective	Melicia Charles, CPUC
9:10- 9:30 am	Welcome by DOE and Perspective	Kevin Lynn, DOE
9:30 - 10:30 am	CAISO and Utilities Perspective	Jim Blatchford, CAISO Thomas Bialek, SDG&E Robert Sherick, SCE Andrew Yip, PG&E
10:30 – 11:00 am	Morning break	
11:00 - 11:45 am	Solar Forecasting and Grid Integration	Jan Kleissl, UCSD
11:45 - 12:30 pm	Integrating PV into Utility Planning and Operation Tools	Tom Hoff, Clean Power Research
12:30 - 1:30	Lunch / Keynote Speaker	TBD
1:30 - 2:15 pm	High Penetration Solar PV Test Cases in the Florida Grid	Rick Meeker, FSU
2:15 -3:00 pm	HIP-PV: PV Visualization and Integration Update	Dora Yen Nakafuji, HECO and Elaine Sison-Lebrilla, SMUD
3:00 - 3:30 pm	Afternoon Break	
3:30-4:15 pm	Evaluation of High Penetration PV on Distribution Circuits	Jack Brouwer and Josh Payne, UCI
4:15 - 5:00 pm	Modeling, Simulation, Testing and Demonstration of A 500kW Commercial Roof-Top PV System on SCE's Distribution System	Barry Mather, NREL
5:00 – 6:30 pm	Reception	

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Day 2 – Thurs, Feb 14, 2013

Time	Agenda/topic areas	Speaker
7:30 – 8:30 am	Breakfast and Registration	
8:30 – 9:15 am	Alternative Screening Methods PV Hosting Capacity in Distribution Systems	Tom Key and Jeff Smith, EPRI
9:15 – 10:00 am	High Penetration of Photovoltaic Generation Study – Flagstaff Community Power	David Narang, Arizona Public Service
10:00 - 10:30 am	Morning Break	
10:30 - 11:15 am	Value of Energy Storage With PV – Initial Findings	Mark Rawson, SMUD
11:15 - 12:00 pm	High-Penetration PV Modeling, Monitoring, and Analysis	Jason Lai, Virginia Polytechnic Institute
12:00 – 12:45 pm	• Plug-and-Play Solar Photovoltaics for American Homes • Cost Effective Residential Plug and Play Photovoltaic System	• Christian Hoepfner, Fraunhofer • Doug Danley, North Carolina State University
12:45 - 1:45 pm	Lunch / Keynote Speaker	TBD
1:45 - 2:30 pm	Development and Demonstration of Smart Grid Inverters for High-Penetration PV Applications	Leon Roose, University of Hawaii
2:30 – 3:15 pm	Transforming PV Installations Toward Dispatchable, Schedulable Energy Solutions	Michael Mills-Price, AE Solar
3:15 – 3:30 pm	Recent DOE Solar Forecasting Awards	Kevin Lynn, DOE
3:30 – 4:00 pm	Final Discussion and Wrap-up Closing Remarks and Next steps	CPUC DOE

CSI RD&D Program

- SB1 signed in 2006: CPUC established CSI RD&D Program in 2007
  - Allocated $50 million for research, development, demonstration and deployment (RD&D) projects to further the overall goals of the CSI Program
  - Adopted the "CSI RD&D Plan"
- CSI RD&D Plan established:
  - Goals and objectives
  - Allocation guidelines for project funding
  - Criteria for solicitation, selection and project funding
- Three Target Areas Established for Program Funding:
  - Grid-Integration: 50-65%
  - Production Technologies: 10-25%
  - Business Development and Deployment: 10-20%
- **CSI RD&D TimeLine To-Date:**

2007 CSI RD&D Adopted by CPUC → **2008** CPUC Selected RD&D Program Manager (Itron) → **2009** Program released two solicitations → **2010** CPUC authorized 18 new grants → **2011** Program released Third Solicitation → 2012 CPUC authorized 7 new grants

CPUC Funding for Grid Integration

- Research is being conducted in the following areas:
  - Solar resource models with improved resolution
  - Assessing impacts of high penetration PV
  - Identifying high value locations for PV
  - Utility models and visualization tools for high penetration PV
  - Integration of solar resource models into grid operation models and planning tools
  - Utility interconnection
- Total of 16 projects with grid integration research
  - 11 projects have primary focus on grid integration
  - 5 projects have secondary focus on grid integration
- To date, over $16 million allocated to research on grid integration

Target Area 1:

Primary Focus on Grid Integration: High Penetration PV

Project Title	Awardee	Partners	Funding	Match
Advanced Modeling and Verification for High Penetration PV	Clean Power Research	NREL, SUNI, NYSERDA, SEPA, SMUD, LIPA, SRP	$ 976,392	$ 543,000
High Penetration PV Initiative	Sacramento Municipal Utility District	HECO, BEW, NREL, EPRI, New Energy Options, Areva, SCS, Augustyn, SynerGEE	$2,073,232	$1,623,859
Analysis of High-Penetration Levels of PV into the Distribution Grid in CA	SCE / NREL	CPR, Electrical Distribution Design, Satcon, NREL	$1,600,000	$1,400,000
Planning and Modeling for High-Penetration PV (partial project)	SunPower Corporation	KEMA, CAISO AWST, Sandia National Lab	$1,000,000	$ 320,000
Improving Economics of Solar Power Through Resource Analysis, Forecasting and Dynamic System Modeling	UC San Diego	EPRI, EDSA Power Analytics, CAISO, SDG&E, NREL	$ 548,147.54	$ 140,839
Development and Analysis of a Progressively Smarter Distribution System	UC Irvine - APEP	PG&E	$ 300,000	$ 100,000
Tools Development for Grid Integration of High Penetration PV	BEW Engineering	SMUD, HECO/MECO/HELCO, PG&E, Roseville Electric	$964,500	$964.500
Quantification of Risk of Unintended Islanding and Re-Assessment of Interconnection	General Electric International, Consulting	PG&E	$629,100	$816,200
Screening Distribution Feeders: Alternatives to the 15% Rule	Electric Power Research Institute	NREL, Sandia, CPR, PG&E, SCE, SDG&E, SMUD	$1,978,239	$1,978,239
Integrating PV into Utility Planning and Operation Tools	Clean Power Research	CAISO, UCSD, EPRI, SUNY, SEPA	$852,260	$875,000
High-Fidelity Solar Forecasting Demonstration for Grid Integration	UC San Diego	SDG&E, Green Power Labs, CAISO	$1,548,148	$1,548,148

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DOE High Penetration Solar Deployment Projects

Solicitation	Project Title	Awardee	Partners
High Penetration Solar Deployment	Community Power Project in Flagstaff, Arizona	Arizona Public Service Company	General Electric, Arizona State University, NREL, ViaSol Energy Solutions
High Penetration Solar Deployment	Sunshine State Solar Grid Initiative (SUNGRIN)	Florida State University Center for Advanced Power Systems (FSU CAPS)	
High Penetration Solar Deployment	Analysis of High-Penetration Levels of PV into the Distribution Grid in CA	National Renewable Energy Laboratory (NREL)	Southern California Edison (SCE), Quanta Technology (QT), Clean Power Research (CPR), Electrical Distribution Design (EDD)
High Penetration Solar Deployment	PV and Storage at Anatolia, California	Sacramento Municipal Utility District (SMUD)	Navigant, GridPoint, SunPower Corp., NREL, California Energy Commission
High Penetration Solar Deployment	Improved Modeling Tools for High Penetration Solar	UC San Diego	California ISO, EDSA Power Analytics, California Energy Commission
High Penetration Solar Deployment	High Penetration Photovoltaic Impacts and Advanced Power Conditioning	Virginia Tech	Electric Power Research Institute, Baylor University
Plug and Play Photovoltaics	Plug and Play Solar Photovoltaics for American Homes	Fraunhofer USA	Lumeta Solar, Petra Solar, Schletter, Inc., City of Boston, Green Mountain Power, Sandia National Laboratories
Plug and Play Photovoltaics	Development of a Low-Cost Residential Plug and Play PV System	North Carolina State University FREEDM Center	NRECA, University of Toledo, Isofoton North America, ABB, Quanta Technology
Solar Forecasting	Watt-Sun: A Multi-Scale, Multi-Model, Machine Learning Solar Forecasting Technology	IBM	Argonne National Laboratory, Arizona Research Institute for Solar Energy, National Renewable Energy Laboratory, Others
Solar Forecasting	A Public-Private-Academic Partnership to Advance Solar Power Forecasting	University Corporation for Public Research	National Renewable Energy Laboratory, Brookhaven National Laboratory, Penn State University, Colorado State University, University of Hawaii, University of Washington, University of Central Florida, Others

California ISO by the Numbers

- **58,698** MW of power plant capacity
  - 5,806 MW of wind
  - 1,345 MW of solar
- **50,270** MW record peak demand (July 24, 2006)
- **26,500** market transactions/day
- **25,627** circuit-miles of transmission lines
- **30 million people** served
- **309 million** megawatt-hours of electricity delivered annually

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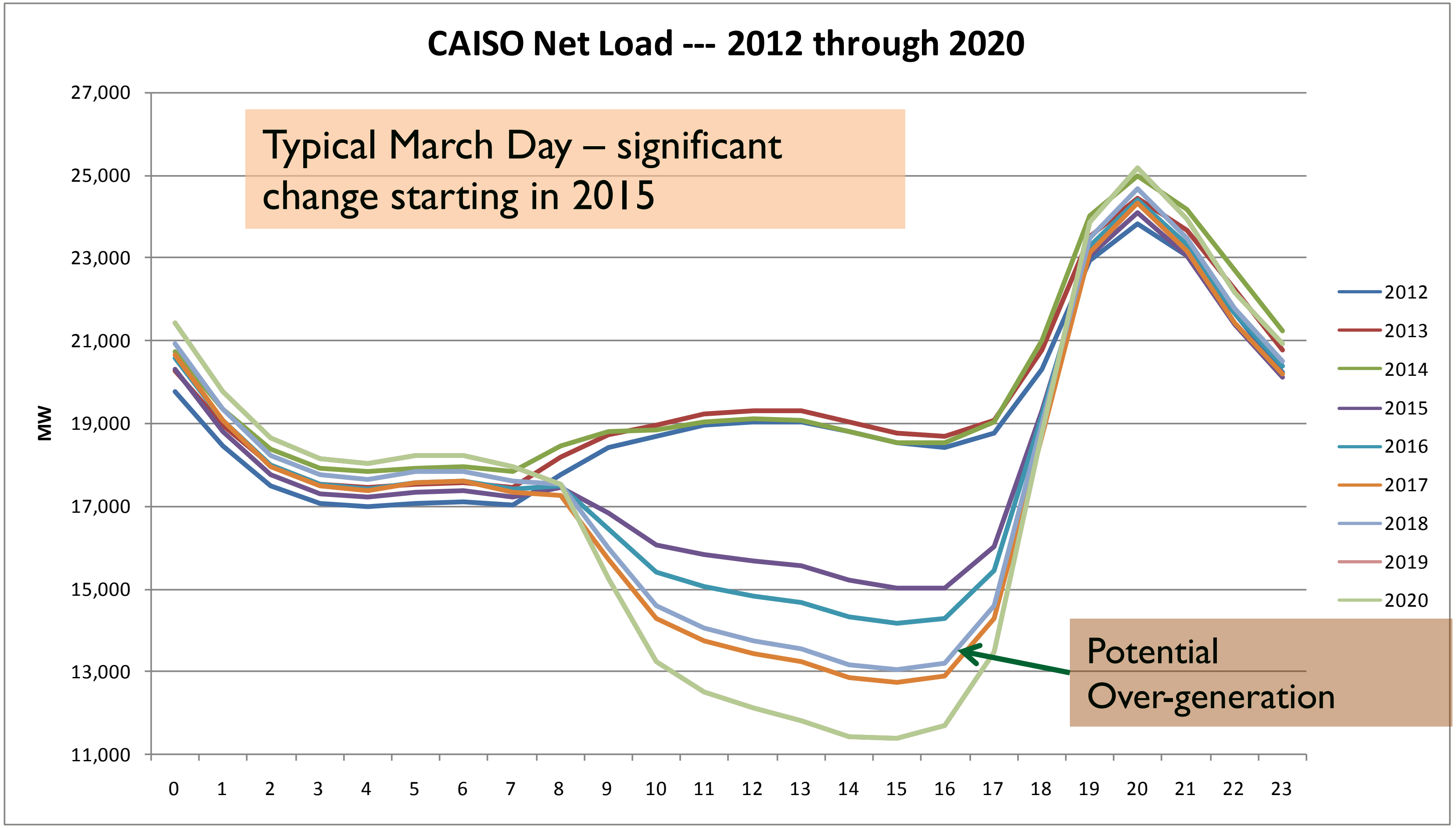
Net Load Pattern Changes Significantly Starting in 2015



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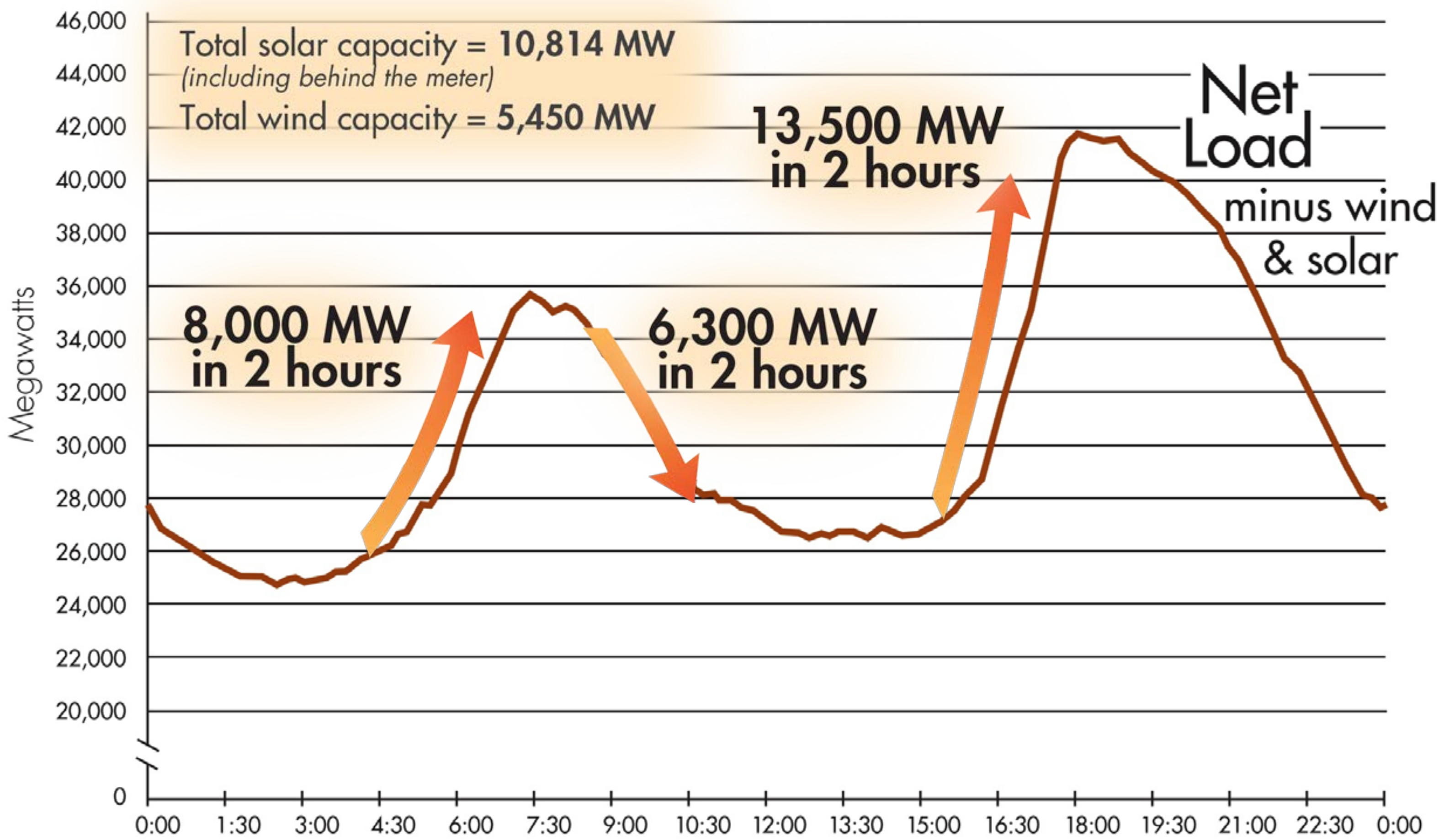
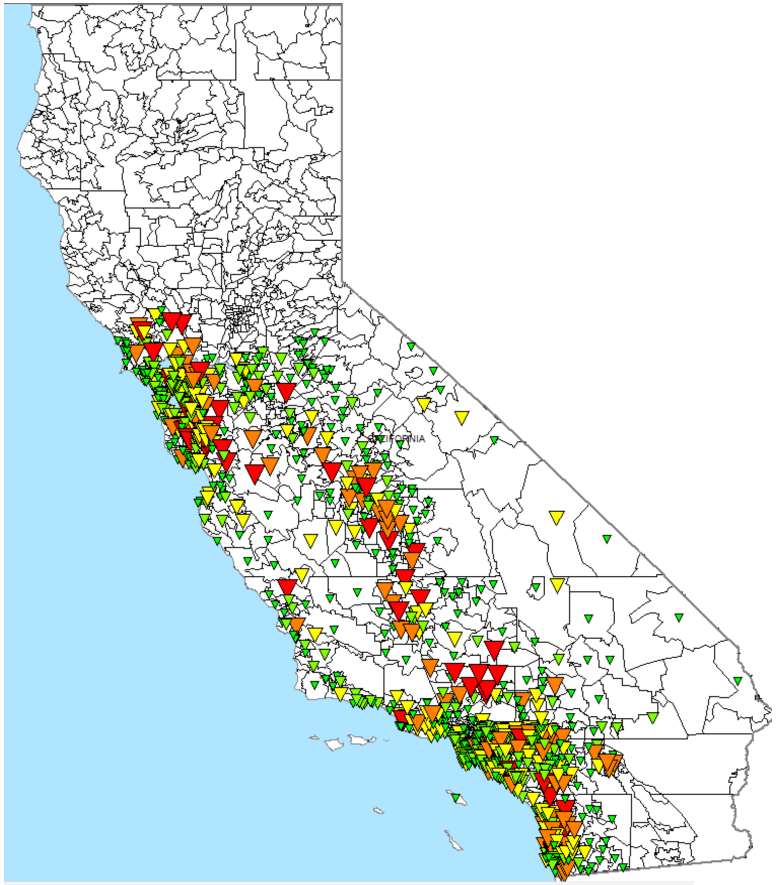
Flexible Resources Will Be Essential to Meeting the Net Load Demand Curve



Distributed Generation Adds to the Changes in the Load Profiles



- Gov. Brown initiative to install 12,000 MW of distributed generation
- 1,555 MW of rooftop solar installed to date
- Limited ISO production visibility

Dots on the map include rooftop and ground-mounted solar, small and community wind, small biomass/biogas production, combined heat and power, and other such local renewables.

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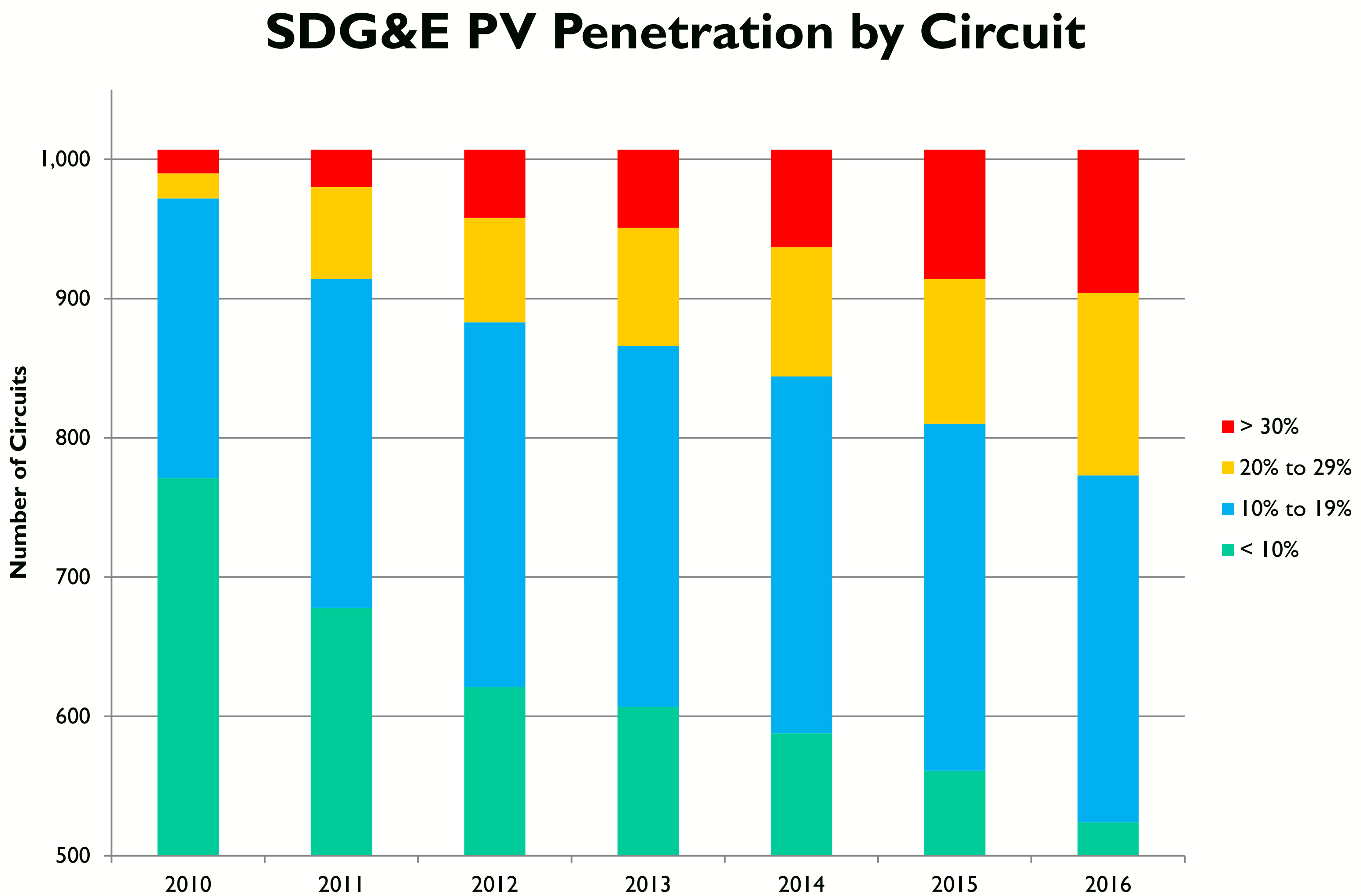
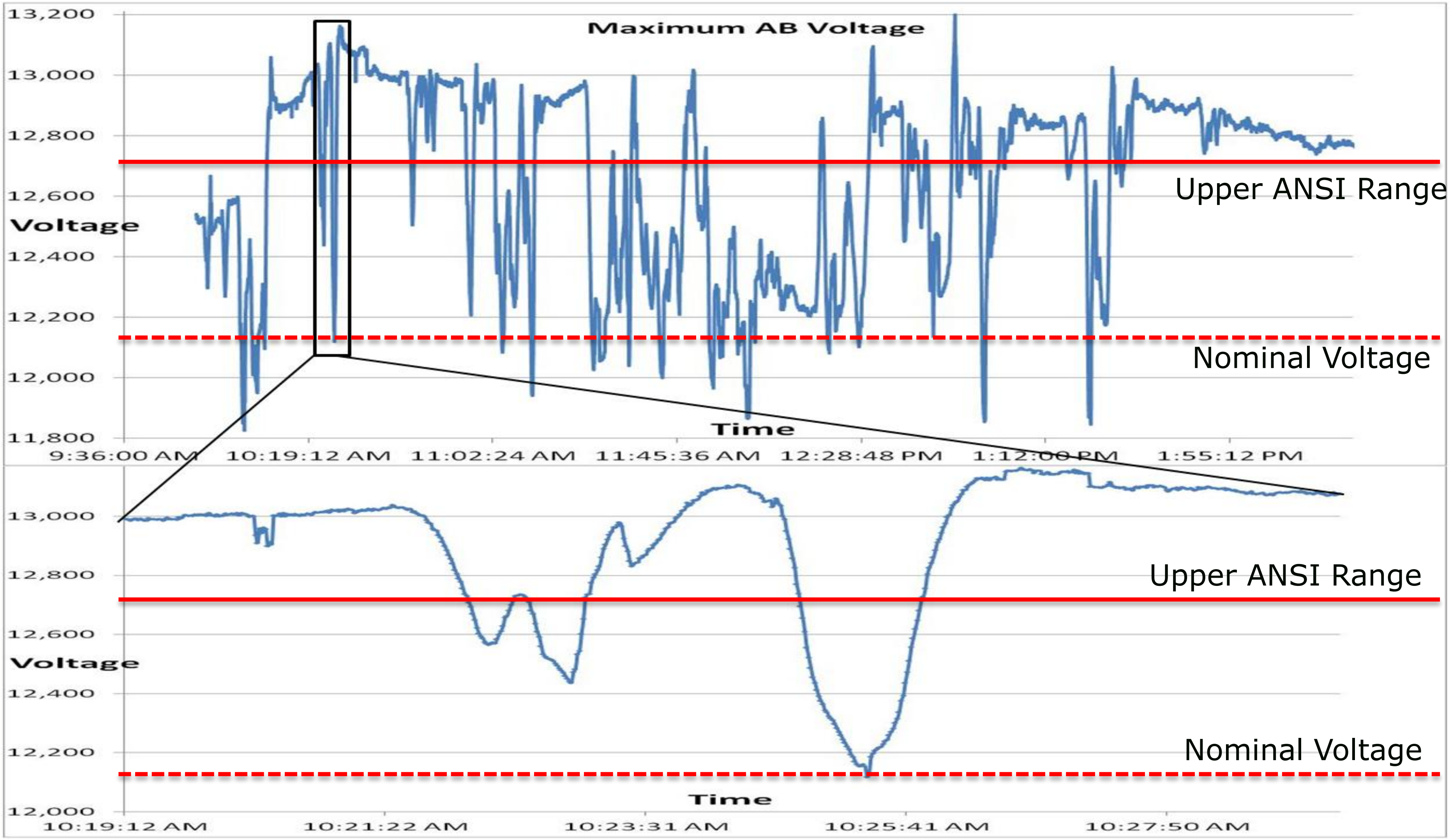
Rooftop PV Generation



PV Issues - Voltage



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Inverter Functions Needed

Desired inverter characteristics:

- Under-frequency trip point
- Low voltage ride through
- Real and reactive power support
- Dynamic VAr injection
- Communications capability

Benefits:

- Operating at various power factors may enable generators to avoid upgrades
- Industry will benefit from improved inverter functionality

Service Standards: Utilities (SDG&E) will develop Service Standards to define interconnection requirements and facilitate interconnection or PV/wind generators

Distribution Grid Integration

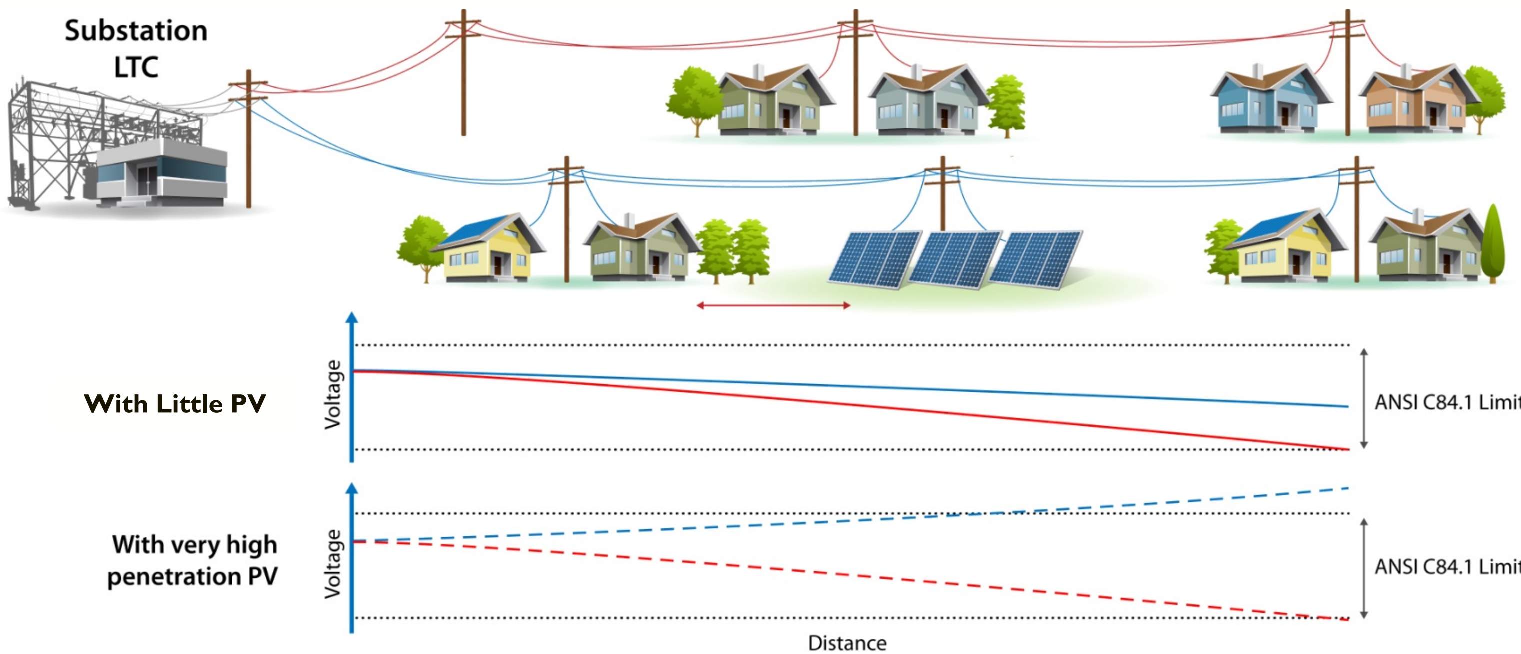
Key Challenges

Voltage	• Overvoltage • Voltage deviations @ regulation equipment • Unbalance
Protection	• Increased fault current contribution • Sympathetic tripping + fuse saving • Two-way power flow
Unintentional Islanding	•Safety, IEEE 1547 series, anti-islanding scheme •Transient overvoltage •Out of phase reclosing and decrease reliability
Distribution Modeling Tools	•Quasi Static Time Series Analysis •Hosting Capacity, Feeder Classification •Feeder monitoring devices, Interoperability
Visibility and Control	•Traditional Voltage Regulation Equipment •Smart Inverters •Holistic control across the feeder
Interconnection Process	•IEEE 1547 series and other standards •SGIP screens, 15% rule •Utility Planning tools

Voltage Regulation

Voltage Rise Issue

- When high level of PV power is injected where load is normally served, voltage at that location will **increase**
- **Voltage rise effect** depends on:
  - Feeder characteristics (voltage rating, conductor size, material, hosting capacity, etc.)
  - **Location** of PV on the feeder:
    - **GOOD** – **closer** to substation due to higher ampacity conductor, lower impedance, "stiffer," and voltage control equipment
    - **BAD** – away from substation due to decrease "stiffness," lower ampacity conductor, higher impedance and less voltage control equipment



Source: White paper – Updating Interconnection Screens for PV System Integration

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Voltage Regulation

Interaction with Load Drop Compensators

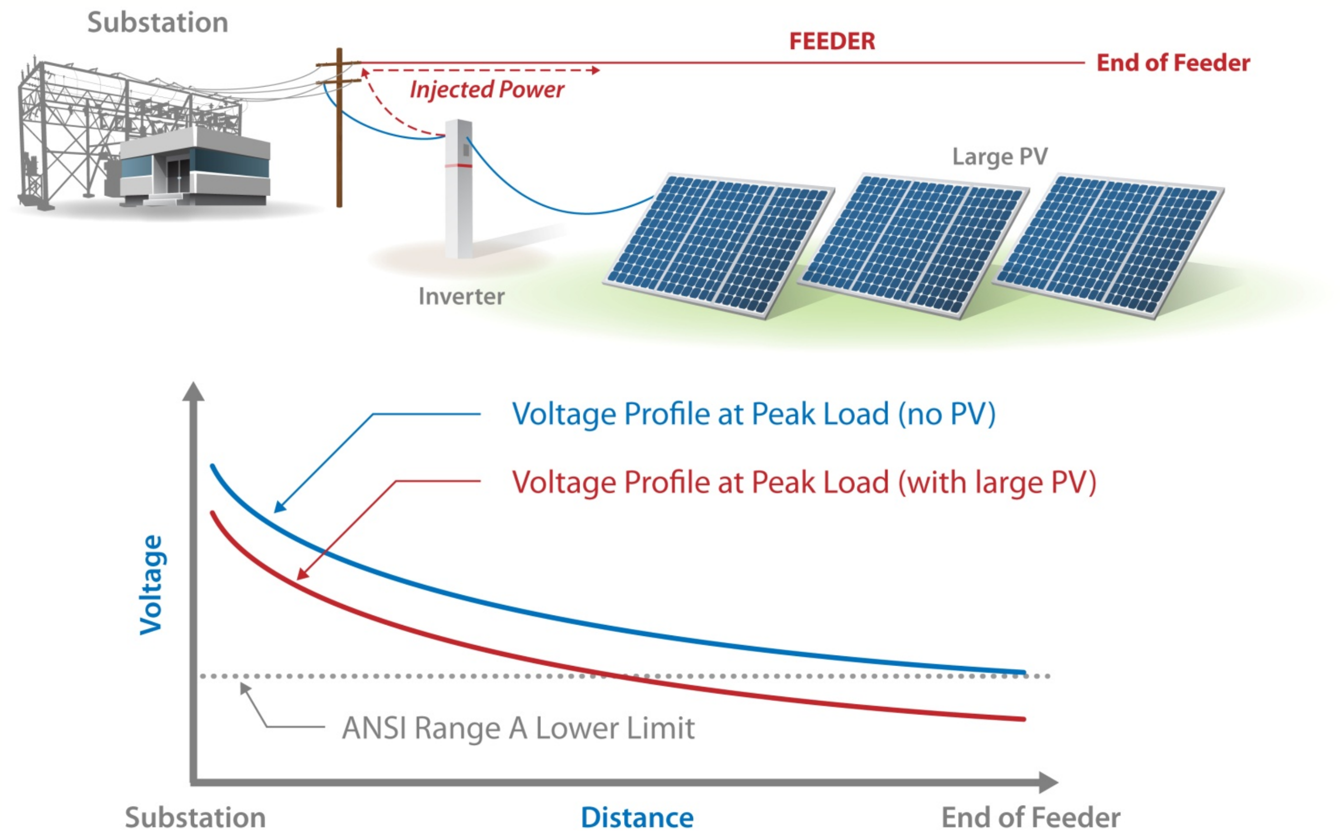

Figure 2.2. Line drop compensation-controlled voltage regulator allows undervoltage at the end of the feeder when the PV generator injects power

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Inverter Tripping in High PV Penetration Scenario

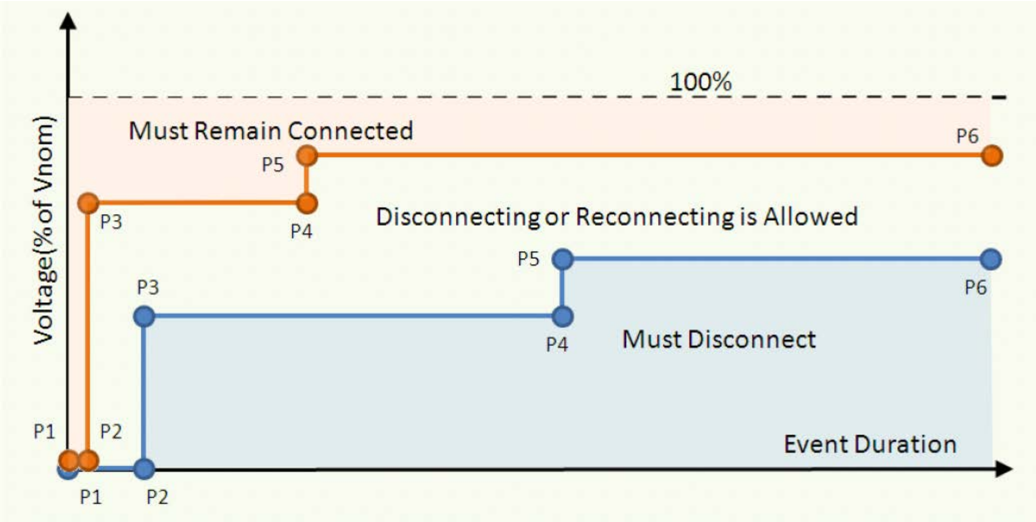
- Problem

According to current IEEE standards

  - Large amount of PV inverter will trip off due to grid voltage and frequency disturbances
  - Causing more imbalance between generation and load
  - As a result, backup generators have to ramp up to support the load

- Solutions
  - Low Voltage Ride Through (LVRT)
  - High Voltage Ride Through
  - Frequency Ride Through

Example LVRT Curve



Protection Coordination

Nuisance or Sympathetic Trips

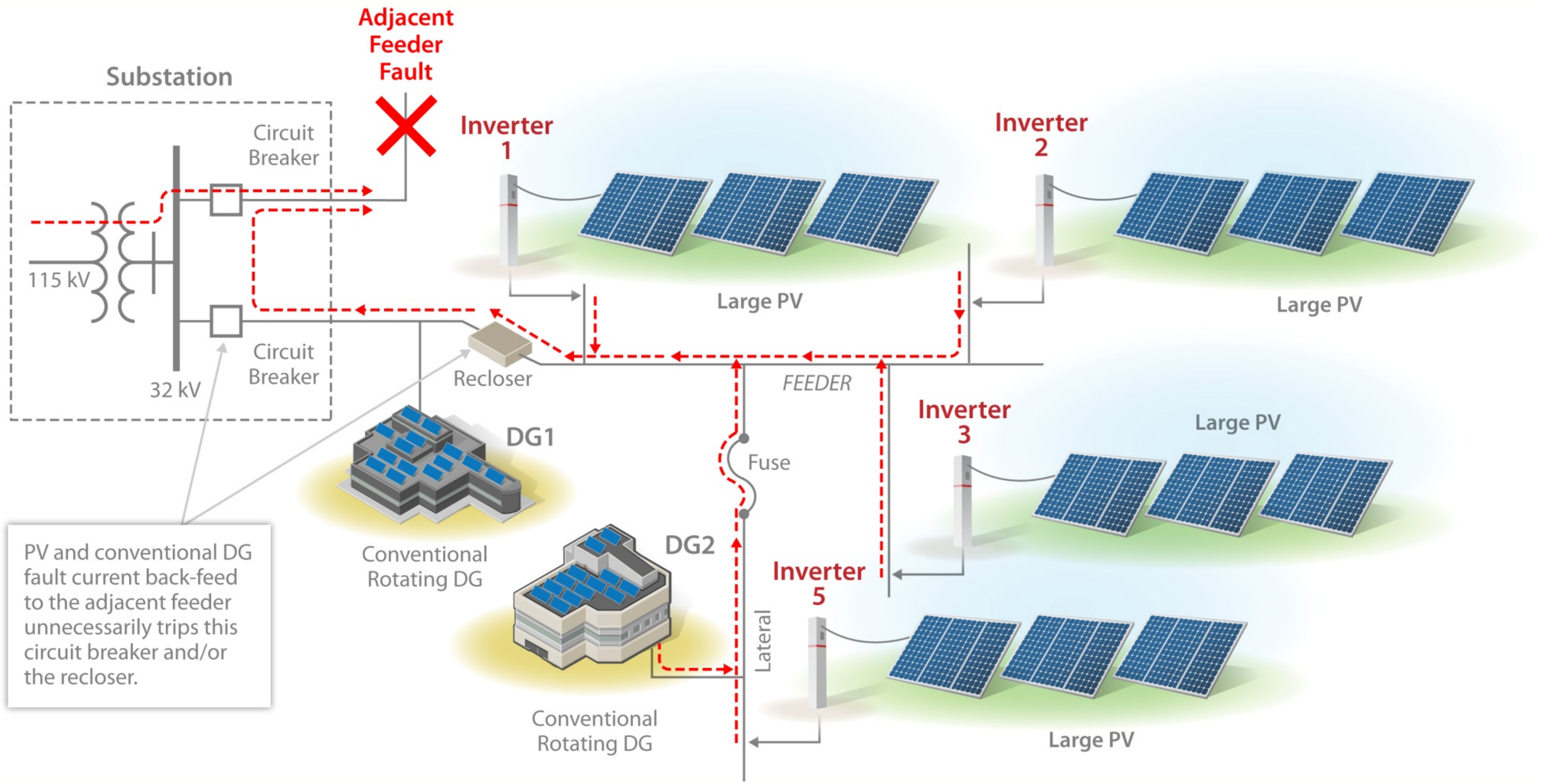


Figure 2.8. Example of how high penetration of DG can cause nuisance trips

Protection Coordination

Effect on Utility Fuse-Saving Scheme

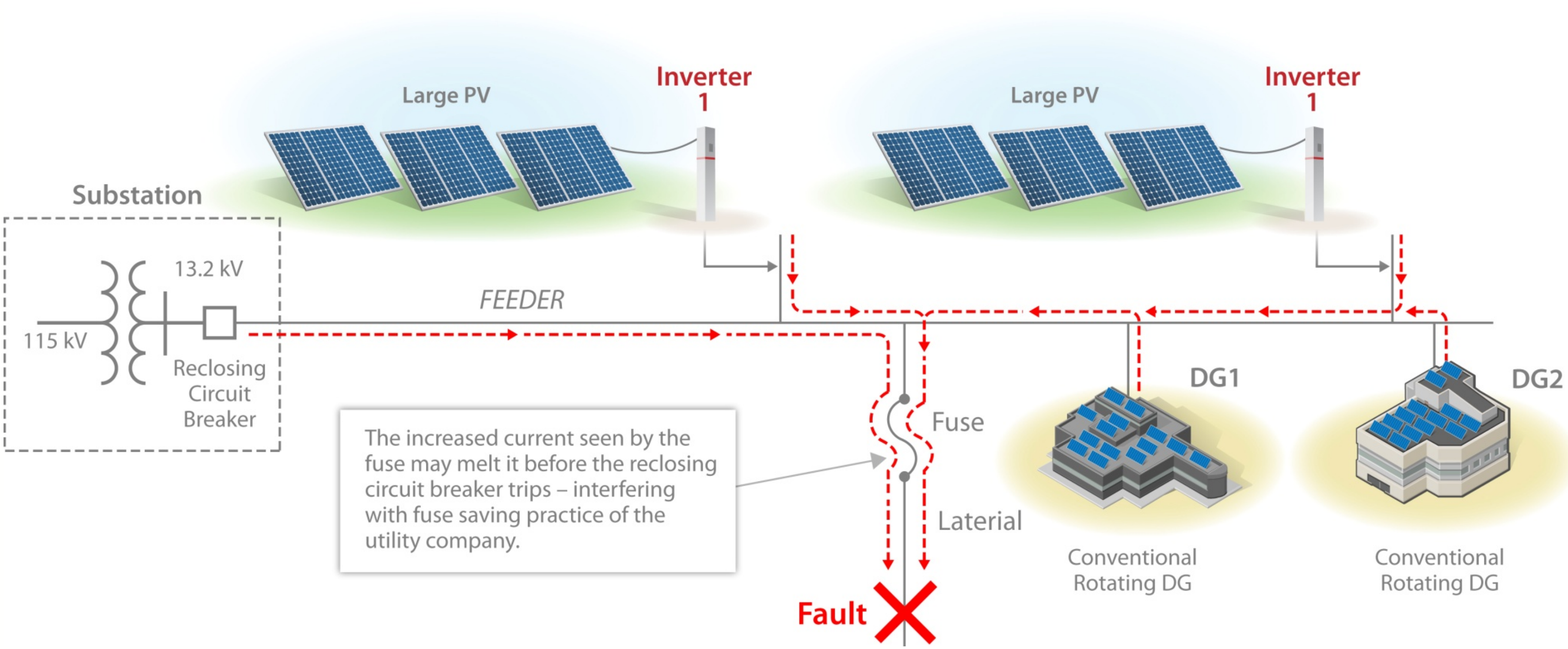
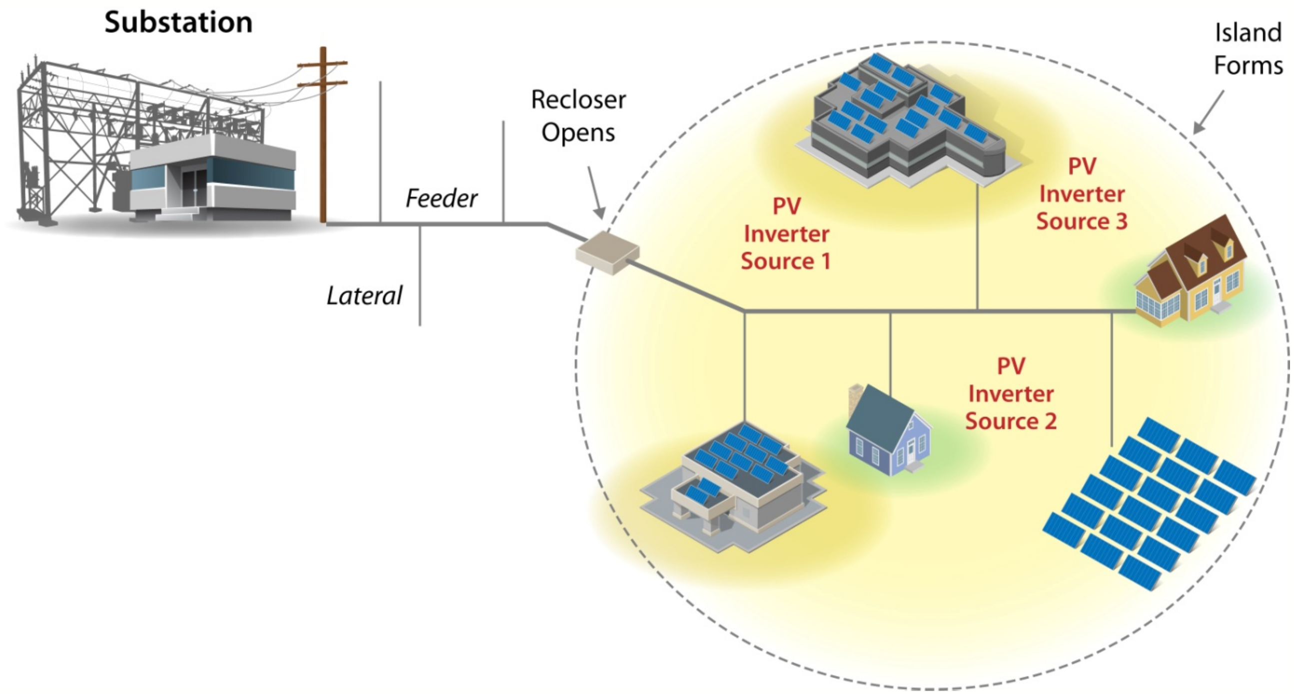


Figure 2.9. How fault contributions from other feeder energy sources such as PV can interfere with fuse and circuit breaker coordination in fuse-saving schemes

Unintentional Islanding



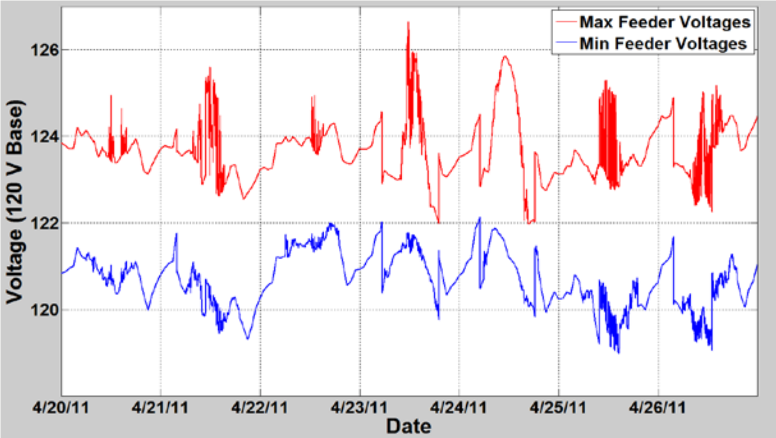
***** IEEE 1547** requires PV interconnection systems to detect the island and cease to energize the utility within two (2) seconds of the formation of an island*

***Islanding** occurs when the DG continues to energize the load after disconnection from the utility source and operates as a separate entity*

- **Safety issue** for both line crews and the **public** due to exposure to energized conductors
- **Transient overvoltage** caused by ferroresonance and ground fault conditions
- **Out-of-phase reclosing** leading to possible damage to distributed generation (DG) systems, customer loads, and potentially utility-owned equipment
- **Increase in restoration time** which may degrade utility system reliability indices (SAIDI, SAIFI & CAIDI)

Distribution Modeling

- The effects of high deployment levels of PV on distribution feeder equipment and the operation of the system cannot be accurately determined with conventional snapshot analysis methods.
- The main advantage of using QSTS simulation is its capability to properly assess and capture the time-dependent aspects of power flow such as the daily changes and interaction of load and PV output and the resulting effect on distribution control systems.
- Utility Interconnection studies using the QSTS analysis solution can more accurately identify both **magnitude and frequency** of the potential electrical impacts and determine **more cost effective** mitigation alternatives.



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Updating Interconnection Screens for PV System

Michael Coddington, Abraham Ellis, Barry Mather, Benjamin Kroposki, Roger Hill, Kevin Lynn, Alvin Razon, Tom Key, Kristen Nicole, Jeff Smith

Interconnection procedures for small generators contain a series of screens to determine whether an interconnection request can be expedited without the need for a detailed study. One of the screens is based on the ratio of total generation to peak load. The threshold typically used is 15%.

The 15% Penetration Threshold

The 15% threshold is based on a rationale that unintentional islanding, voltage deviations, protection miscoordination, and other potentially negative impacts are negligible if the combined DG generation on a line section is always less than the minimum load.

Upgrading the 15% Screen

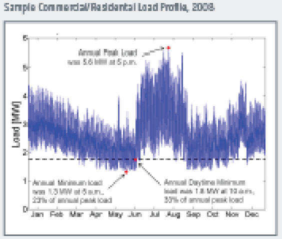
During review of PV interconnection requests in regions with a high level of PV deployment, the 15% interconnection screen often triggers the need for supplemental studies. In many cases, even when PV penetration is substantially above 15%, the supplemental review does not identify any necessary system upgrades. There are many circuits across the United States and Europe with PV penetration levels well above 15% where system performance, safety, and reliability have not been materially affected.

Possible Short-Term Alternatives to the Existing 15% Screen

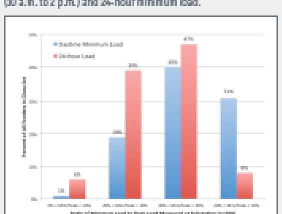
Base Screen on Minimum Daytime Load

A screen may set a threshold at minimum daytime load, where daytime is defined as the period between 10:00 a.m. and 2:00 p.m. If the PV system passes the additional screen it passes the penetration screen.

Sample Commercial/Residential Load Profile, 2008

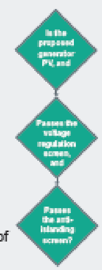


Ratio of minimum load to peak load for daytime minimum load (10 a.m. to 2 p.m.) and 24-hour minimum load.

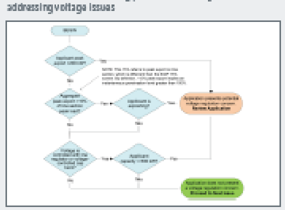


Apply Supplementary Screens

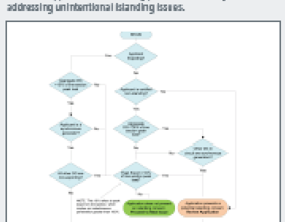
Applying supplementary screens to identify possible technical issues, regardless of penetration level. The idea is to conduct more comprehensive analyses as part of the initial review in order to eliminate the possibility of voltage regulation issues and the creation of unintentional islands.



Possible additional screening procedure for PV systems addressing voltage issues



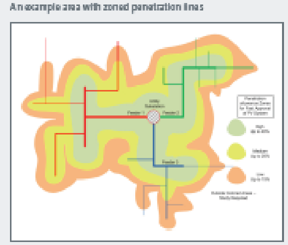
Possible supplemental screening procedure for PV systems addressing unintentional islanding issues.



Utility Identified Zones of Penetration Levels

One concept for increasing penetration screening criterion is to identify zones where higher penetration is acceptable. These zones would be identified by utilities through a transparent and open process administered by a regulatory body that takes into account stakeholder input, and should not exclude PV interconnection outside the zones

An example area with zoned penetration lines



Long-Term Solutions

Develop Higher Accuracy Screening Metrics and Formulas

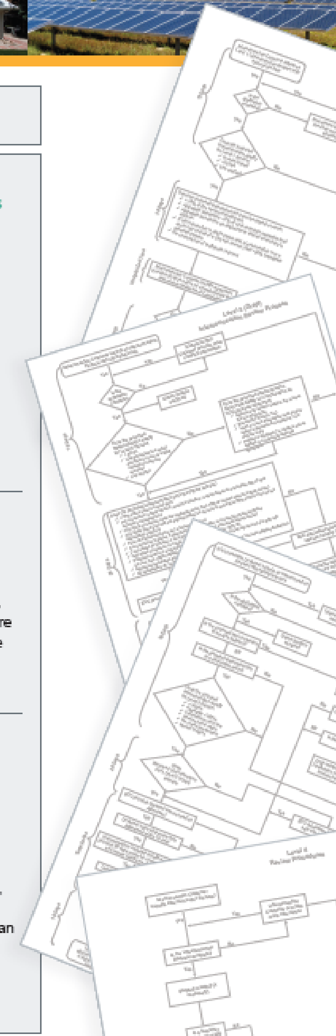
PV penetration metrics alone are insufficient indicators of the expected distribution system level impacts from PV interconnection. More effective and technically sound screening metrics should be developed and adopted. An interconnection impact metric that directly addresses voltage effects, unintentional islanding, and protection coordination issues or concerns, could be developed.

Upgrade Distribution Circuit Design for PV-Hosting Applications

Upgrading existing conductors, installing voltage regulation devices, and increasing operating voltages are ways to maintain acceptable voltage levels and increase the PV hosting capacity of a feeder.

Deploy Inverters with Advanced Functions

PV inverters are highly capable in terms of responsiveness and controllability. Advanced inverters and controllers can provide real-time reactive power compensation, real power curtailment, watt-voltage, and watt-frequency management. Configurable autonomous actions can mitigate impacts of high penetration PV and support the grid during abnormal voltage or frequency conditions.



New Interconnection Screening Method

- Feeder's ability for hosting PV without adverse impact on performance depends upon many feeder-specific factors
- "Rule-of-thumb" penetration limits such as 15% rule are not very accurate
- Typical characteristics used to classify/screen feeders (i.e., voltage class and load level) may not be sufficient
- Example illustrates different hosting capacity for "similar" circuits
  - Lead: EPRI
  - Technical Partners: NREL, Sandia National Laboratories
  - Utility Partners: SDG&E, SCE, PG&E, SMUD

Interconnection

Distribution Models

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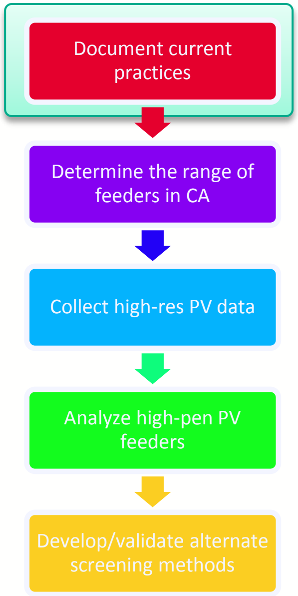
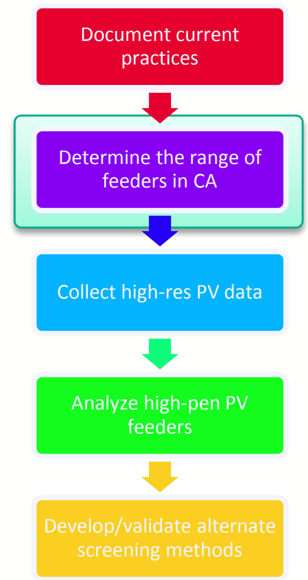
Step 1: Current Screening Practices

- Task Purpose
  - Investigate and document current practices for screening PV interconnection requests among California utilities and from other sources outside California.
- Approach
  - Consider federal, state, and local interconnection procedures pertaining to CA (Rule 21, WDAT, SGIP)
  - Consider non-CA and European utility screening practices as well



Step 2: Define Feeder Configurations in CA

- Purpose of task
  - Determine the range of feeder configurations and characteristics for CA utilities
  - The representative feeders selected will be used in developing and validating the proposed screening methodology
- Approach
  - Develop database of feeder characteristics for statistical processing
  - Identify 20 feeders representative of range of distribution feeder types for the grid in CA
    - 15 Test Feeders for methodology development
    - 5 Control Feeders for methodology validation



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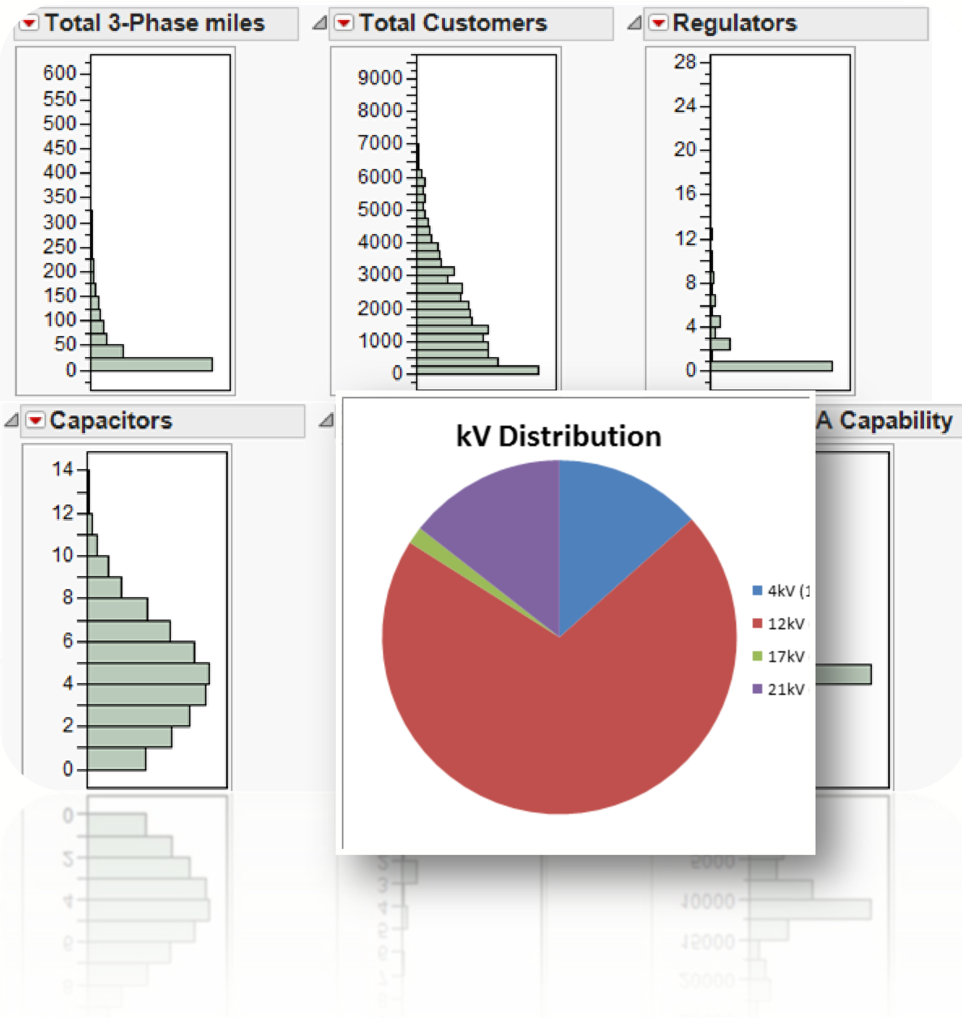
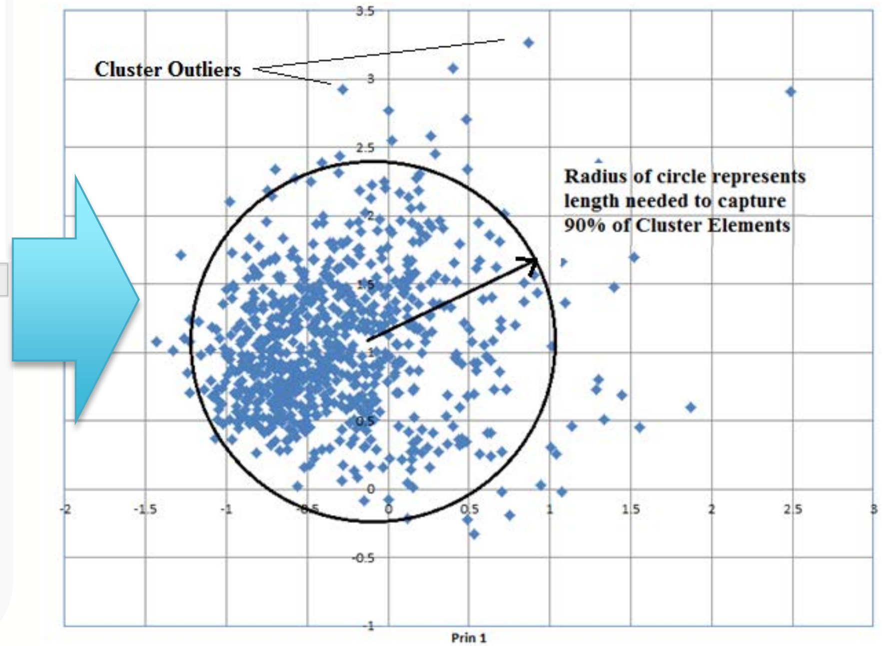
Evaluate Distribution Feeder Characteristics

Clustering of data to select feeders

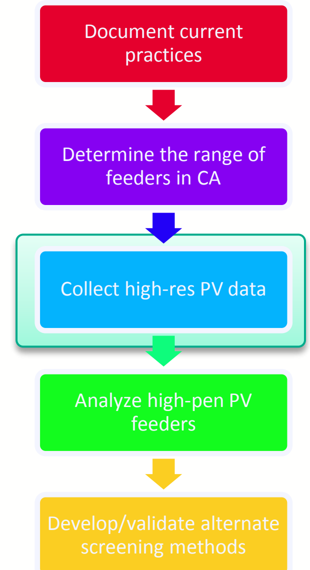


- 1000s of feeders
- Clustering of feeder data characteristics
- Select 20 feeders for analysis



Step 3: Collect High-Resolution Solar Data

- Purpose of Task
  - Collect high-resolution, time-series solar output data that can be used for
    - Validation of feeder models
    - Definition of scenarios for high-penetration PV output
    - Verification of screening method with empirical data
- Approach
  - Install monitoring equipment via pole-mount and at existing PV facilities (provided by EPRI, installed by utilities)
  - From selected feeders ID'd in Task 3, obtain high-resolution (1-sec) PV production data via field monitoring

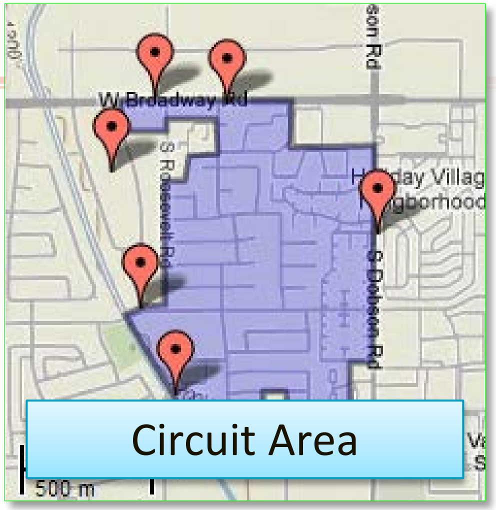


Distributed PV Monitoring

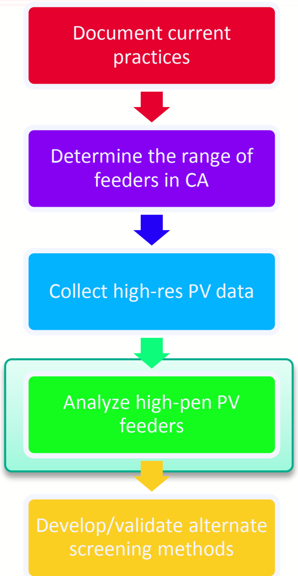
Leveraging Utility Research

Field monitoring to characterize PV system performance & variability

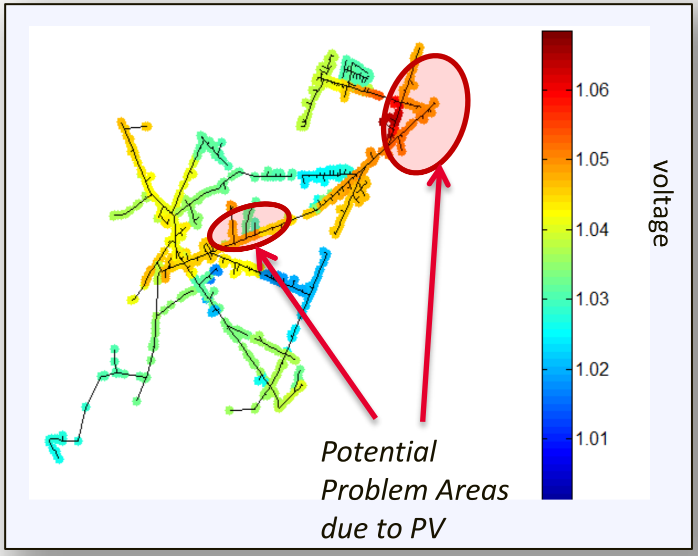
- **Utility interactive PV systems**
  - ✓ Single modules on poles
  - ✓ 1MW plants
  - ✓ 200+ sites committed nationwide
- **Field measurements for 1+ years**
  - ✓ AC power meter
  - ✓ Plane-of-array pyranometer
  - ✓ Module surface temperature
  - ✓ …More sensors on select sites
- **Data acquisition**
  - ✓ 1-second resolution
  - ✓ Time synchronized
  - ✓ Automated uploads to EPRI
  - ✓ Structured data storage at EPRI



Step 4: Modeling and Hi-Pen Analysis



- Purpose of Task
  - Perform high-penetration assessment of the test feeders to determine each specific feeder's hosting capacity for solar PV
- Approach
  - Utilize EPRI's Distributed PV (DPV) Feeder Analysis Method for determining feeder impacts and hosting capacity
  - Simulate a wide range of PV deployment scenarios and penetration levels on each feeder



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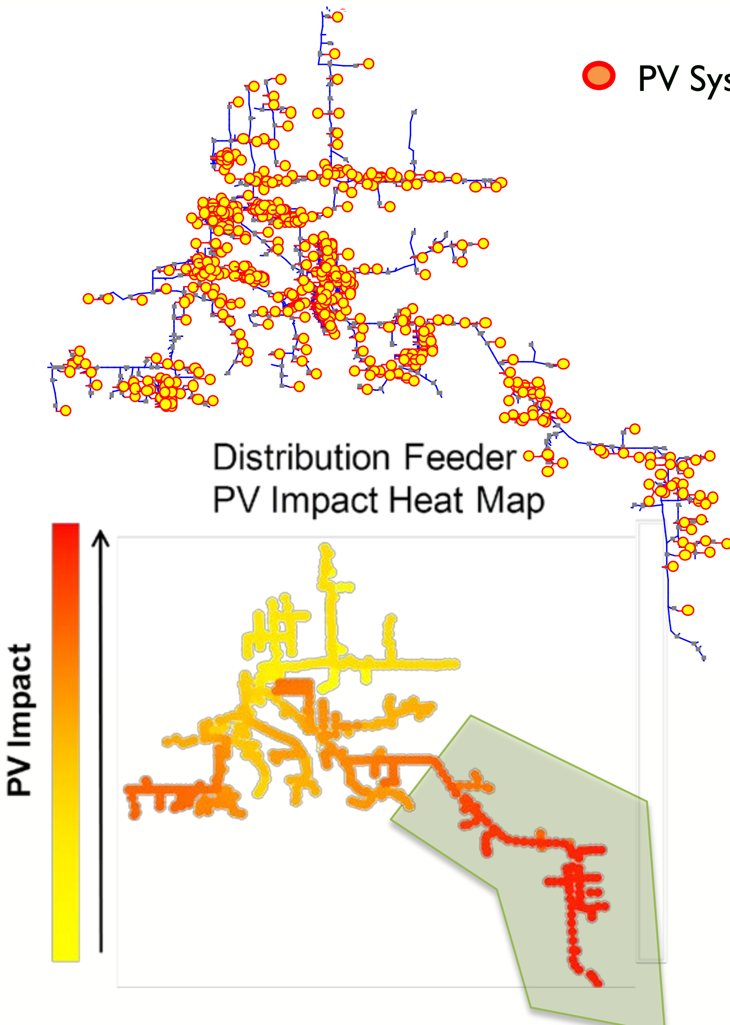
PV Analysis: Determining Feeder Hosting Capacity

Leveraging an EPRI Research Project



Baseline – No PV

PV Penetration 1

PV Penetration 2

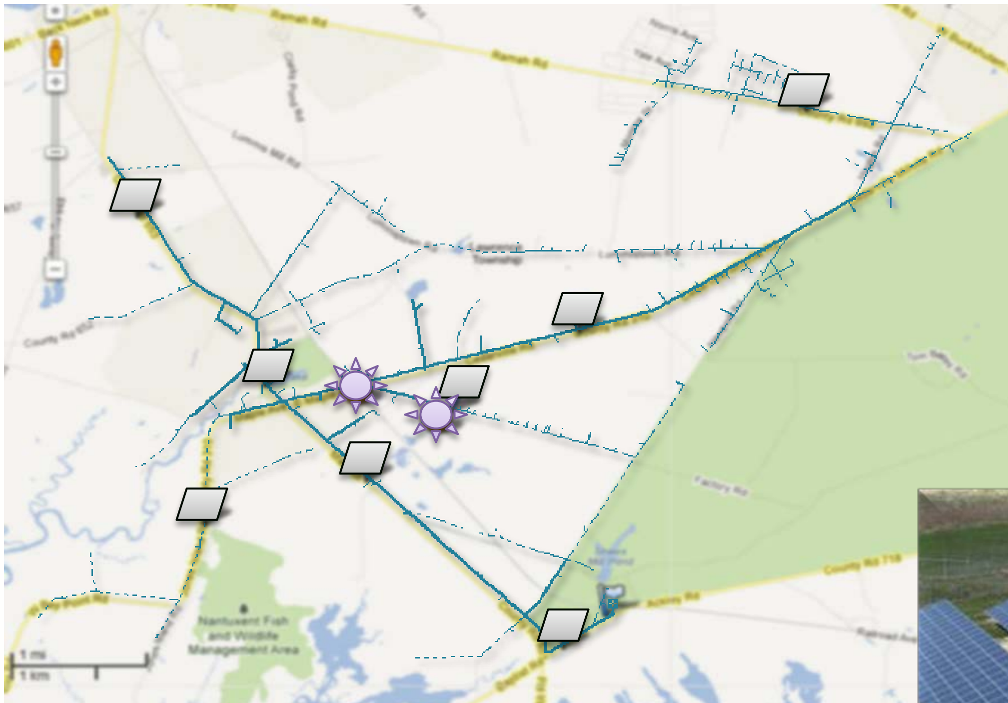
PV Penetration 3

Beyond…

Process is repeated hundreds of times to capture many possible scenarios

Increase Penetration Levels Until Violations Occur

High Penetration Solar Deployment:
Virginia Tech and EPRI



DPV Pole-Mount Panels
Metered Large-Scale PV

Hosting Capacity Comparison

- Each feeder has **similar** characteristics that are **typically** used to classify feeders (load level and voltage class)

- Two significantly different PV penetration levels can be accommodated before violating voltage criteria

Feeder Comparison			
		Feeder A	Feeder B
Feeder Characteristics	Voltage (kV)	13.2	12.47
	Peak Load	5 MW	6 MW
	Minimum Load	0.8 MW	0.7 MW
	Min Daytime Load	1.1 MW	0.7 MW
	Existing PV (MW)	1.0	1.7
	Total Circuit Miles	28	58
Minimum Hosting Capacity (kW)			
Voltage	Primary Overvoltage	>3500	420
	Regulator Deviation	>3500	250
Protection	Total Fault Contribution	>3500	1685
	Sympathetic Tripping	1478	1426
	Reduction of Reach	>3500	1489
	Fuse Saving	1771	1426
	Anti-Islanding – Breaker	777	390

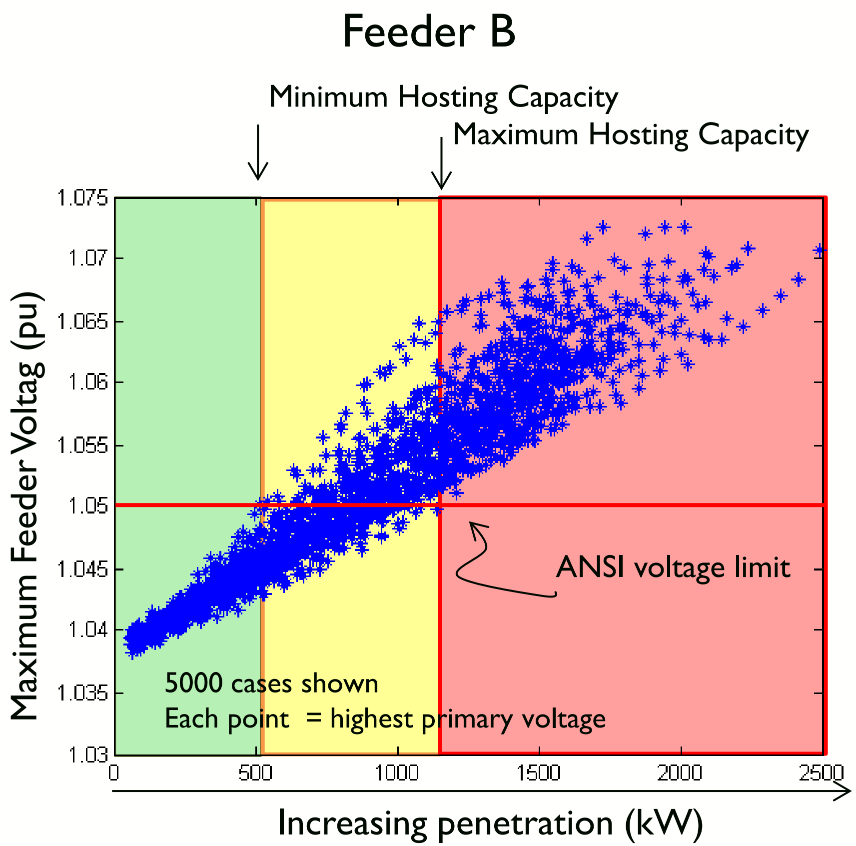
Customer-based PV results shown

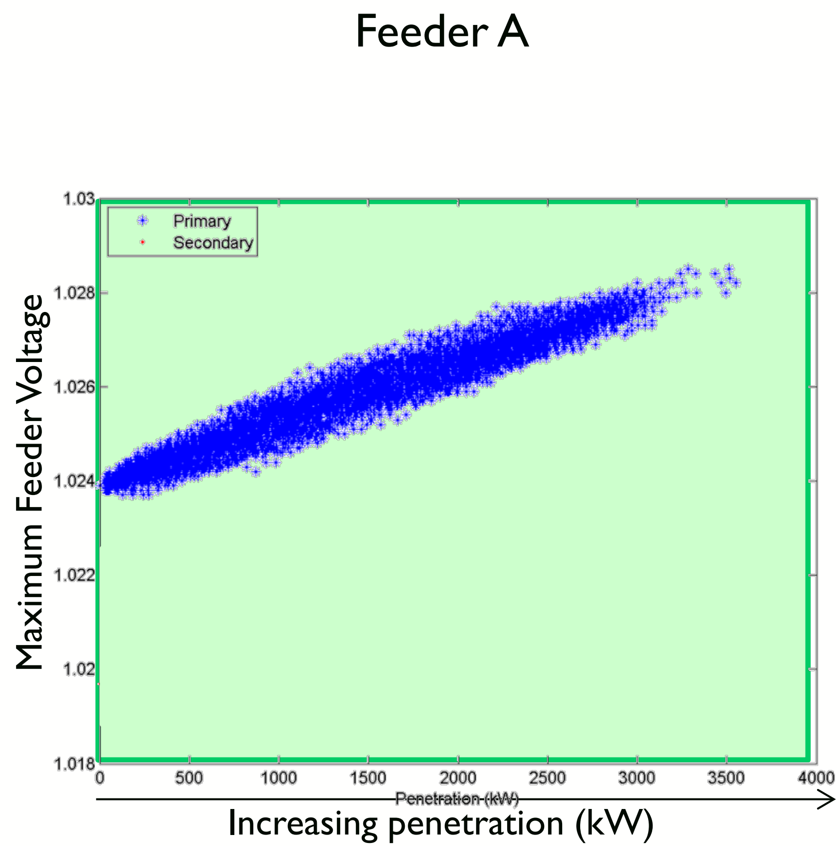
70% of Peak Load

4% of Peak Load

Hosting Capacity Comparison

Quick Look at Overvoltage Impacts





No observable violations regardless of size/location

Possible violations based upon size/location

Observable violations occur regardless of size/location

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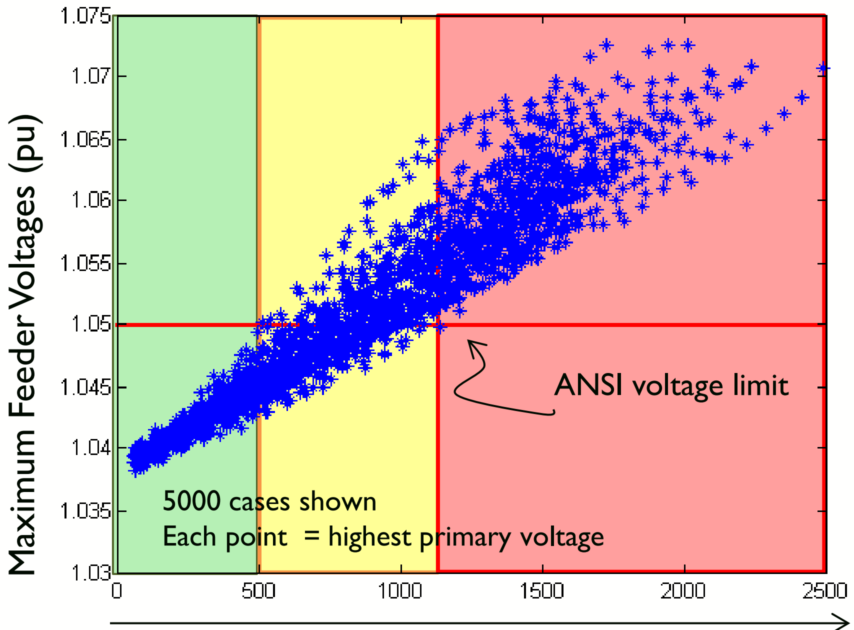
Increasing Hosting Capacity with Smart Inverters

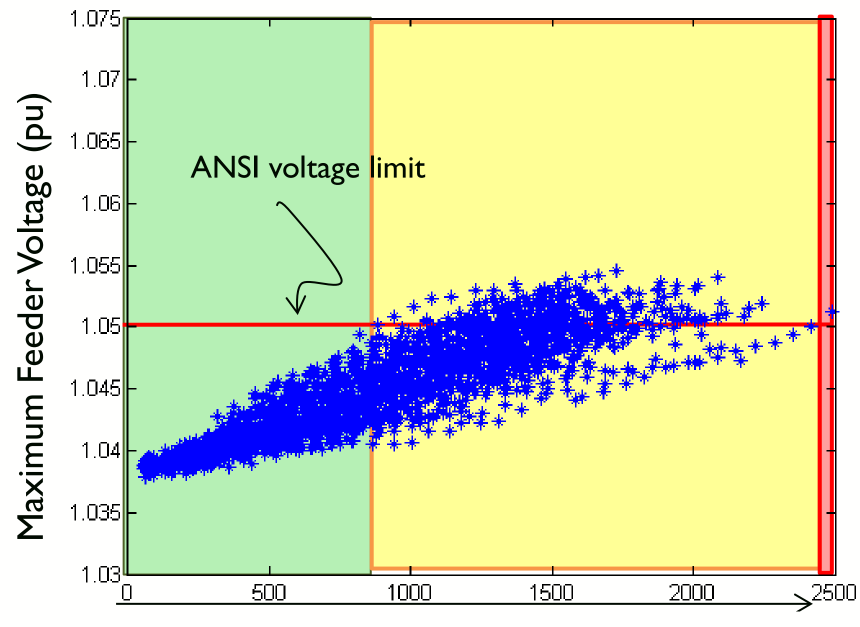
Sample Results from Feeder with Limited Hosting Capacity

Without Volt/var Control



Increasing penetration (kW)

Volt/var Control



Increasing penetration (kW)

		PV Hosting Capacity (kW)	
		Without Volt/var	With Volt/var
Primary Voltage Deviation	1st violation	938	>2500
	50% scenarios with violation	1323	>2500
	All scenarios with violation	1673	>2500
Primary Over Voltage	1st violation	540	880
	50% scenarios with violation	871	1464
	All scenarios with violation	1173	2418

160% increase in hosting capacity

60% increase in hosting capacity

More Information

- Links to all the 2013 High Pen Forum presentations can be found here:
  - https://solarhighpen.energy.gov/2013_doe_cpuc_high_penetration_solar_forum
  - http://www.calsolarresearch.ca.gov/Funded-Projects/solarforum.html

Thank you.

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