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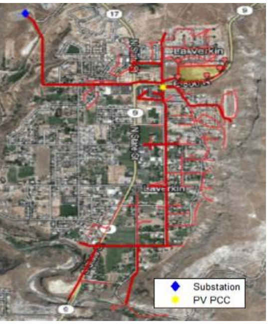

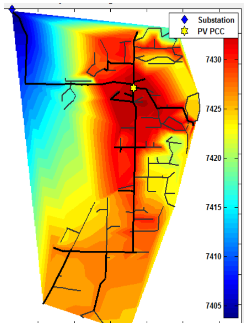

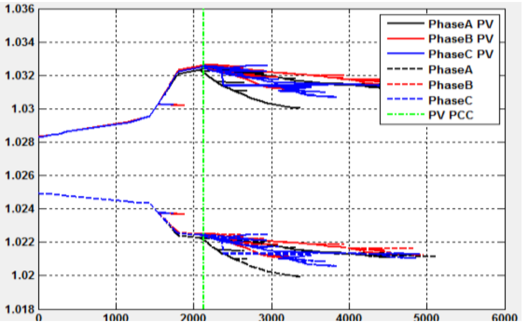

Accelerating Solar Deployment on the Distribution Grid and Developing Enhanced Grid Operation and Control Strategies

Matthew Reno,

Sandia National Laboratories

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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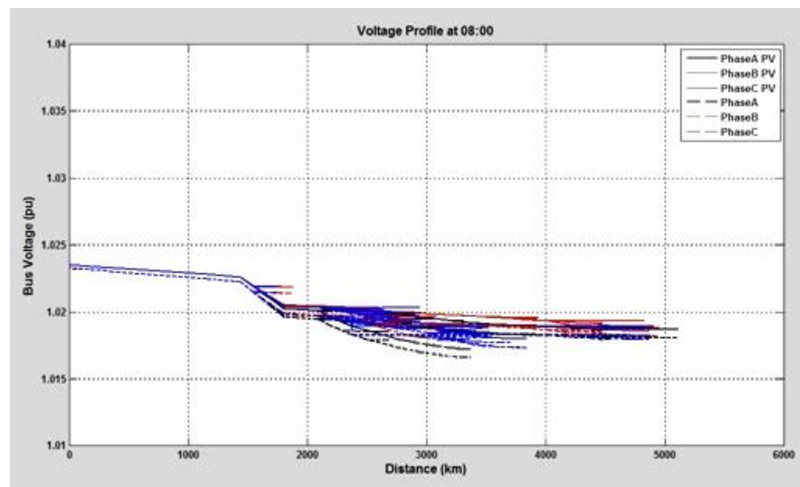
Impact Analysis

- High penetrations of PV can affect the distribution feeder equipment and the operation of the system
  1. Designed for radial flow in one direction from the substation
  2. Designed for aggregated loads with little short-term variability

- Distribution system impacts
  - Voltage Regulation Device Operations
  - Steady State Voltage
  - Voltage Flicker
  - Protection Coordination



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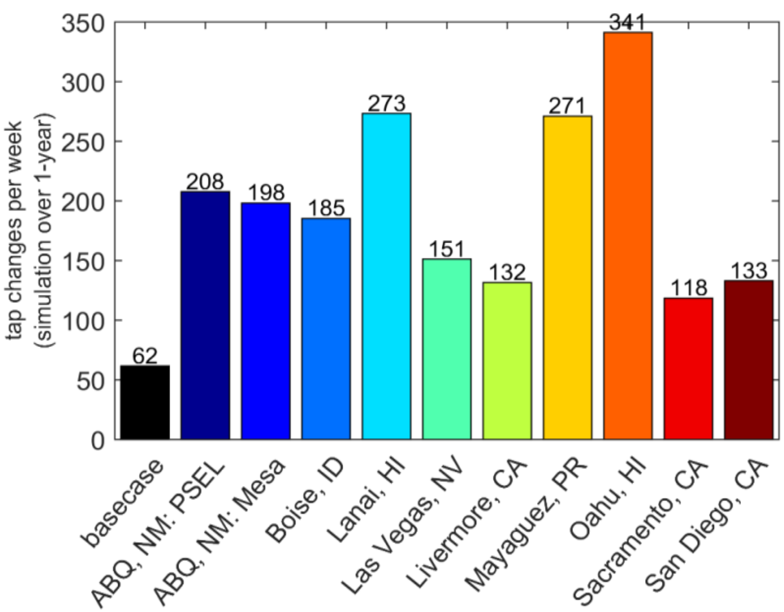
Time Series Simulations

- PV output is highly variable and the potential interaction with control systems may not be adequately analyzed with traditional snapshot tools and methods
- Quasi-static time series (QSTS) analysis
- Captures time-dependent aspects of power flow, including the interaction between the daily changes in load and PV output
- Requires more data to represent the time-varying PV output coincident with time-varying load

Time Series Results

- QSTS simulates the number of tap changes on voltage regulators
- Results depend the input data and seasonal variations
- QSTS simulations present a significant computational burden



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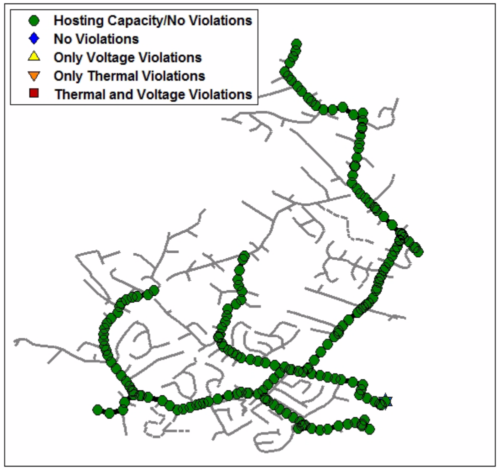
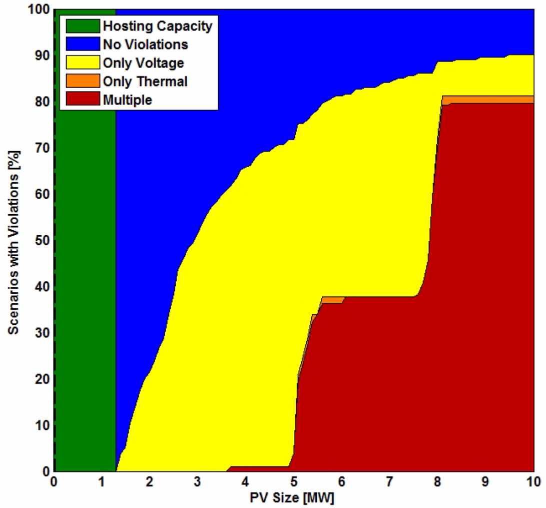
Current Projects

- Rapid QSTS Simulations for High-Resolution Comprehensive Assessment of Distributed PV
- Current snapshot tools only investigate specific time periods. Currently QSTS analysis is not possible for utilities – limited high-resolution data for inputs, and the computational burden
- Existing QSTS algorithms can take anywhere from 10 to 120 hours to perform a 1-year simulation at 1-second resolution.
- During the course of the project, algorithms will be developed to dramatically reduce the computational time to less than 5 minutes for a year-long high-resolution time-series simulation, allowing QSTS to be incorporated into the utility interconnection process and decision support tools.

Feeder Analysis

- Advanced PV hosting capacity simulation tool to quantify system impacts for many PV interconnection scenarios, configurations, and locations, which can be generalized to develop improved future interconnection screening criteria
- The PV hosting capacity analysis is performed for a large range of different distribution systems in order to analyze the risks associated with different feeder topologies and characteristics





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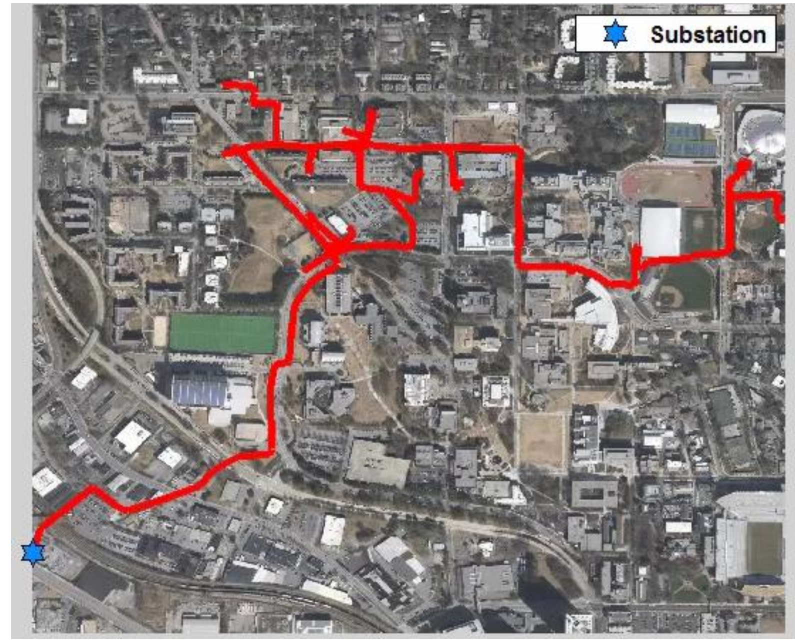
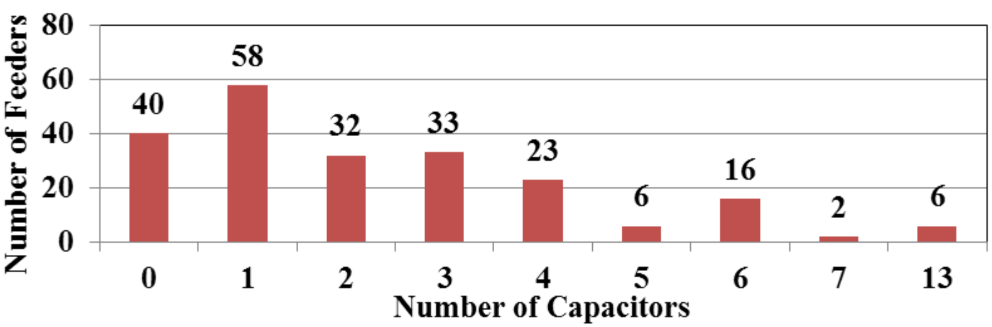
Distribution Systems for Analysis

- 216 actual distribution systems located in the United States (~10 different utilities)
- Each model includes the full details about substation impedance, voltage regulator settings, capacitor switching controls, an approximate model of the secondary system, and a year of SCADA data





Voltage Level	4 kV	12 kV	12.47 kV	13.2 kV	13.8 kV	16 kV	19.8 kV	20.78 kV	22.9 kV	24.9 kV	33 kV	34.5 kV
Feeders	18	43	96	3	8	2	16	6	3	9	1	11

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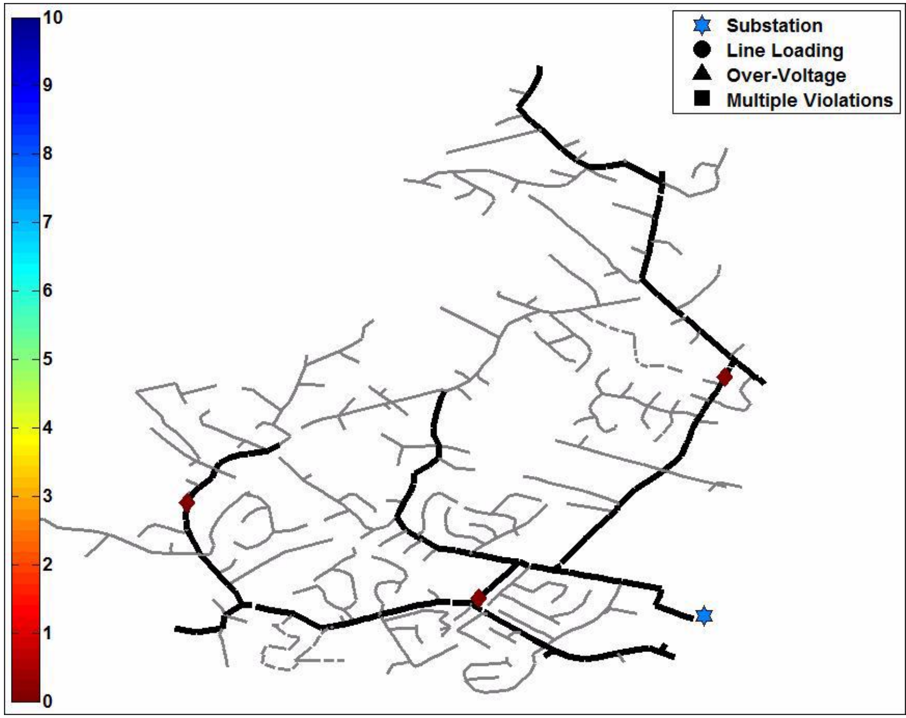
Hosting Capacity Analysis

- Detailed analysis of a large number of potential PV scenarios (combinations of PV size and location) to determine if there is any impact to the operation of the distribution system
- For each PV scenario, a series of simulations are performed in OpenDSS to detect any potential violations caused by the PV interconnection
  - Range of feeder load values that occurred during daytime hours of 10am to 2pm in the year
  - Range of all potential states of the feeder (regulator taps and switching capacitor states)
  - Temporary over-voltages are considered with extreme ramps in PV output faster than the voltage regulation equipment can react



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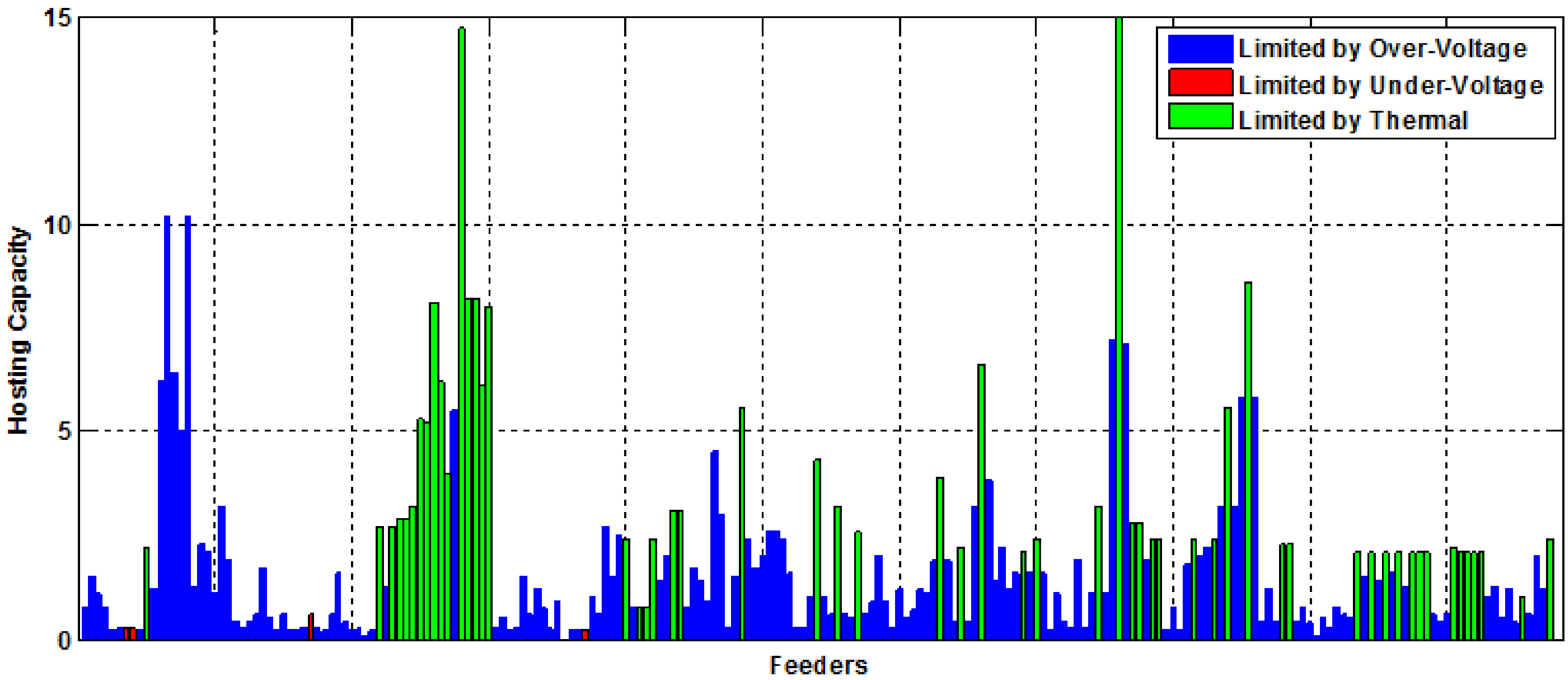
Hosting Capacity for 216 feeders



- Analyses captures a wide range of feeder types, voltages, topologies and controls.
- For the 216 feeders, 70% of the feeders are limited by over-voltages on the feeder, 3% of the feeders are limited by under-voltages, and 26% are limited by the thermal ratings.

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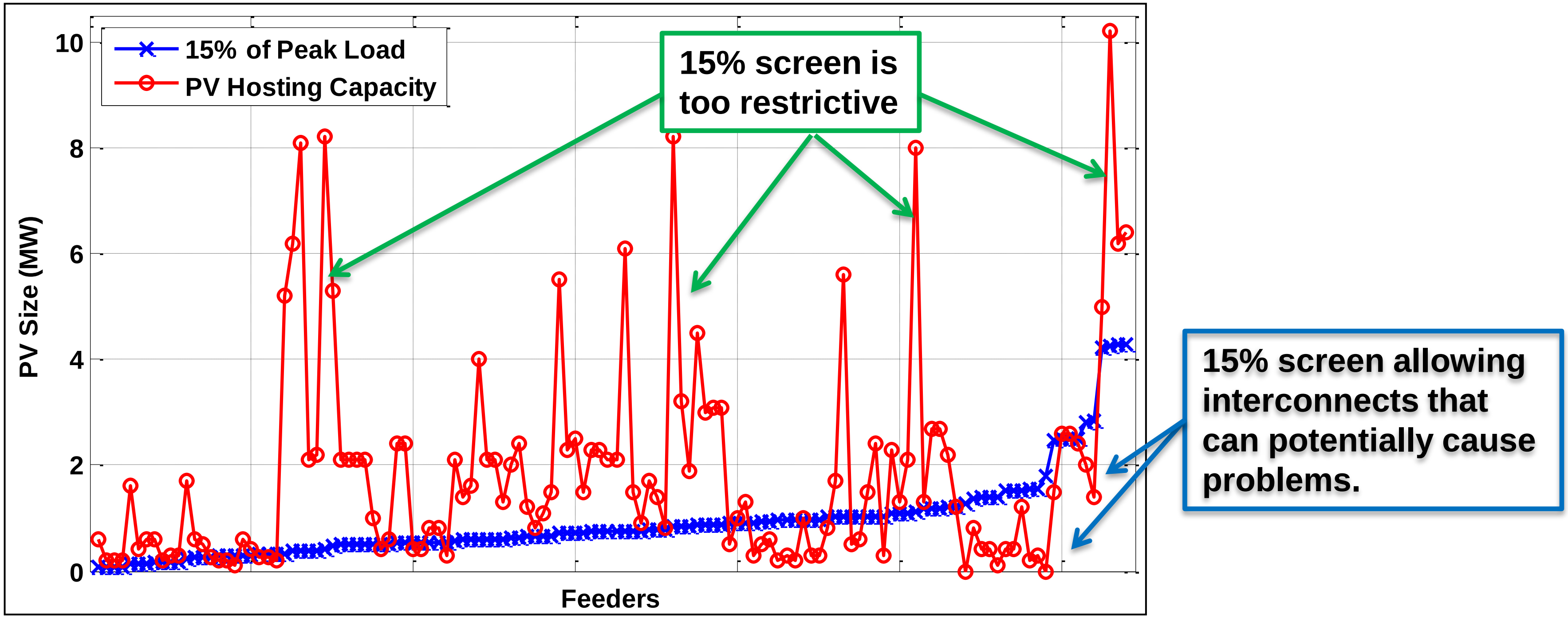
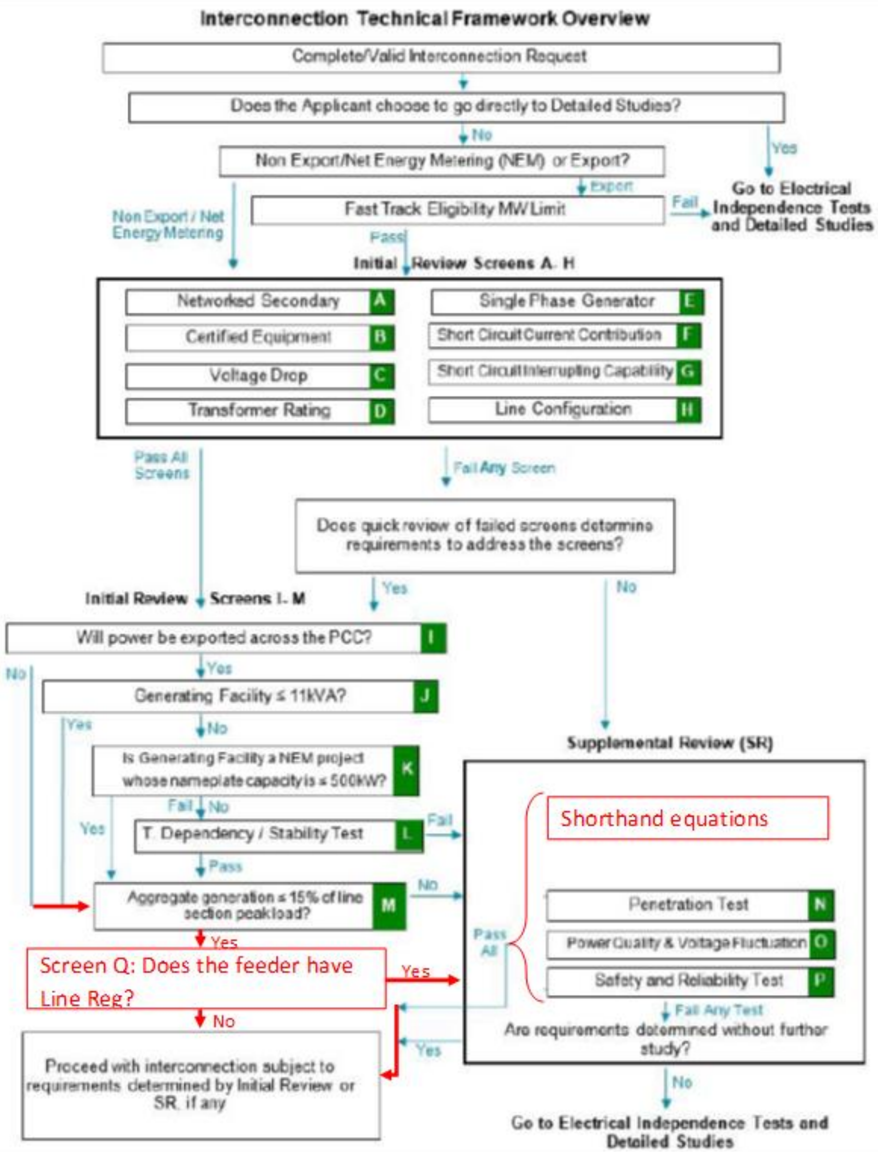
Existing PV Interconnection Screening

- The current interconnection screening methods are not accurate
- The most common method is 15% of the feeder peak load
- We have also studied methods of clustering feeders



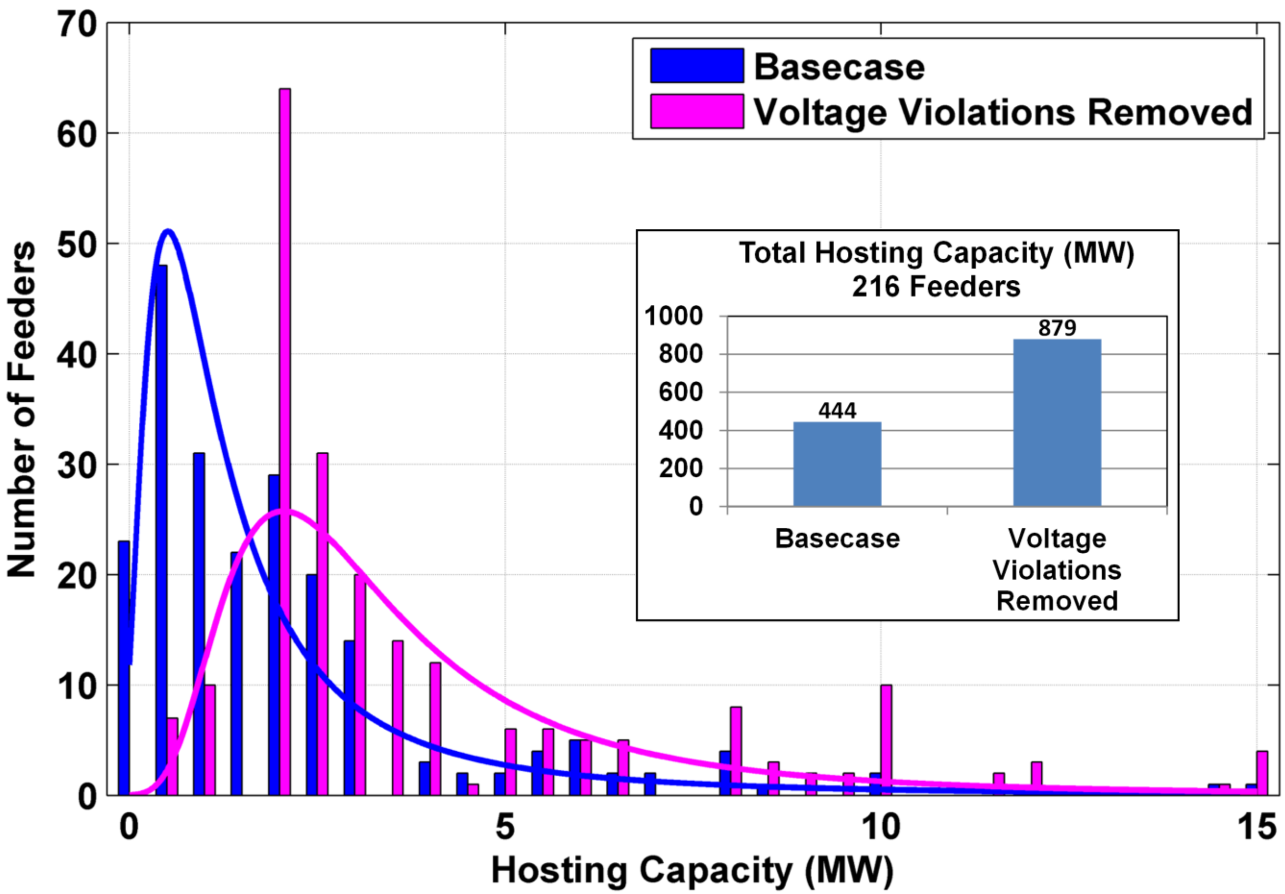
Revised California Rule 21

- Collaborative project with EPRI and NREL, funded by the CPUC, to develop new screening methods
- Based on PV hosting capacity results, we proposed new short-hand equations for calculating the approximate amount of PV a feeder can handle



Current Projects

- Advanced inverter functions present new opportunities to increase feeder hosting capacity



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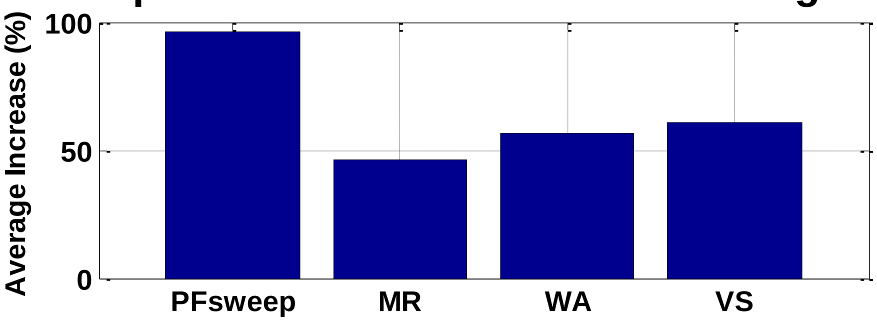
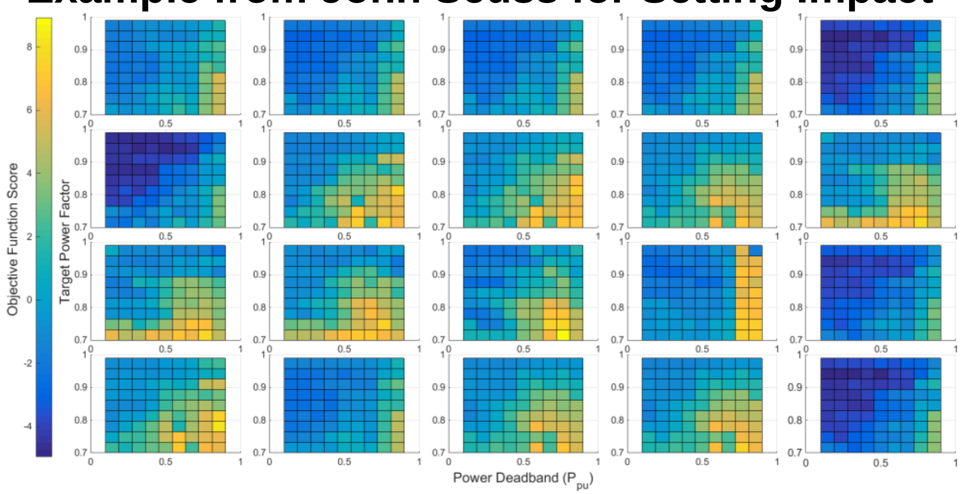
Current Projects

- Project funded by the CPUC to determine advanced inverter settings to accommodate more PV without system upgrades
- Investigating such functions as fixed power factor, volt-var, volt-watt, and others

Example of 4 Advanced Inverter Settings



Example from John Seuss for Setting Impact



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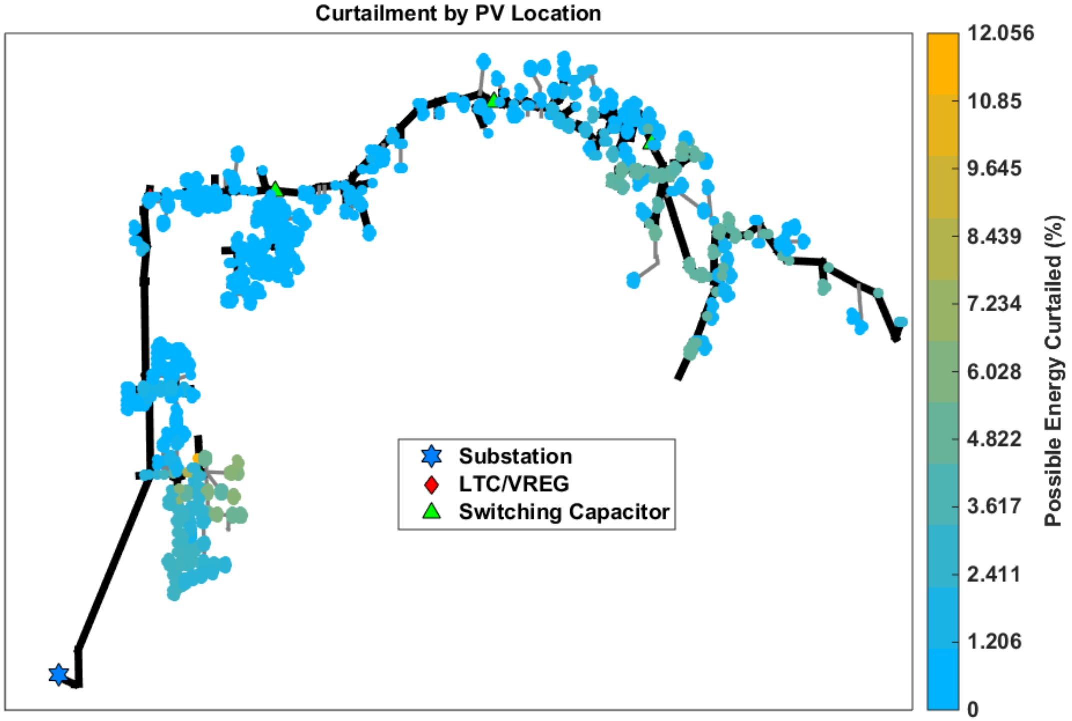
Control of DER

- Enhanced grid operation and optimized PV penetration utilizing highly distributed sensor data
- Local, centralized, or distributed control of storage and PV with advanced inverter capabilities



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PV Power Control Strategies

- Developed different control methods that achieved curtailment of less than 3% of kWh produced by PV on the feeder while maintaining feeder voltages within ANSI standards 98%+ of the time
- Investigated reactive power control in PV inverters: results show that real-power curtailment could be avoided over 97% of the time while maintaining feeder voltages within ANSI standards at all times.

Comparison of the performance of PV inverter control types

Control Type	ZCI	Volt/ Watt	Volt/V ar	Central Fair (1m)	Central Fair (5m)	Sensitivity-based (1m)	Sensitivity-based (5m)
Violations Mitigated (%)	100.0	100.0	98.7	99.0	91.7	100.0	99.7
Power Curtailed (%)	21.6	5.39	0	5.89	5.89	3.99	4.58
Curtailment Deviation (%)	0.75	6.2	0	0.36	0.16	8.21	8.23

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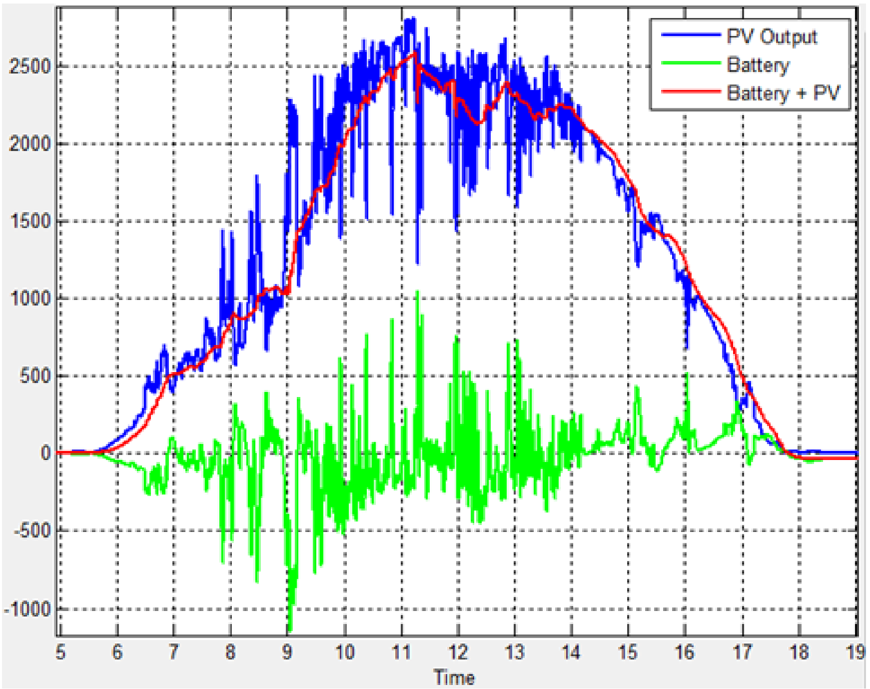
Distributed Storage For Smoothing PV Ramps



- A control algorithm smooths the variability of PV power output by using distributed batteries (300 +systems).
- Both local and central control algorithms demonstrate that large numbers of highly distributed current, voltage, and irradiance sensors can be utilized to control distributed storage in a more optimal manner.
- Centralized energy storage control for PV ramp rate smoothing does require very fast communication of less than 15 second update rate.

Control Name	Regulator Tap Changes (weekly)	Total Required Storage (kWh)
Basecase with PV and No Batteries	193	-
Local 1	154	662
Local 2	137	2710
Central 1	152	629
Central 2	135	2648

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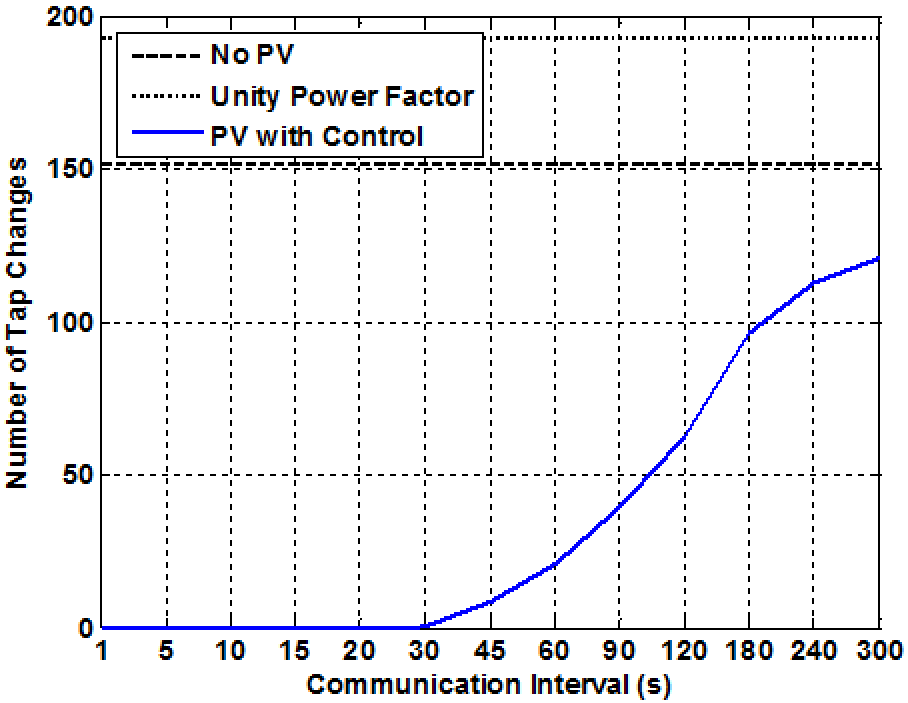
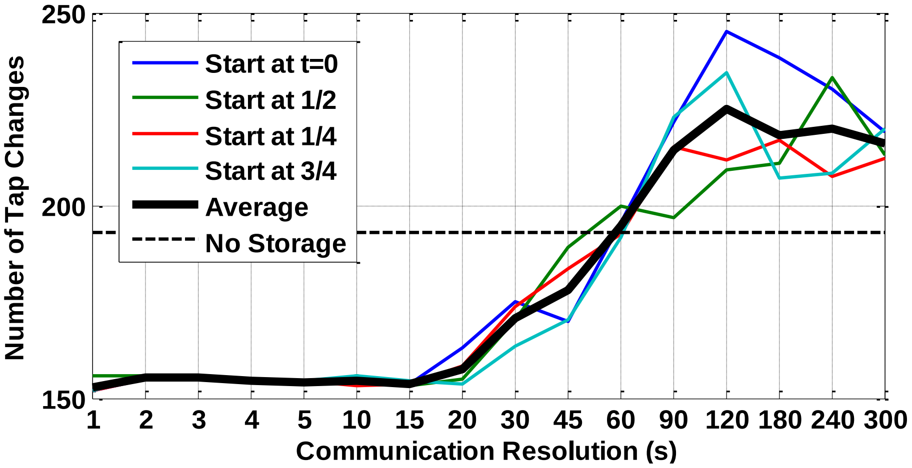
Current Projects

- Recently funded 3-year project investigating the requirements for the communication infrastructure for DER control
- Analysis of communication delays, cyber security, and bandwidth limitations on distributed control





Current Projects

- Vermont Regional Partnership Enabling the use of DER
- Development of innovative control strategies (utilizing aggregates of storage systems along with improved wind and solar forecasts and controllable loads) that will reduce peak transmission demand costs while also mitigating solar-induced feeder voltage variability problems.
- There is also a power systems planning component to develop methods to determine the optimal amount and placement of DER (PV and storage) on distribution feeders

QUESTIONS?

Sandia National Laboratories

Robert J. Broderick

rbroder@sandia.gov

Matthew J. Reno

mjreno@sandia.gov