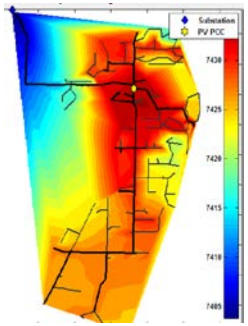
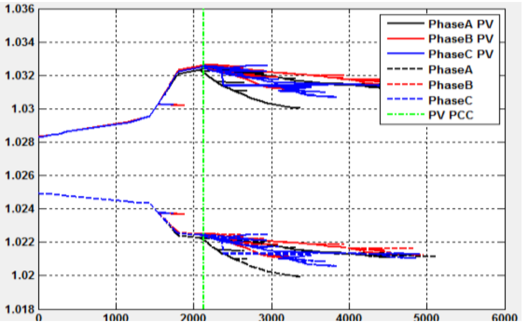




Advanced Inverter Planning: Voltage and Protection

Sandia National Laboratories

May 3, 2018

SAND2018-4987C.

U.S. DEPARTMENT OF ENERGY

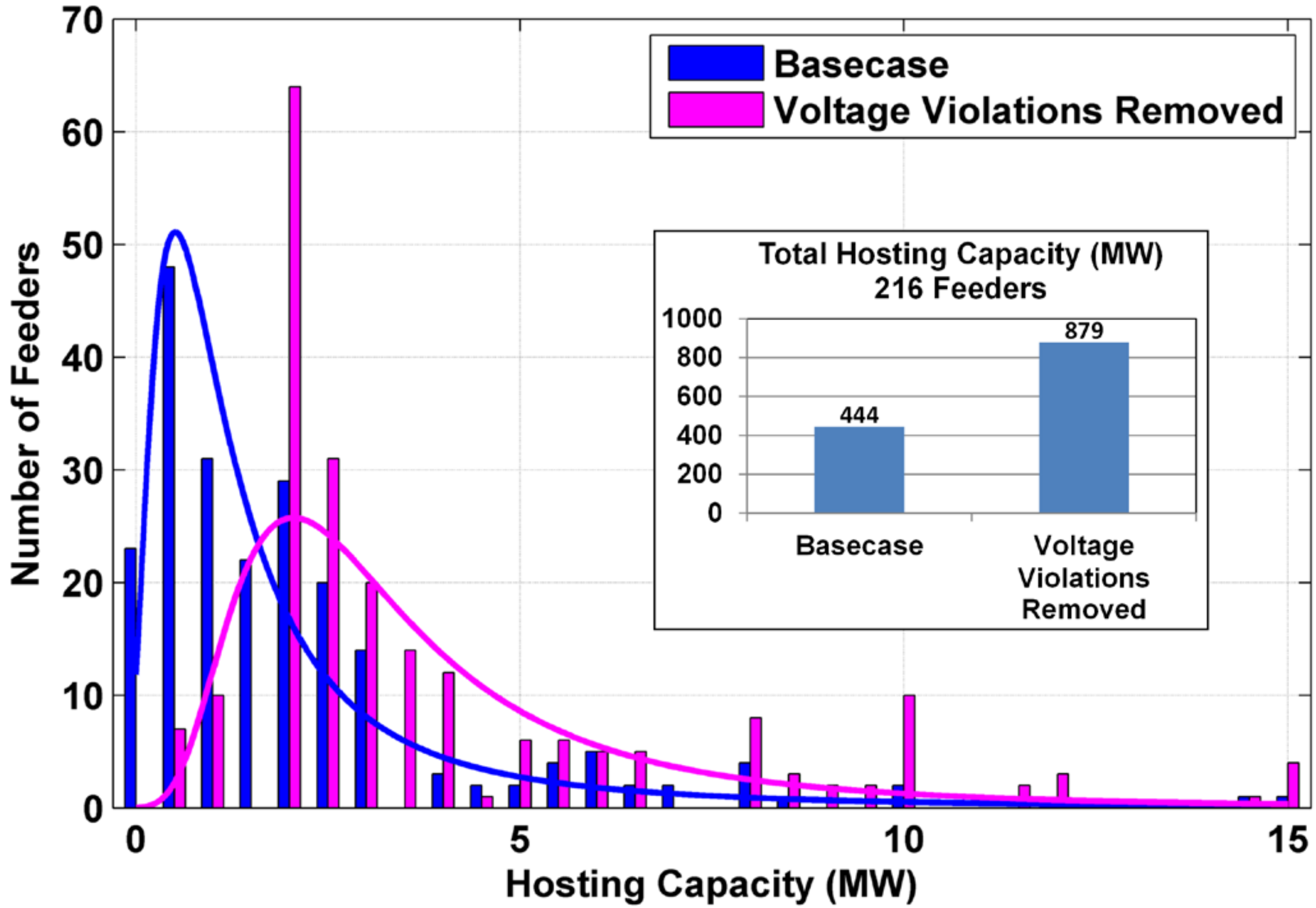
NNSA National Nuclear Security Administration

This research was supported by the DOE SunShot Initiative, under agreement 30691. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

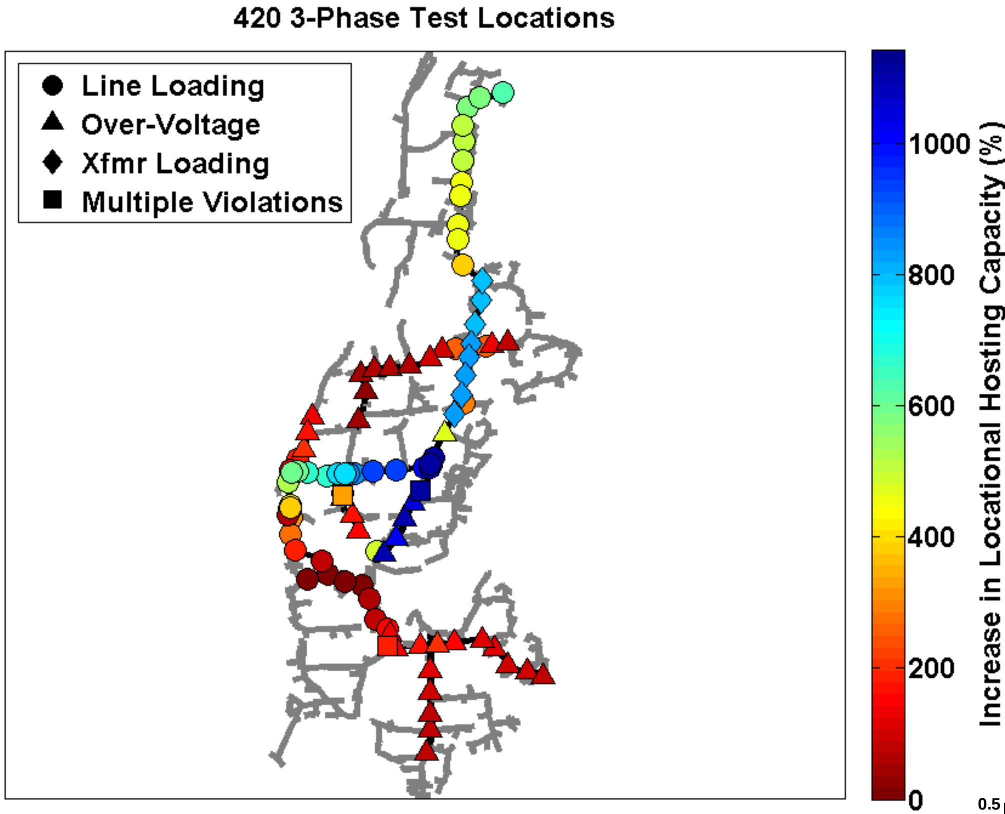
Sandia National Laboratories

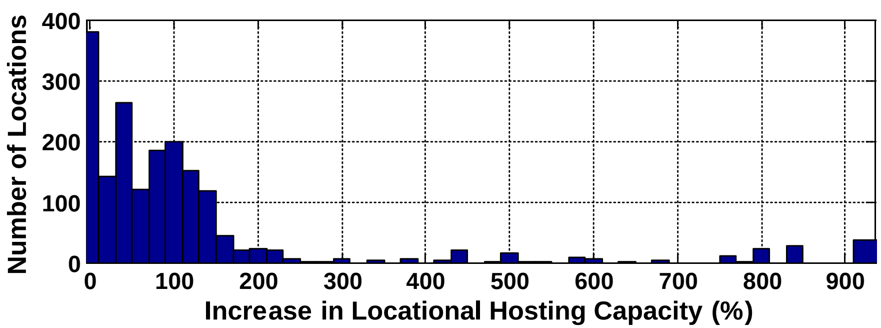
PV Advanced Inverters

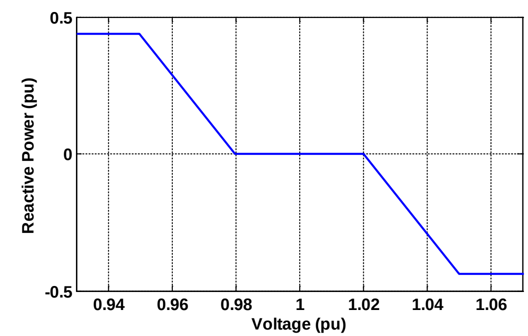
- Advanced inverter functions (like volt-var) present new opportunities to increase feeder hosting capacity



Hosting Capacity With Volt-Var

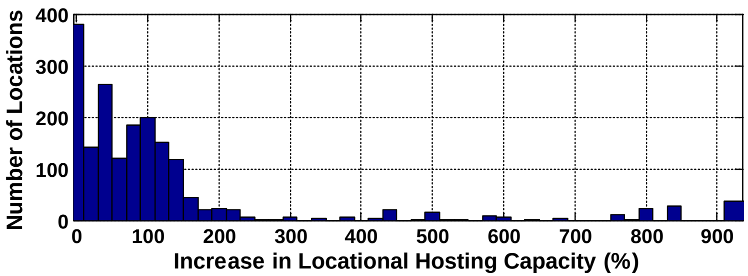


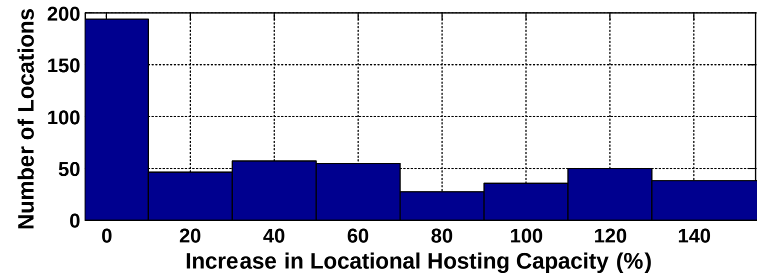


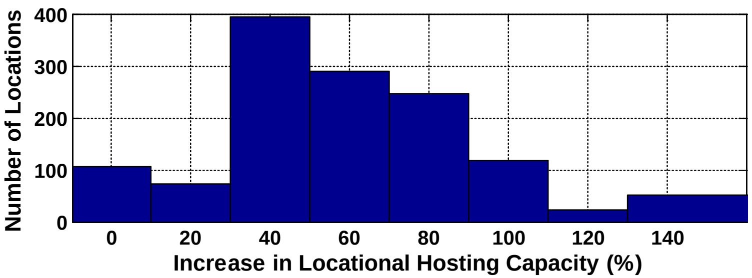


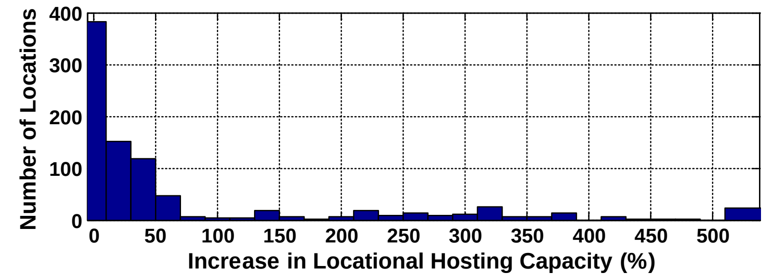
Sandia National Laboratories

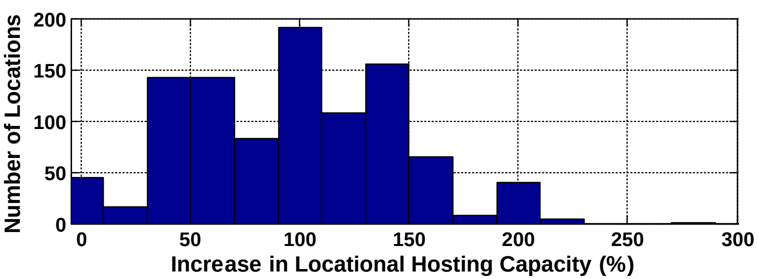
Volt-Var Benefit For Different Feeders

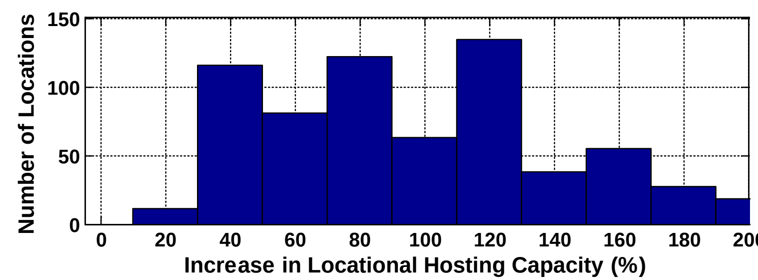


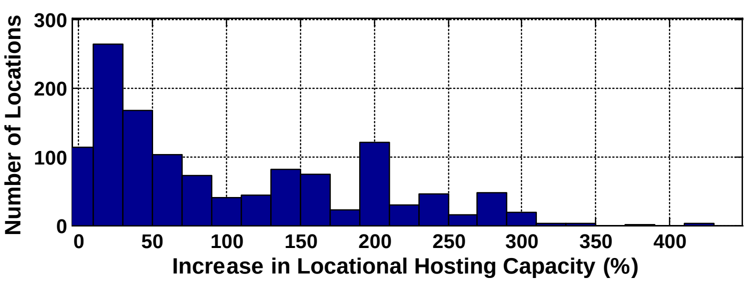


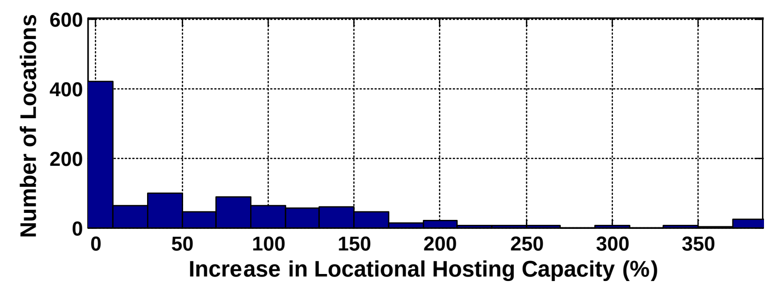




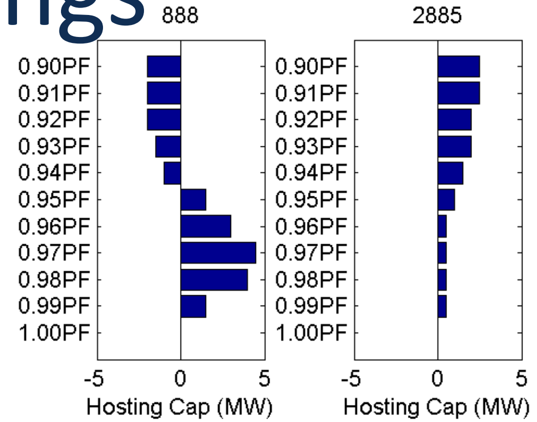






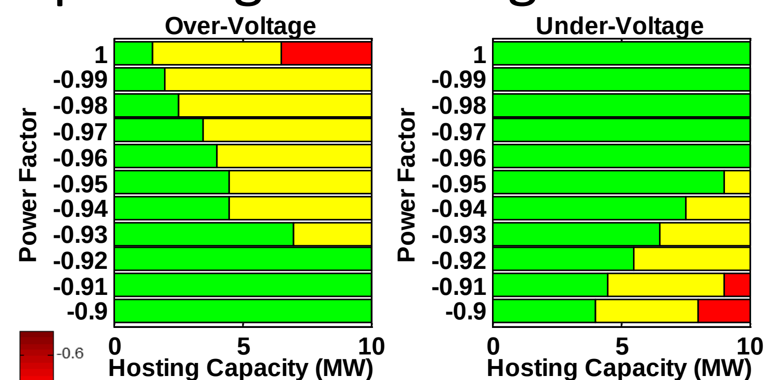


Determining Inverter Settings

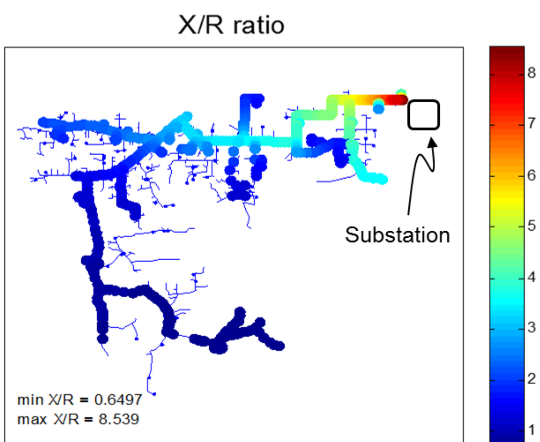


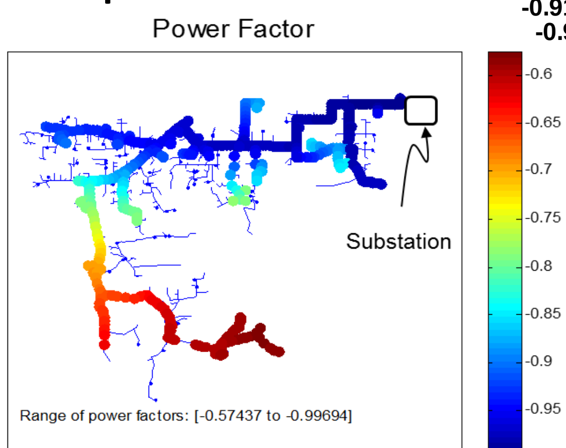
- Settings are unique to each feeder

- The limiting factors (issues) change depending on settings



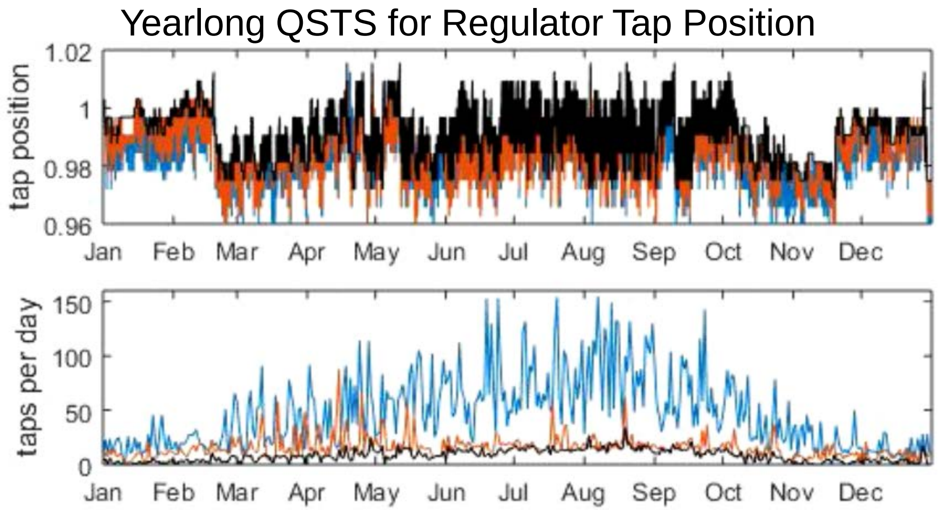
- Settings are location specific





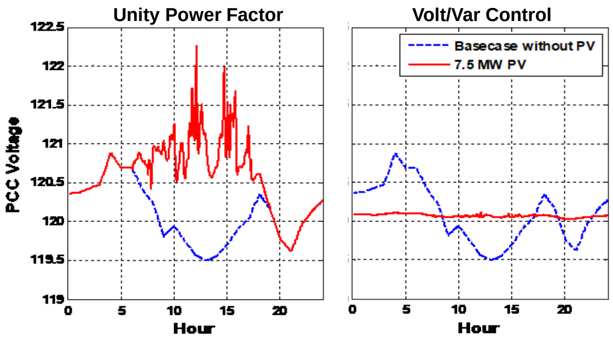
Quasi-Static Time-Series Simulations

- Quasi-static time series (QSTS) analysis is defined by the IEEE guide for *conducting distribution impact studies for distributed resource interconnection* (P1547.7):
  - *"Quasi-static simulation refers to a sequence of steady-state power flow, conducted at a time step of no less than 1 second but that can use a time step of up to one hour. Discrete controls, such as capacitor switch controllers, transformer tap changers, automatic switches, and relays, may change their state from one step to the next."*
- QSTS power flows use the information from the previous time-steps



Quasi-Static Time-Series (QSTS)

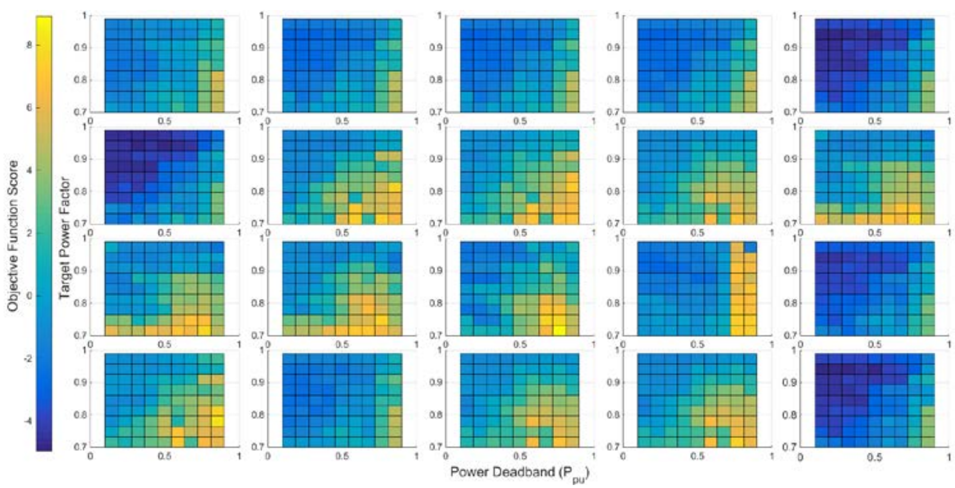
- QSTS analysis captures higher-frequency time-dependent characteristics of power flows, including the interaction between controllers and smart inverters
- QSTS simulations are needed today to understand:
  - Rapid fluctuations due to highly variable PV
  - Impact to voltage regulators and switch capacitors
  - Temporary extreme conditions before controls reach steady-state
- The need will continue to increase in the future:
  - Study interactions between advanced inverters with volt-var
  - Simulate fast operating FACTS devices
  - Research new distribution control strategies

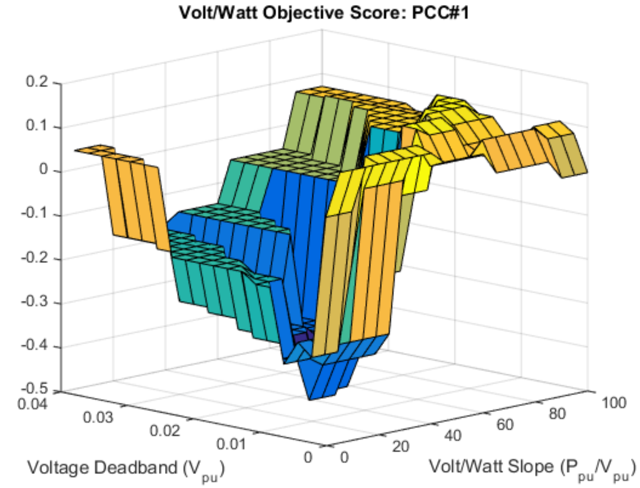


M. J. Reno, R. J. Broderick, and S. Grijalva, "Smart Inverter Capabilities for Mitigating Over-Voltage on Distribution Systems with High Penetrations of PV," in IEEE Photovoltaic Specialists Conference, 2013.

Derive Custom Settings Using QSTS

- A parametric study is performed using quasi-static time series (QSTS) analysis for each control type to determine how well certain measurable network metrics improve as a function of the control parameters
- Impacts considered for each control:
  - Time over-voltage, Time under-voltage, Regulator tap changes, Capacitor switches, Network losses, PV power curtailed, PV vars generated
- Analysis investigates settings for inverter controls:
  - Ramp-Rate Control, Fixed Power Factor Control, Volt/Watt Control, Watt-Var Control, Watt-Priority Volt/Var Control, Var-Priority Volt/Var Control



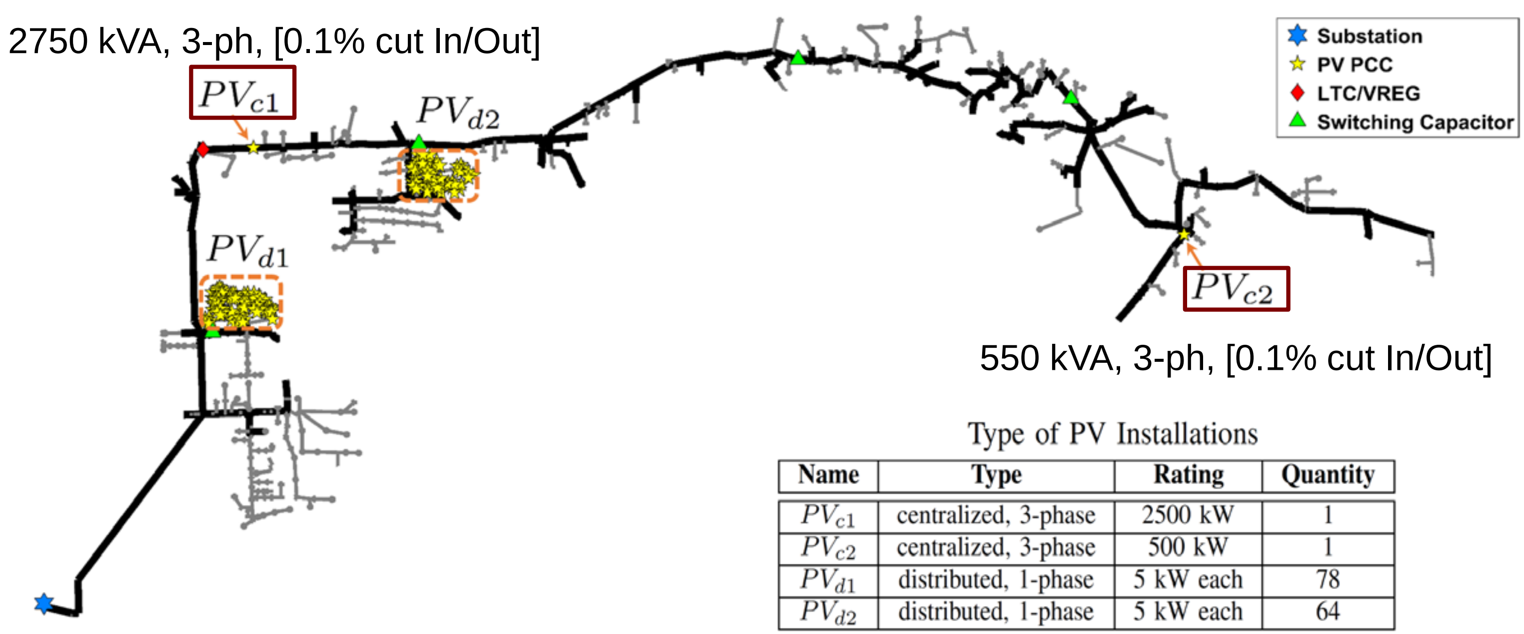


Rapid QSTS Simulations for High-Resolution Assessment of Distributed PV

- Address the limitation of QSTS due to the speed - Enable year-long QSTS distribution simulations by reducing analysis time from days to minutes
- **Objective**: Reduce the computational time (10-120 hours) and complexity of QSTS analysis to achieve year-long time-series solutions that can be run in less than 5 minutes
- There are several ways to improve the speed of QSTS
  1) Fast Time-Series Approximations
  2) Improved Power Flow Solution Algorithms
  3) Circuit Reduction
  4) Parallelization of QSTS (Temporally or Spatially)

Rapid QSTS Results

- We have developed a collection of rapid QSTS algorithms, each demonstrating significant speed improvements (>1000x speed improvement combined)
- Solve yearlong QSTS simulation with advanced inverters in 5 minutes instead of 3 days!



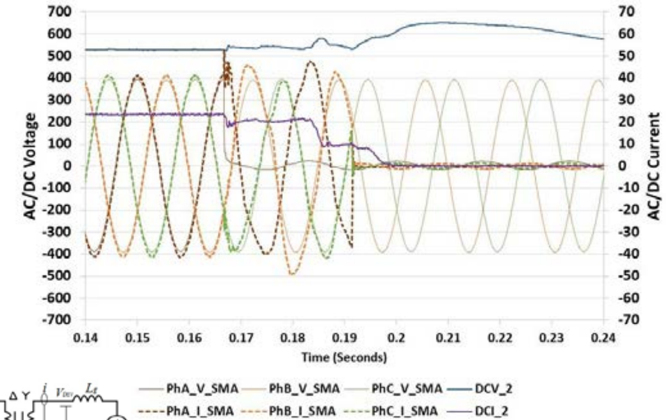
Type of PV Installations

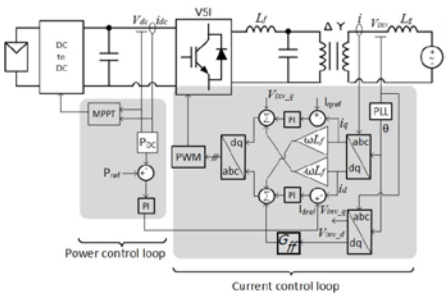
Name	Type	Rating	Quantity
PV_{c1}	centralized, 3-phase	2500 kW	1
PV_{c2}	centralized, 3-phase	500 kW	1
PV_{d1}	distributed, 1-phase	5 kW each	78
PV_{d2}	distributed, 1-phase	5 kW each	64

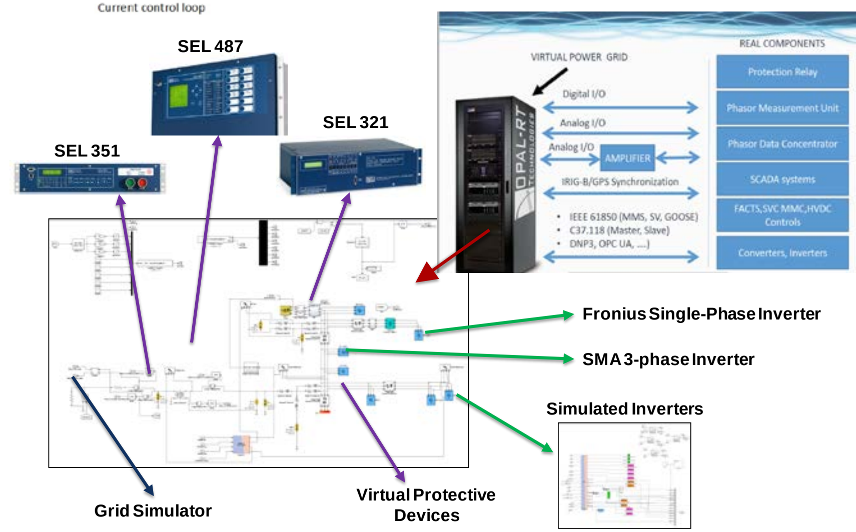
Protection Schemes for Inverter-Based Systems

Advanced Cyber-Secured Protection for Renewable-rich Distribution Systems and Microgrids

- PV Inverter models for fault studies
- Distribution system and microgrid protection design under high inverter-based DER penetration
- HIL protection analysis
- Cybersecurity of protection relays
- Protection schemes for DC microgrids
- Fault location schemes for systems with high DER penetration
- Protection for networked microgrids
- Development of protection algorithms into ADMS

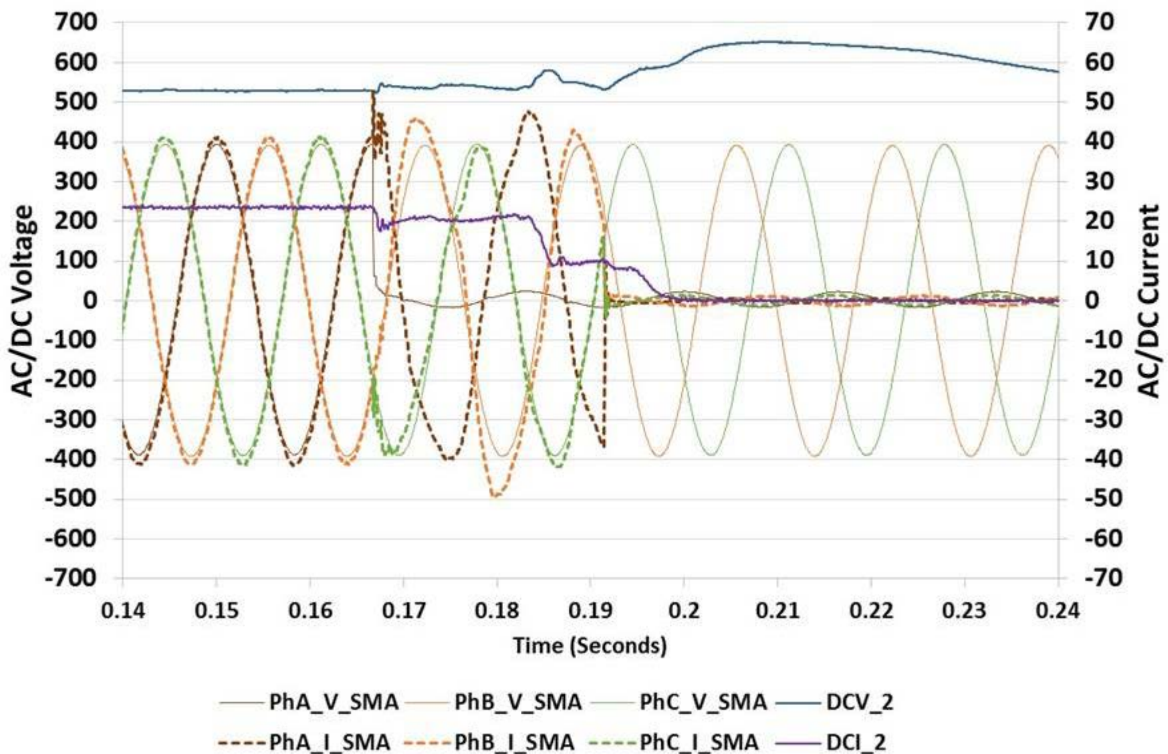


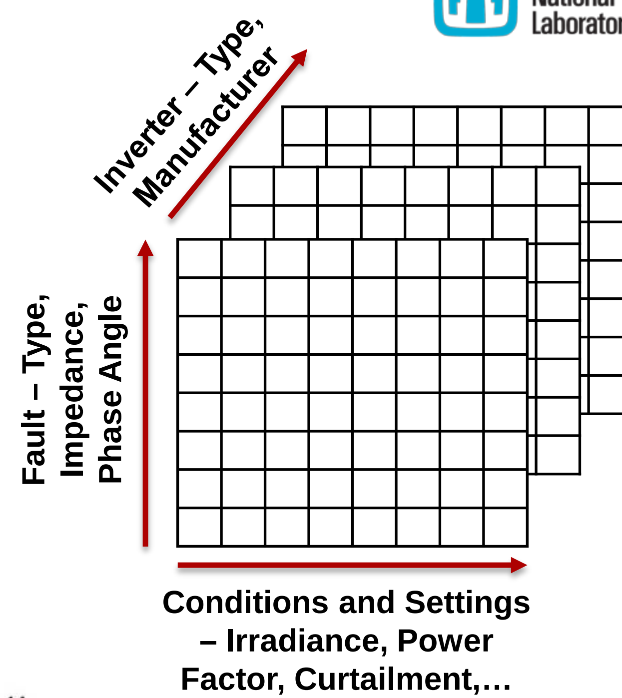




Inverter Fault Modeling

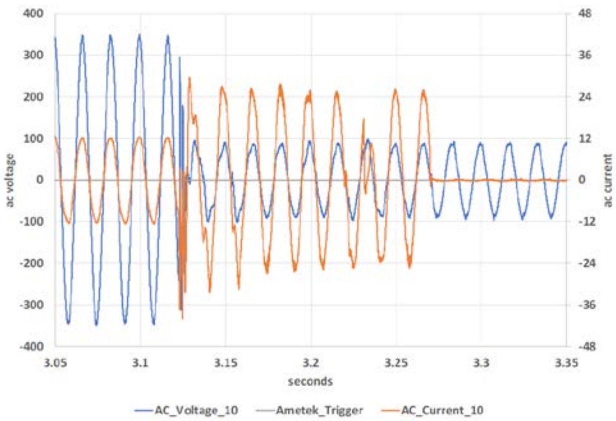
- Validating inverter models using DETL.
- Fault current measurements for different faults, conditions, settings, and inverters



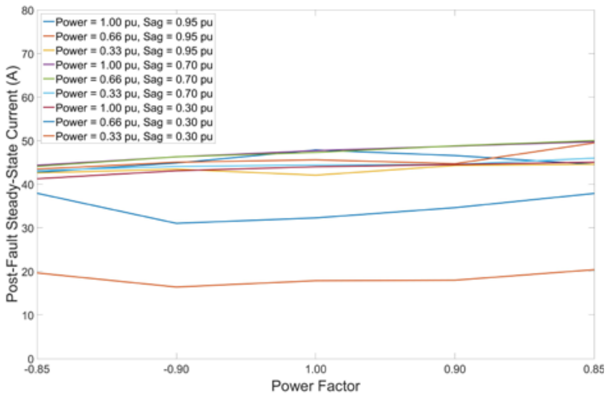


Advanced Inverter Functions Under Faults

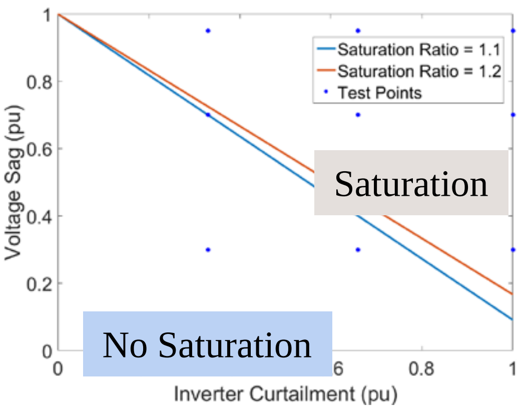
- Curtailment (commanded or volt-watt) will reduce the fault current, so long as the inverter is below its limit of ~1.1-1.2 pu.
- We can use this information to limit inverter fault contributions to prevent protection miscoordination.



Current contribution from single-phase PV inverter which a 70% voltage sag.



Fault current from DER with different power factors and curtailment levels.



Saturation limit for a PV inverter.

QUESTIONS?