CESA Webinar

Enabling High Penetrations of Distributed Solar through the Optimization of Sub-Transmission Voltage Regulation

March 28, 2019

Clean Energy States Alliance

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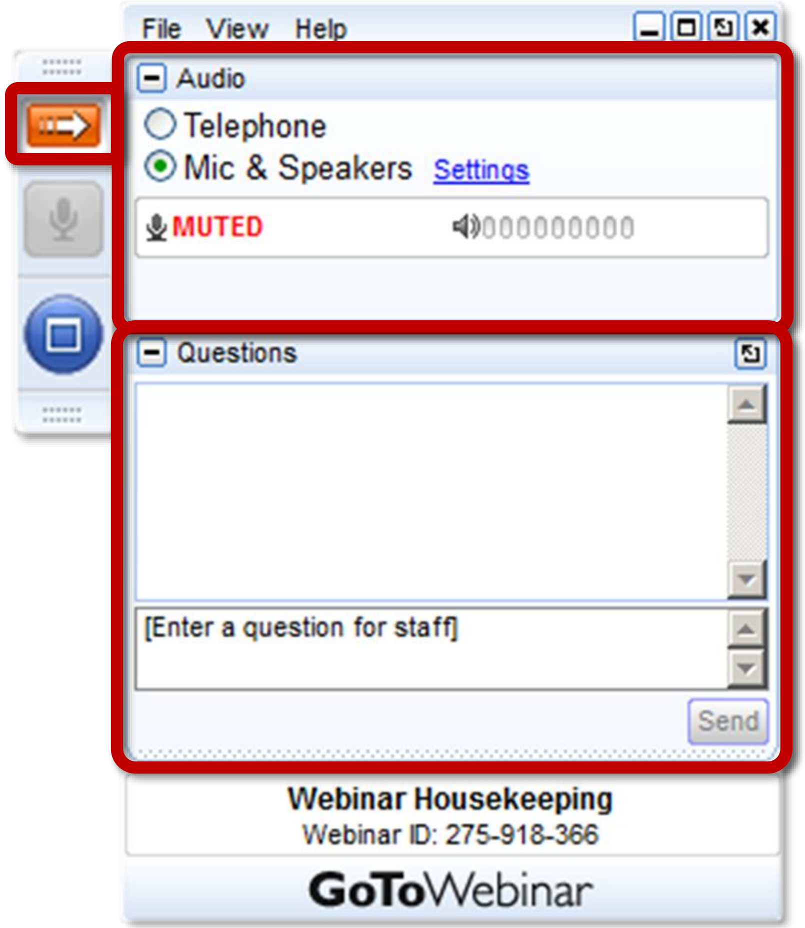

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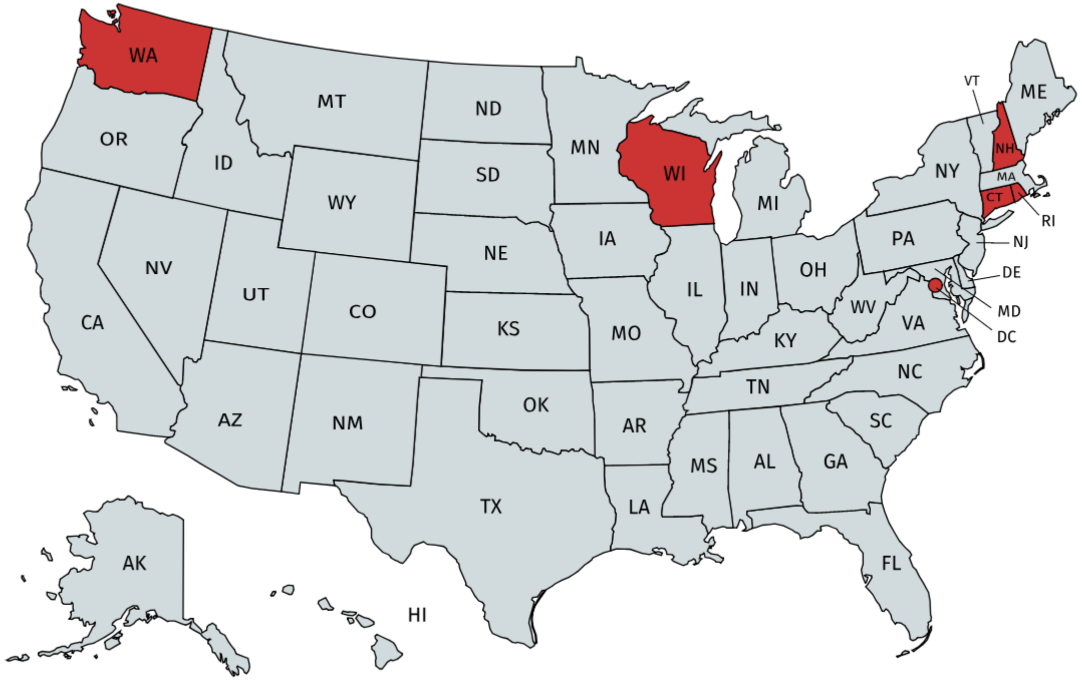
The Clean Energy States Alliance (CESA) is working with five states and the District of Columbia to identify locations where solar and other DERs could increase the reliability and resilience of the electric grid.



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CleanEnergy
States Alliance

Enabling High Penetration of Distributed PV via Optimization of Subtransmission Voltage Regulation

Nader Samaan, PhD, PE (PNNL)

Project Team: Prof Alex Huang (UT)
Prof. Ning Lu (NCSU)
Dr. Yazhou Jiang (GE),
Dr. Greg Smedley (One Cycle Control)
Mr. Brant Werts (Duke Energy)

Clean Energy States Alliance (CESA) Webinar

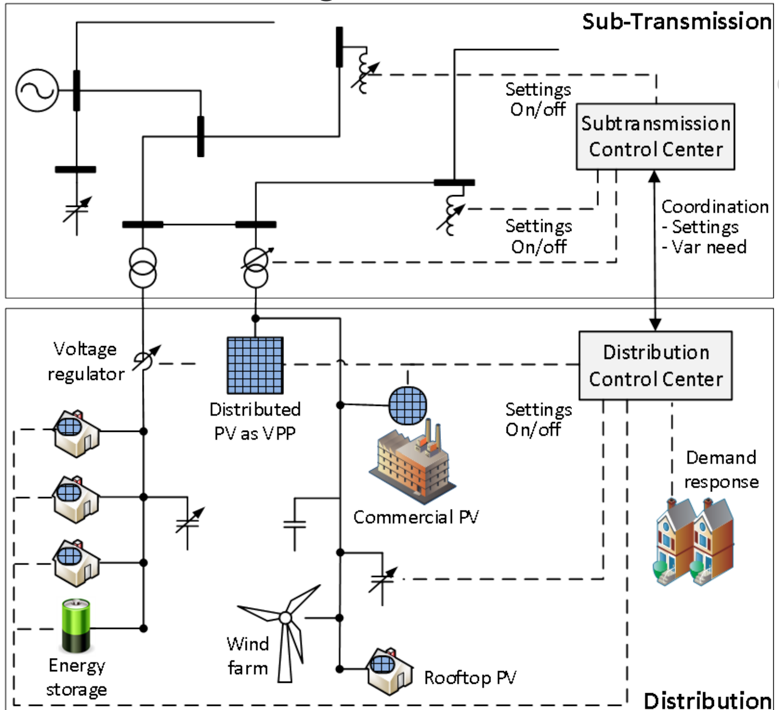
March 28, 2019

PNNL is operated by Battelle for the U.S. Department of Energy

Overview

Challenges

- Voltage regulation at subtransmission impedes solar penetration.
- Regulation devices are uncoordinated, unable to cope independently with system net load changes.



Solutions

- Develop a Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT):
  - autonomous and supervisory control via flexible algorithm
  - co-optimization of distribution and subtransmission scales
- Develop an Optimal Future Sub-Transmission Volt-Var Planning Tool (OFuST-VPT):
  - Determine the size and location of new reactive compensation equipment needed to integrate high penetration of photovoltaic (PV) generation.
  - Consider the coordination achieved by CReST-VCT.

Outcomes

- High penetration of PV (100% of substation peak load, without violating voltage requirements)
  - Allow utilities to meet ANSI, IEEE, and NERC standards.
- Planning and operational support to utilities
  - Reduce interconnection approval time and cost.

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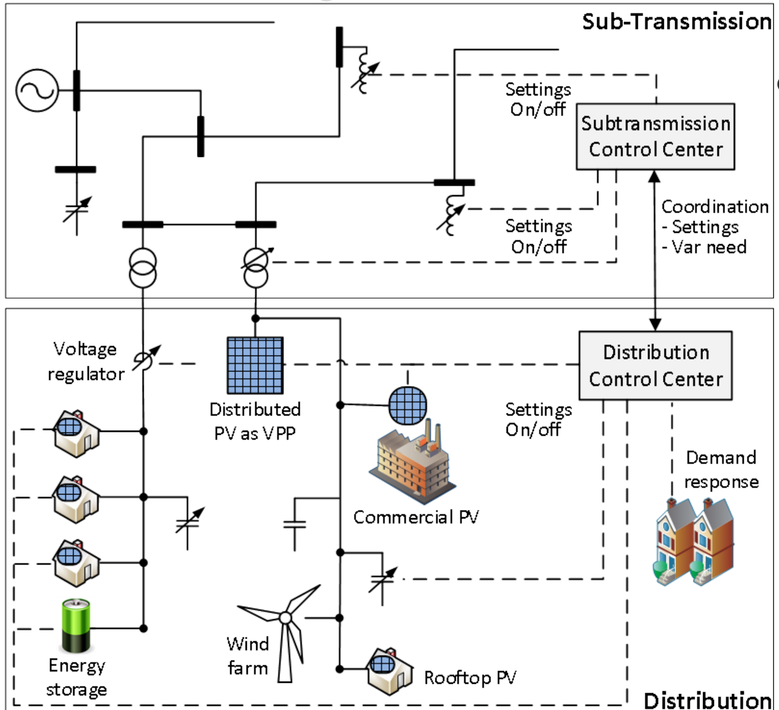

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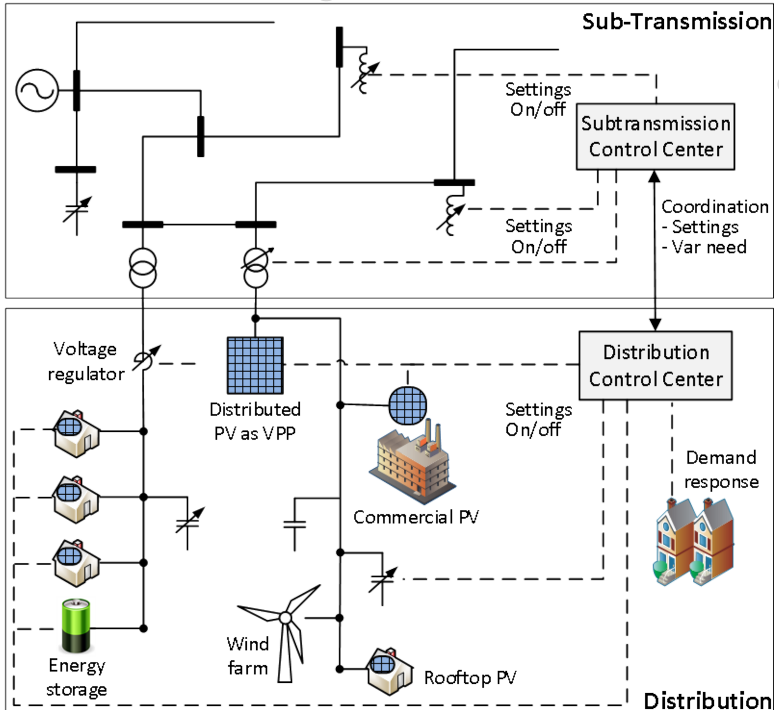

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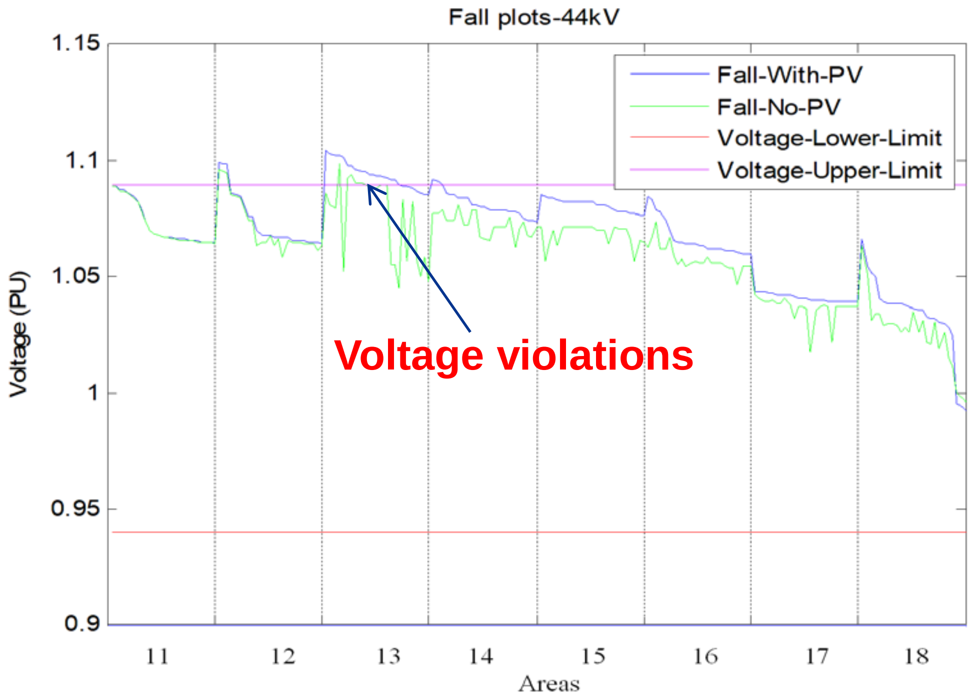
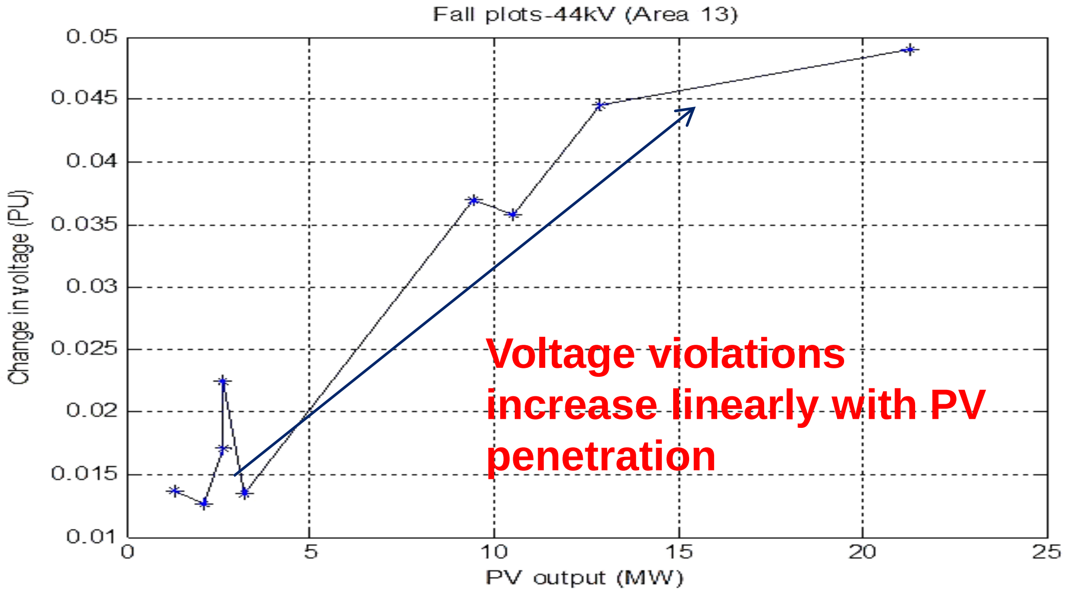
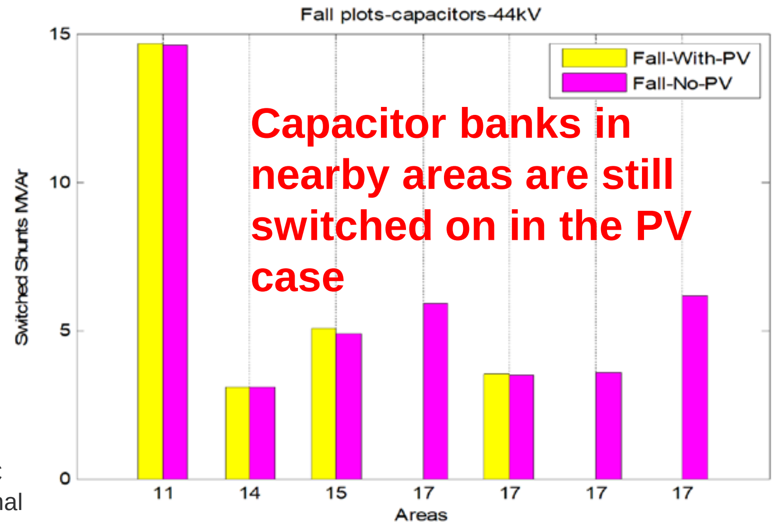
PNNL Study* Showed Volt/Var Regulation Challenge at Subtransmission Level





System voltage magnitudes increases almost proportionally when the PV outputs increase

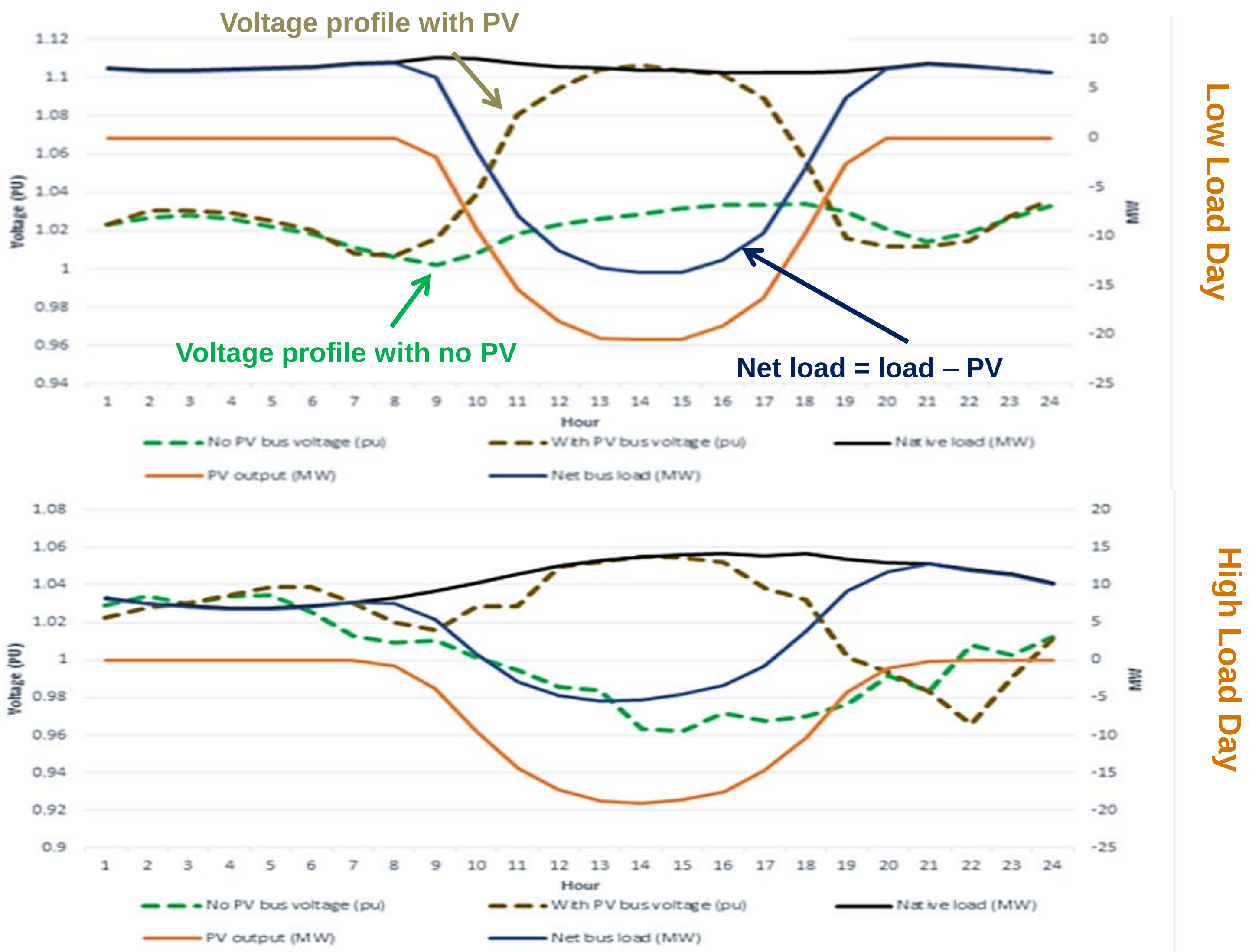
- Under modest penetration of distributed PVs, controlling overvoltage becomes a challenge at the subtransmission level.
- Voltage regulation challenges at subtransmission are a barrier to high penetration of PVs. Developers of new PV projects target interconnection to subtransmission to reduce interconnection cost.



No coordination of capacitor bank switching

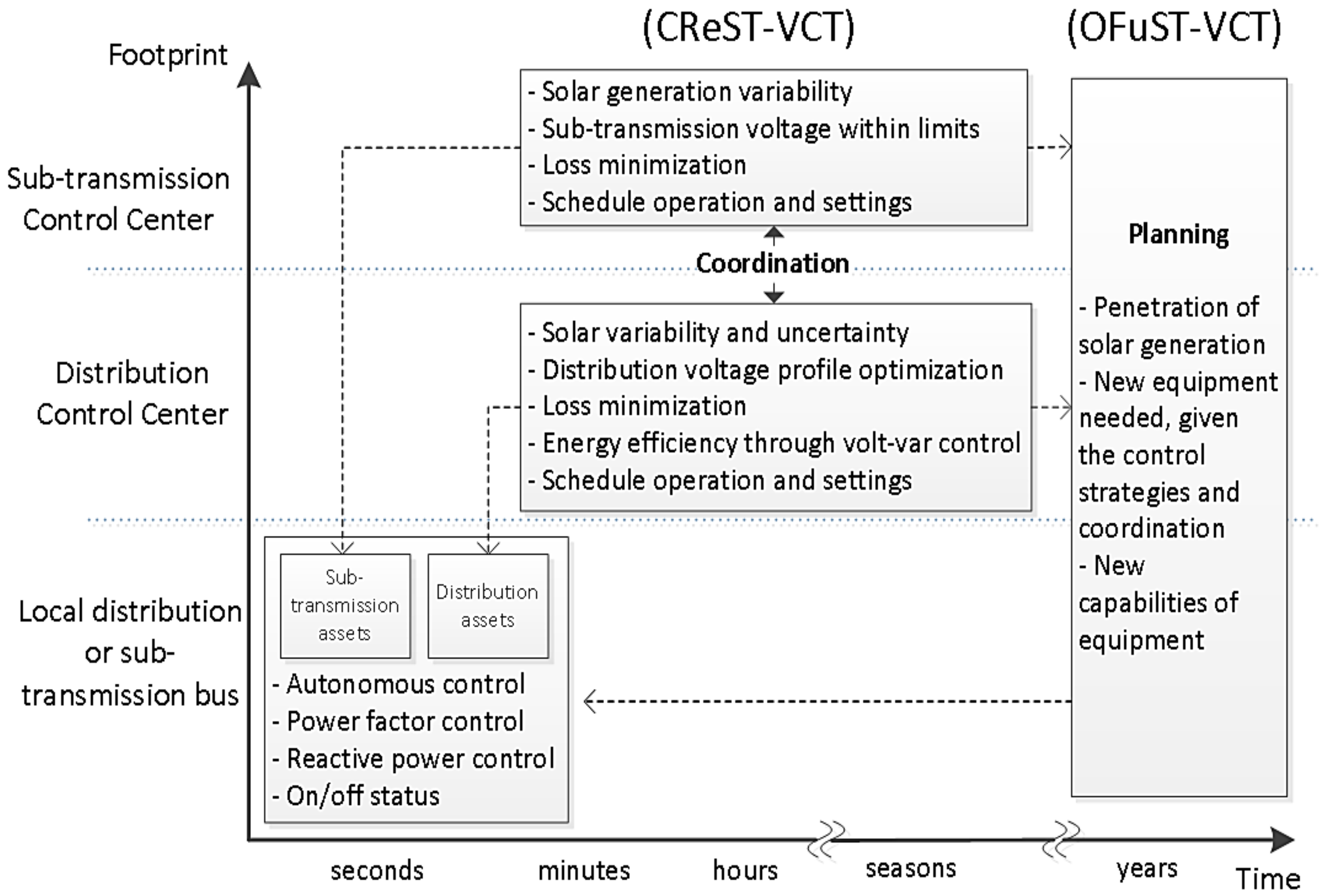
*Lu S, NA Samaan, D Meng, FS Chassin, Y Zhang, B Vyakaranam, WM Warwick, JC Fuller, R Diao, TB Nguyen, and C Jin. 2014. *Duke Energy Photovoltaic Integration Study: Carolinas Service Areas*. PNNL-23226, Pacific Northwest National Laboratory, Richland, WA. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22117.pdf

Substation Voltage Profile Comparisons under High PV Penetration (Low vs. High Load)



Under low load condition and high PV penetration, there is a potential for overvoltage problems.

Project Objectives

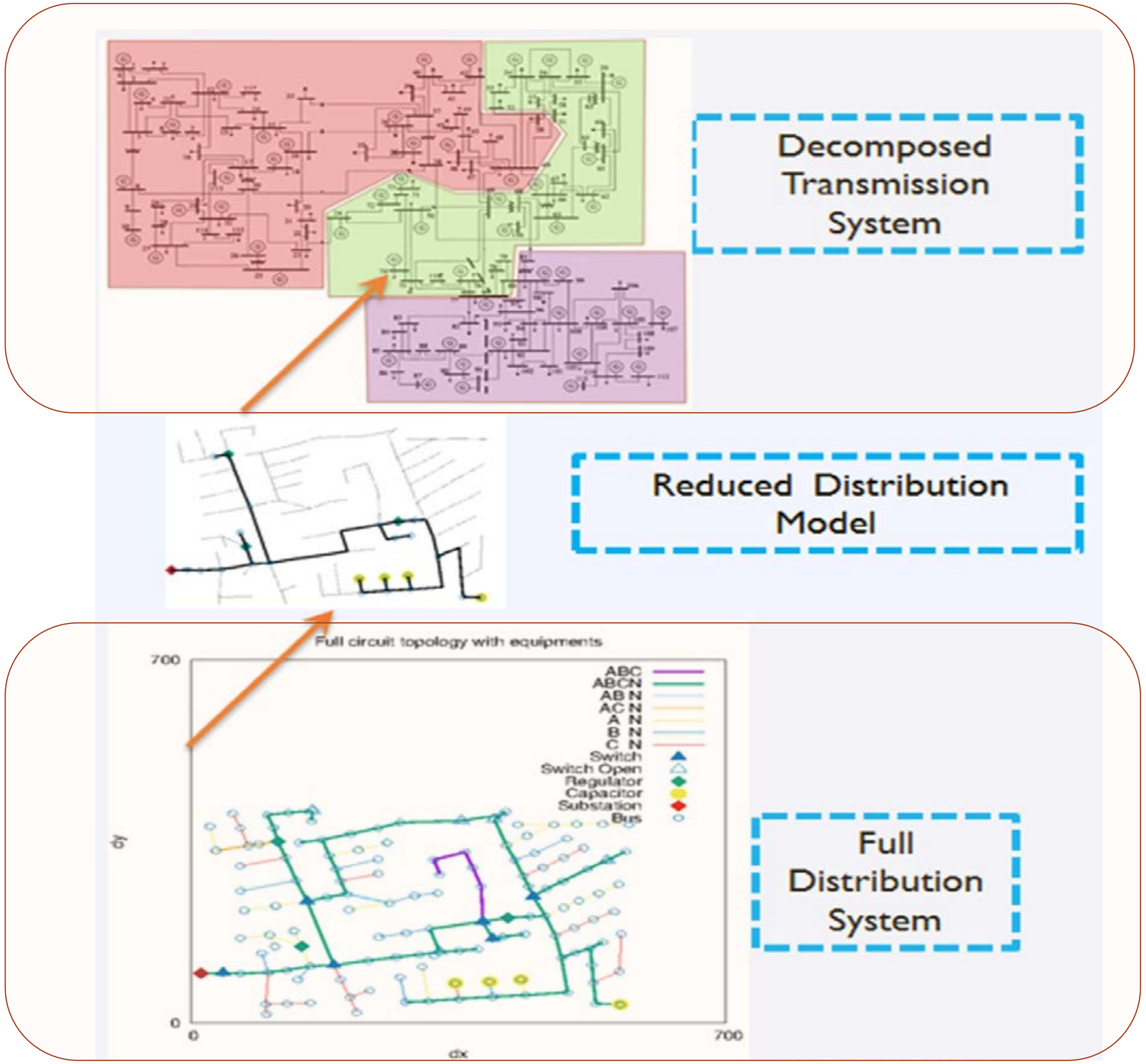


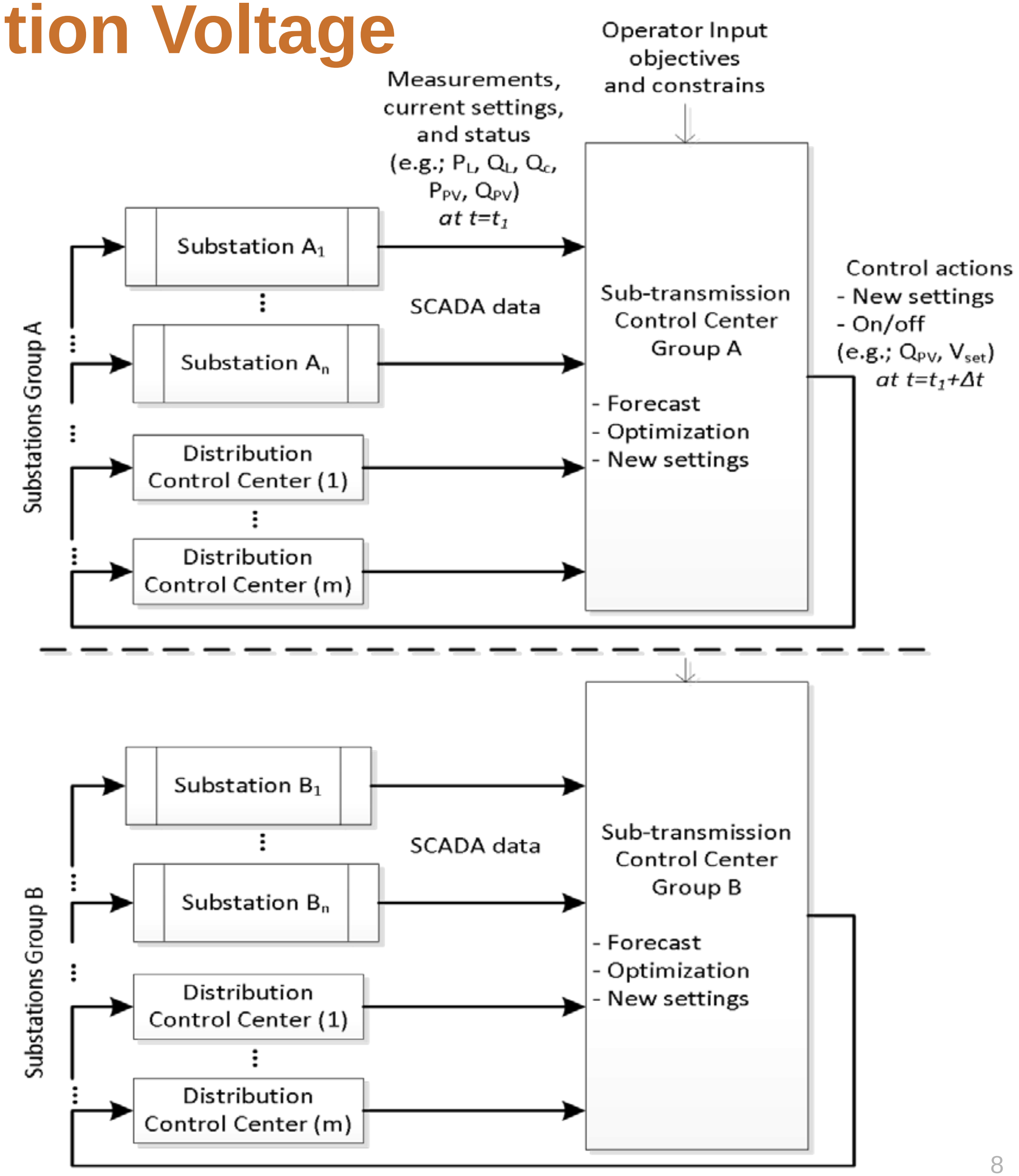
- Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT)
- Optimal Future Sub-Transmission Volt-Var Planning Tool (OFuST-VPT) for short- and long-term planning

Key Milestones and Deliverables

Year 1	Stand-alone prototype of CReST-VCT
Year 2	Simulation demonstration of CReST-VCT and prototype of OFuST-VPT
Year 3	Field demonstration of CReST-VCT, industry outreach, final report, and the codes for the two tools

Scalability of the Solution: Co-Optimization of Transmission and Distribution Voltage





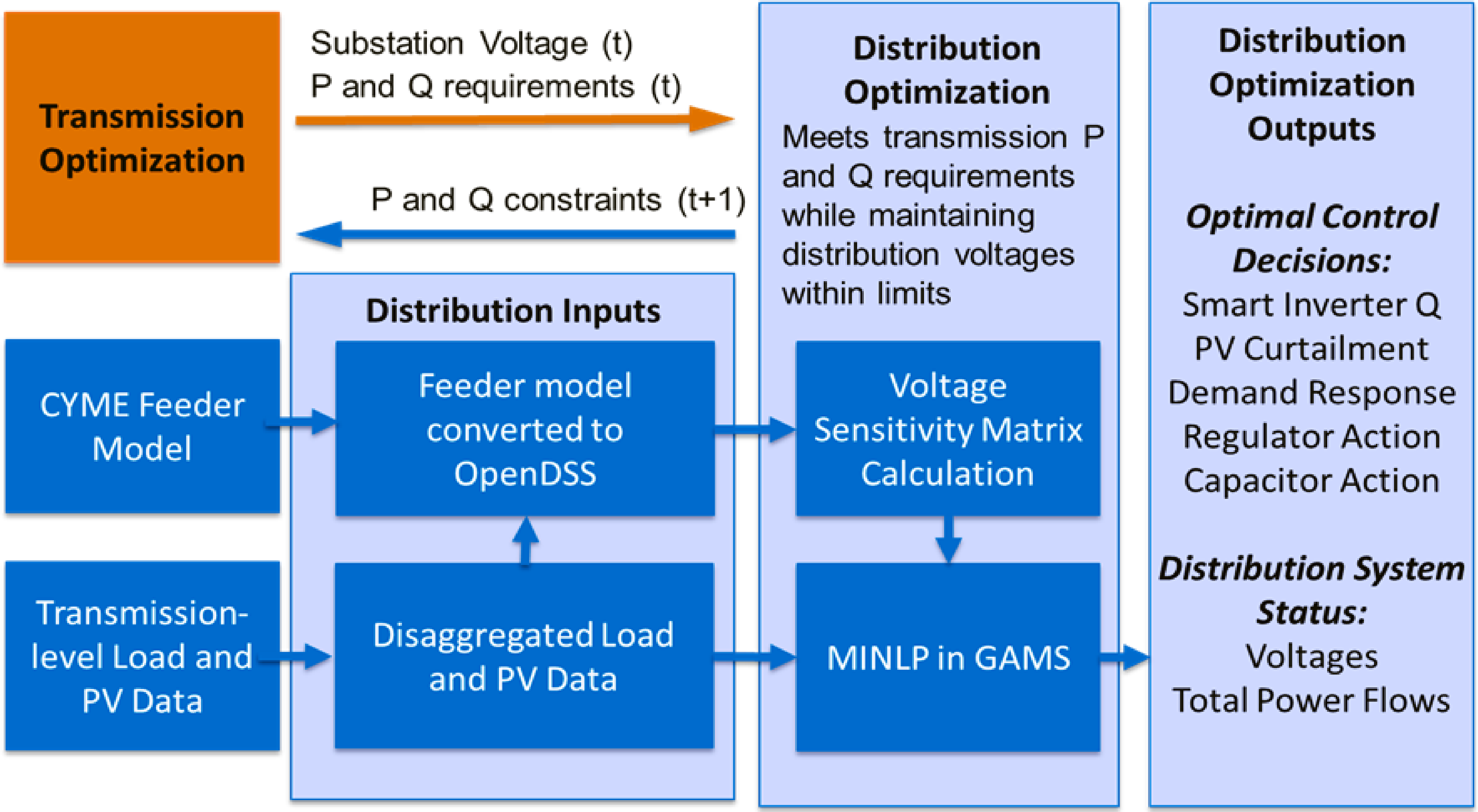
Transmission AC Optimal Power Flow for Reactive Power Optimization

- Objective function: minimize weighted sum of
  - load bus voltage deviation from target value
  - transmission losses
  - capacitor bank switching
  - curtailment of controllable distributed solar output
  - use of demand response

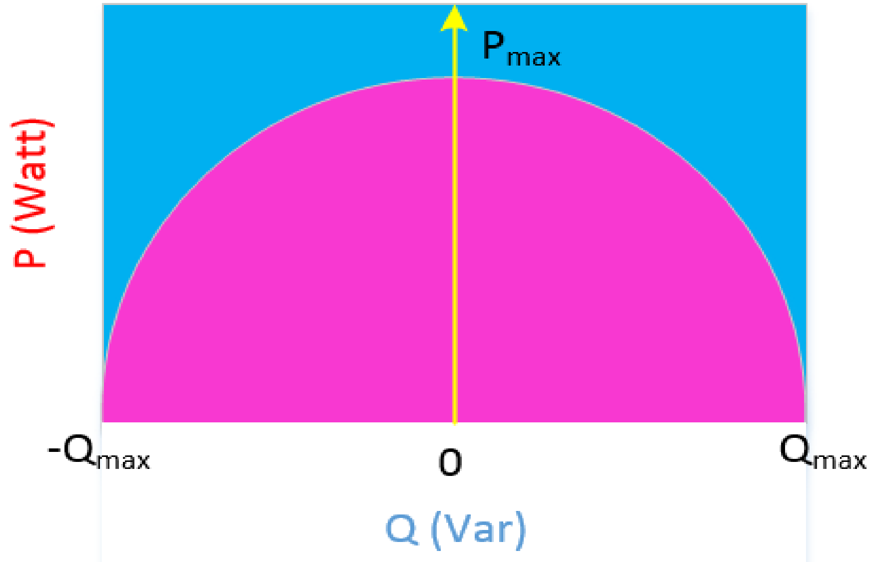
- Subject to
  - AC power flow balance on each bus
  - power plant scheduled real power, except on distributed slack
  - power plant scheduled voltage and reactive power limits
  - load real and reactive power
  - distributed solar real power output
  - bounds on reactive power from distributed solar

- Output variables:
  - reactive power requirements from distributed PV at each substation
  - reactive power form capacitor banks at different substation
  - real/reactive power required from demand response
  - real power curtailment from PV

Distribution Volt/Var Optimization Tool (NCSU)



Improved PV Inverter Active and Reactive Constraint Model



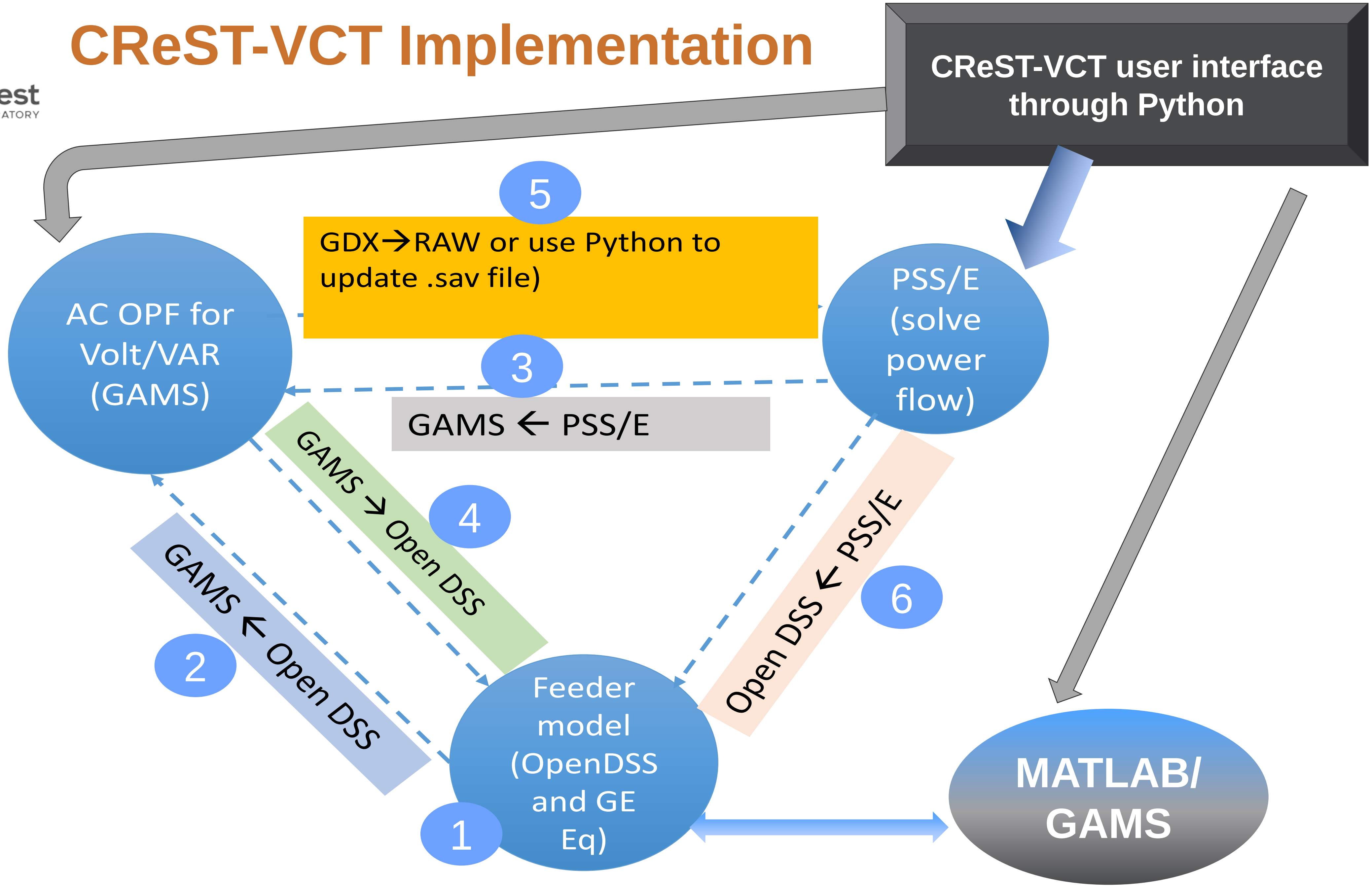
$$\frac{P^2}{P_{max}^2} + \frac{Q^2}{Q_{max}^2} \leq 1$$

$$Q_{max} = kP_{max}$$

k is the **improved factor** for reactive power constraint, **1.1** for a normal **IGBT-based** PV inverter

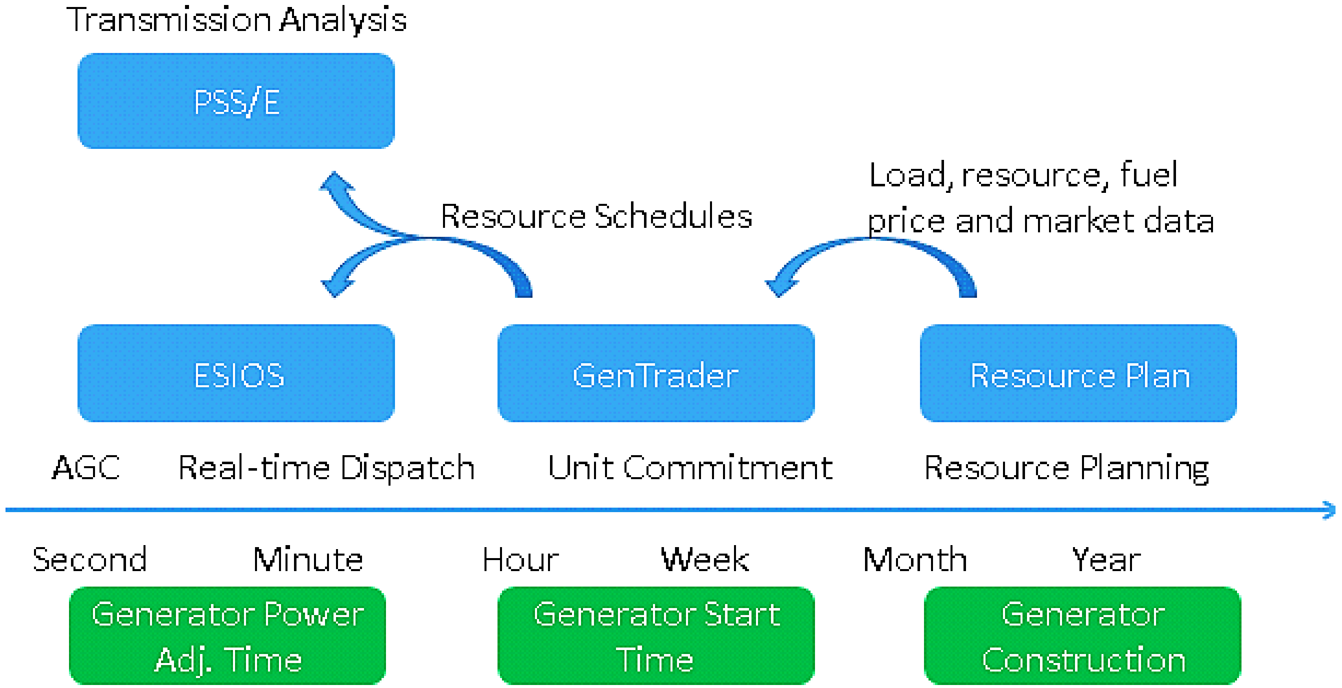
- *k* should be adjusted based on power electronics devices and modulation method.
- The *P*/*Q* constraint is also dependent on the filter and DC capacitor design.
- During nighttime when *P* = 0, reactive power injection results in additional power losses that might become an economic constraint.
- Three different reactive power regulation modes can be provided by the inverter (constant *Q*, constant Power Factor, and volt-var). We are using constant *Q* that is obtained from the optimization engine.

CReST-VCT Implementation

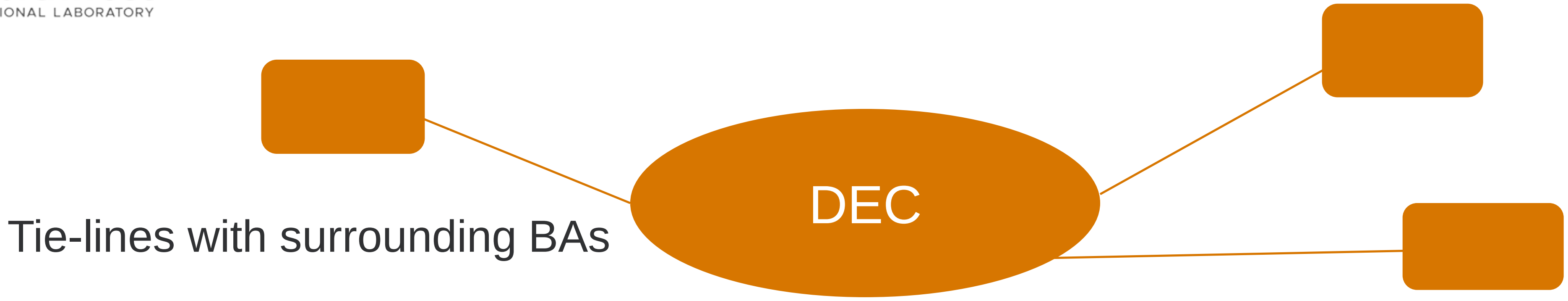


Duke Energy Generation Dispatch Simulation Approach

- Methodology
  - PNNL is leveraging from previous efforts performing solar integration studies for Duke Energy
  - Production cost simulations for an entire future year, with and without PV were used
    - ✓ Hourly scheduling of generation resources using GenTrader software
    - ✓ Real-time (5 min) redispatch of peaking and Automatic Generation Control (AGC) units using ESIOS (PNNL tool)



Duke Energy Data Collection Transmission Model



- Start with a 2025 Eastern Interconnection base power flow case; build an island of the DEC transmission system.
  - Identify all tie-lines for each island.
- Use consistent import, export, generation, PV, and load assumptions with generation analysis.
- Aggregate distributed PV to the nearest substation on the transmission model.
- Run chronological AC power flow for the whole system and for the entire study year (8760 power flow cases).

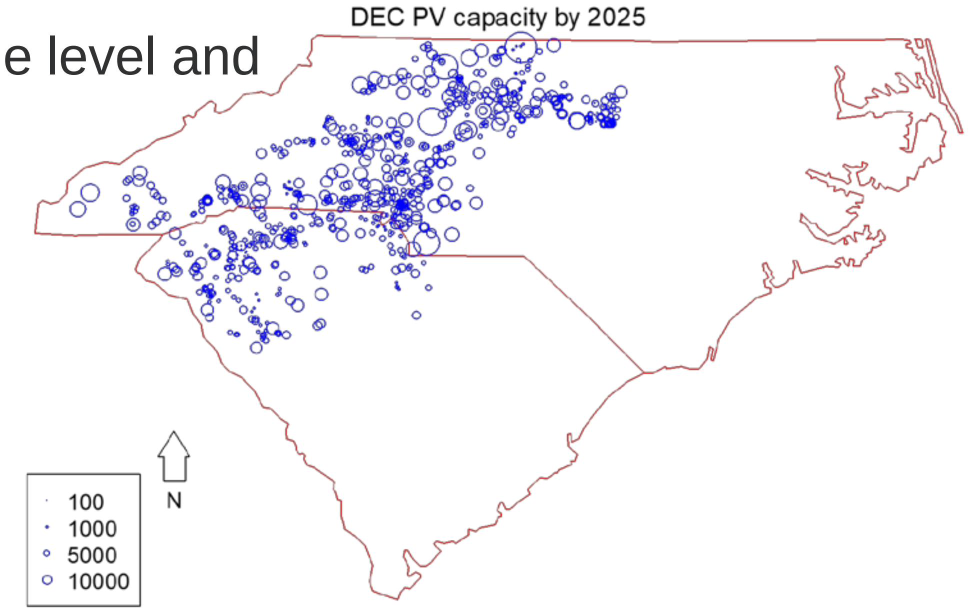
Duke Energy Study Case System Summary

- **DEC/DEP System**
  - Maximum load of 39,114 MW
  - Maximum PV output is 9,435 MW (24.1% of the peak load)
  - PV installed capacity is 9,379 MW (24% of the peak load)
- This covers the two Duke Energy balancing authorities, DEC and Duke Energy Progress (DEP).
- We did the analysis for **DEC only**.

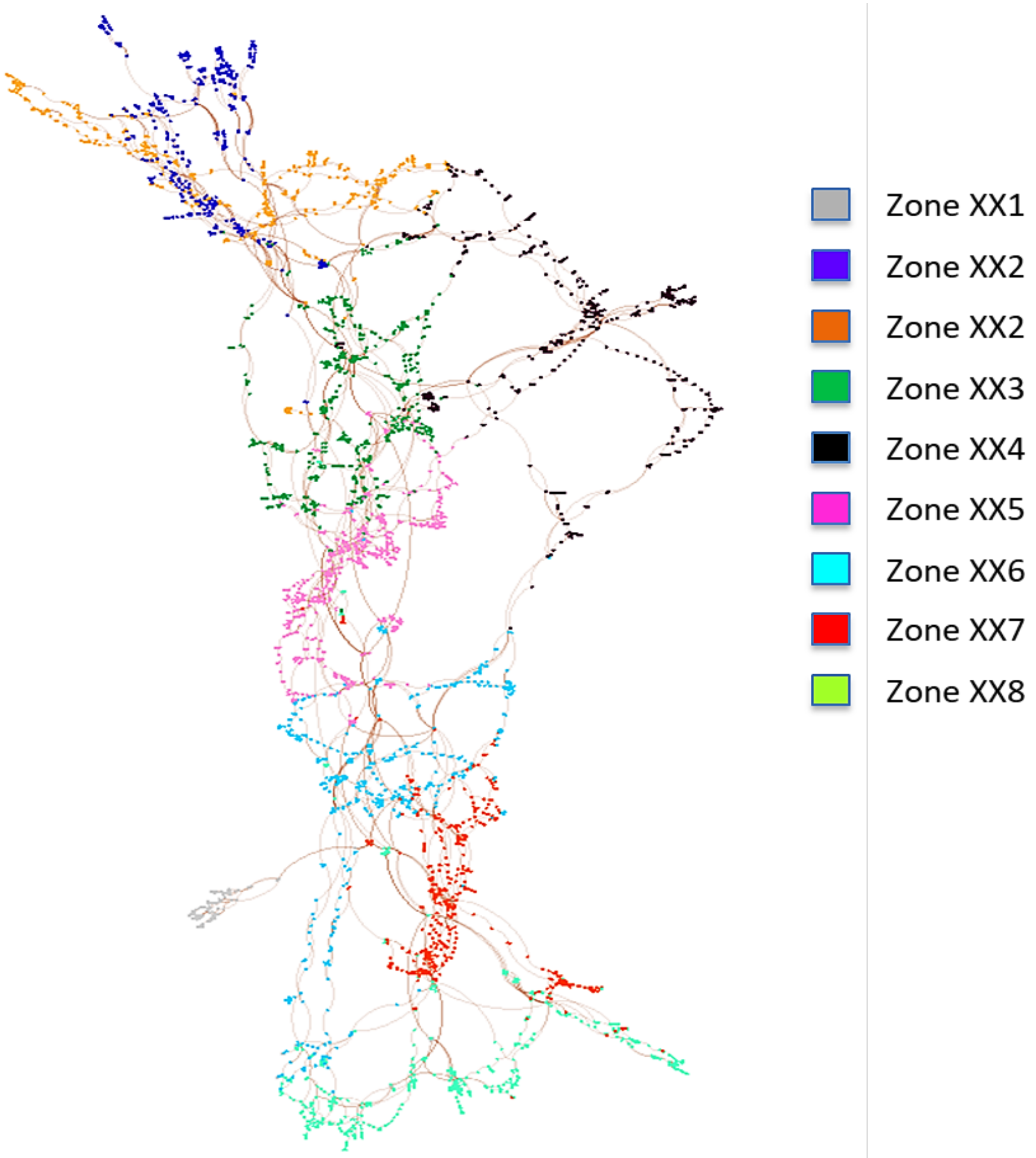
DEC Data	
No. of Buses	3,246
No. of Generator Buses	194
No. of Load Buses	2690
Total Load	20,337 MW
PV Generation	5,056 MW
Total Conventional Generation	25,881 MW

PV Locations (DEC)

- Approximately 25% PV penetration was studied in the base PV cases. Projected PV locations in the Carolinas were based on existing systems and interconnection queue
- Projections of the size, technology, and locations of future distributed + utility-scale solar were made.
- High resolution (1 min or less) solar data was developed based on the selected reference weather model
- Simulated solar time series were developed at ZIP-code level and then aggregated at substations for generation and transmission analysis.



Decomposition of Duke Carolinas Network (DEC) for Vol/Var Control



- No. Buses = 3246
- No. PQ (demand) buses = 3203

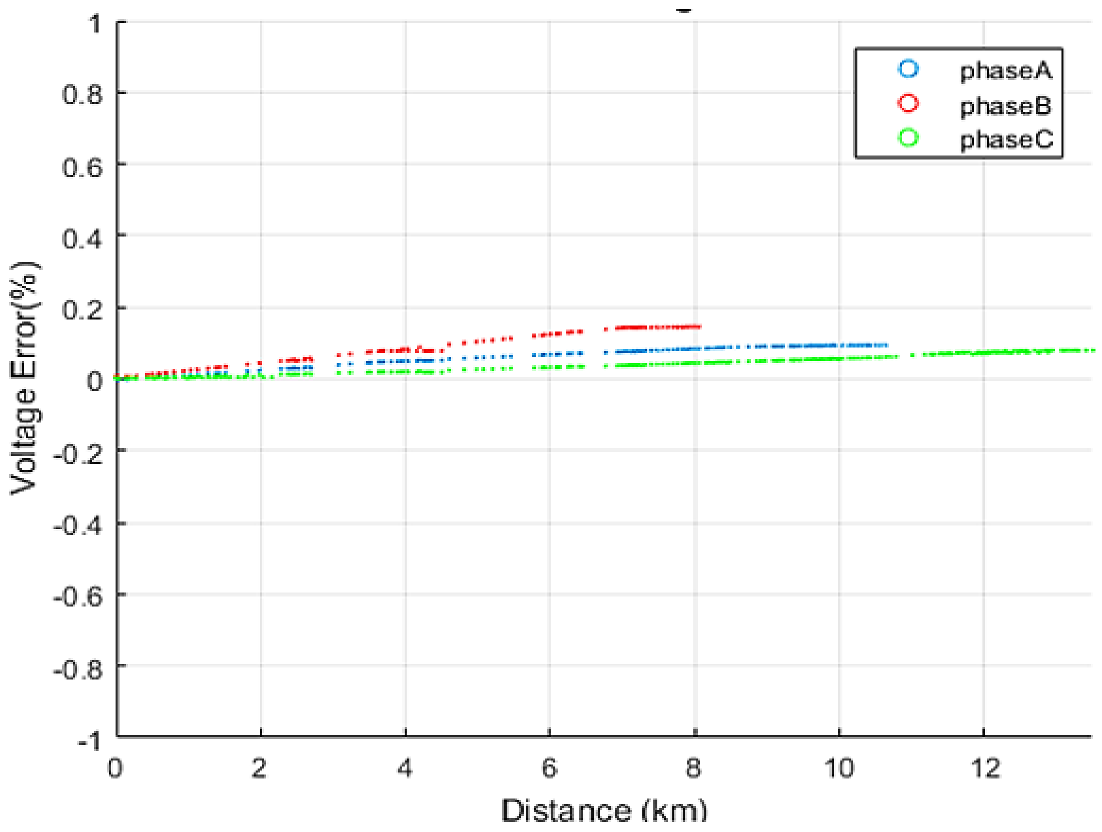
Zone No.	No. Buses	Zone No.	No. Buses
XX1	384	XX5	388
XX2	369	XX6	460
XX3	394	XX7	354
XX4	480	XX8	329

- Network connectivity graph of Duke network
- Not to scale
- Not representative of geographical locations

Distribution Feeder Models

Feeder Model Conversion, Validation, and Data Preparation

- ✓ 10 Duke Energy feeders have been converted from CYME format and validated for OpenDSS.
- ✓ Voltages in OpenDSS are within 1% of voltages in CYME for all feeders.



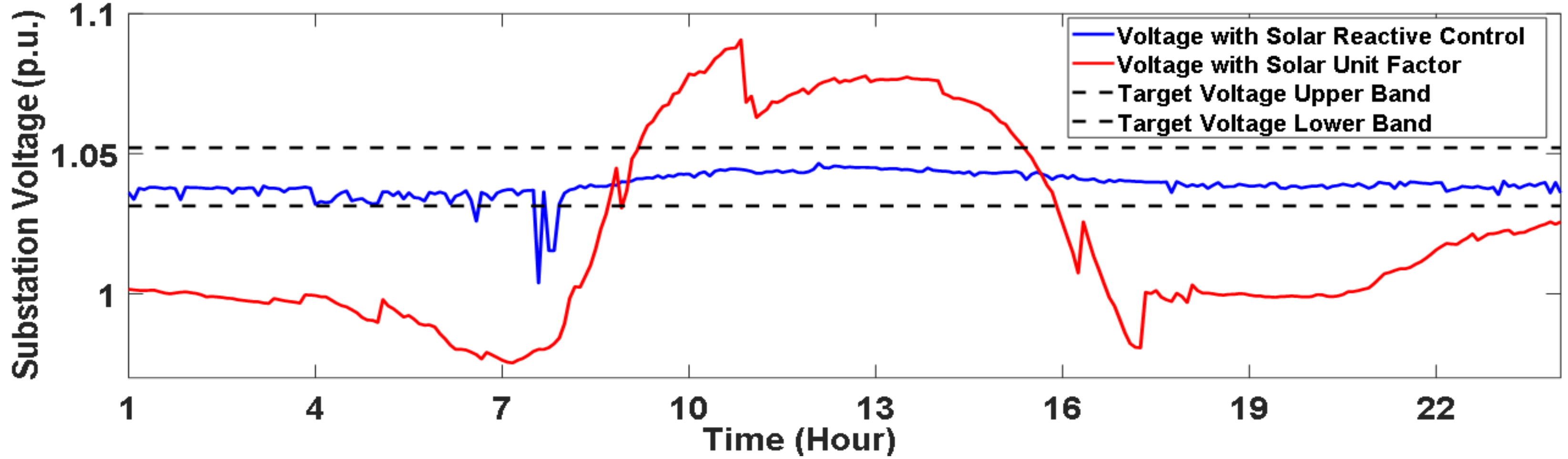
PV Disaggregation at Distribution Feeders

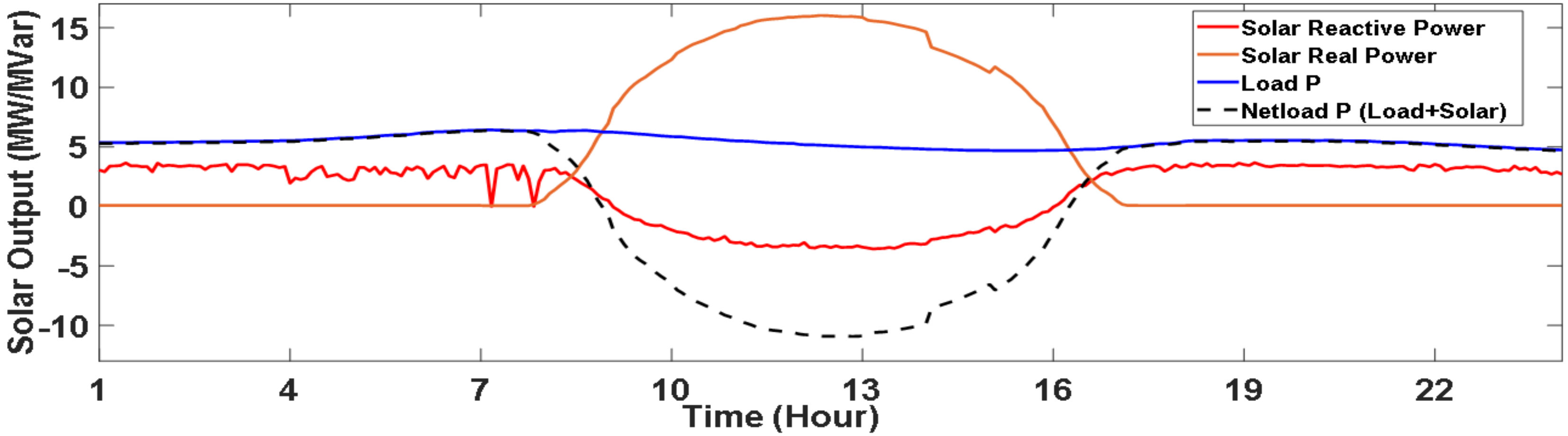
Feeder Model Conversion, Validation, and Data Preparation

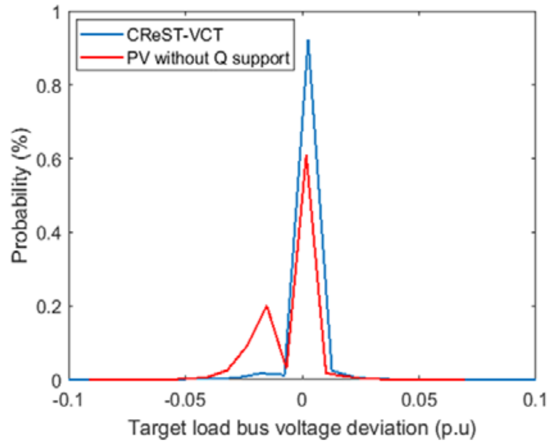
- Aggregated PV at the substation level has been allocated to *3 circuits for substation R* and *2 circuits for substation G* using
  - present locations of PV projects
  - future locations

Feeder Name	Number of utility scale PV	Utility scale PV capacity (kW)	Number of residential PV	Residential PV capacity (kW)	Total PV capacity (kW)
R 1201	3	3,157	0	0	3,157
R 1202	0	0	325	1,624	1,624
R 1203	1 (existing)	5,000	0	0	5,000
G 1202	1	5,000	0	0	5,000
G1203	1	5,000	665	4,825	9,825

Voltage Profiles at Substation for a Winter Day (PV at Unity PF vs. PV Providing Reactive Power Support through CReST-VCT)





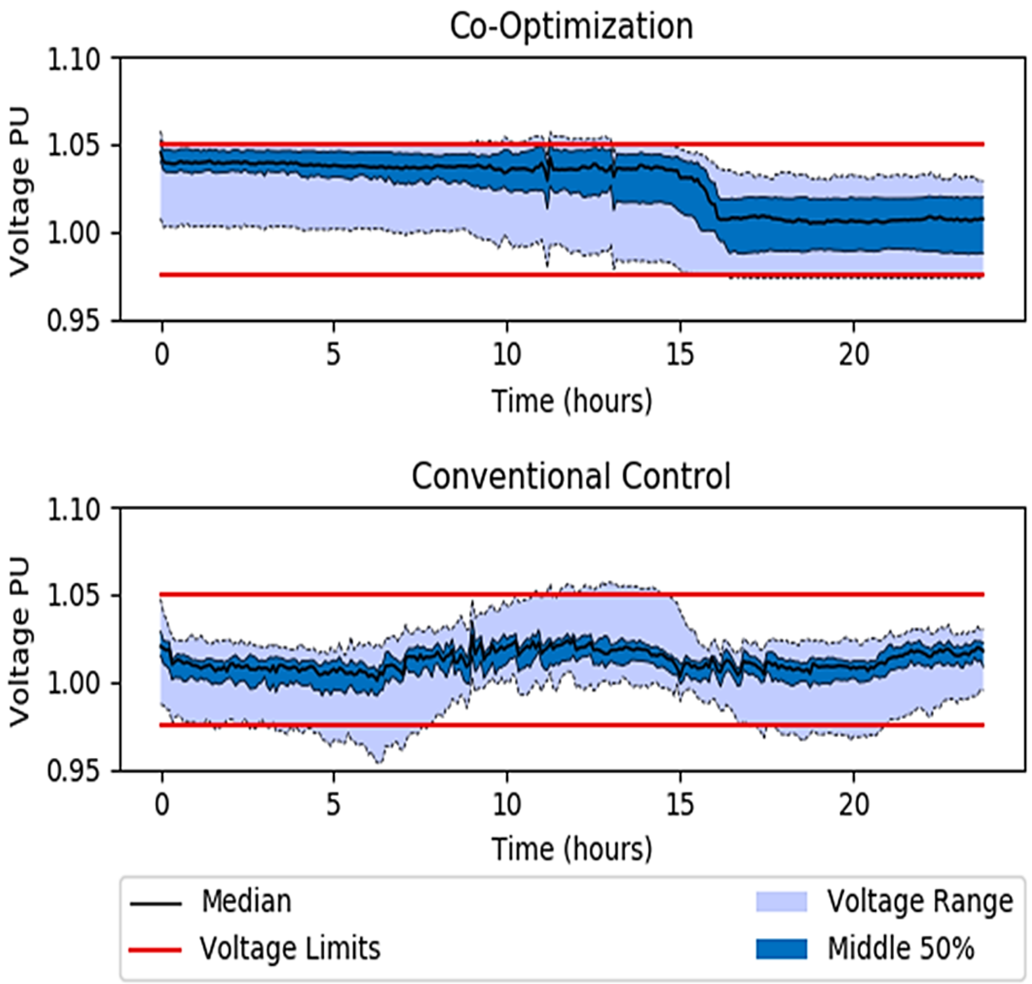


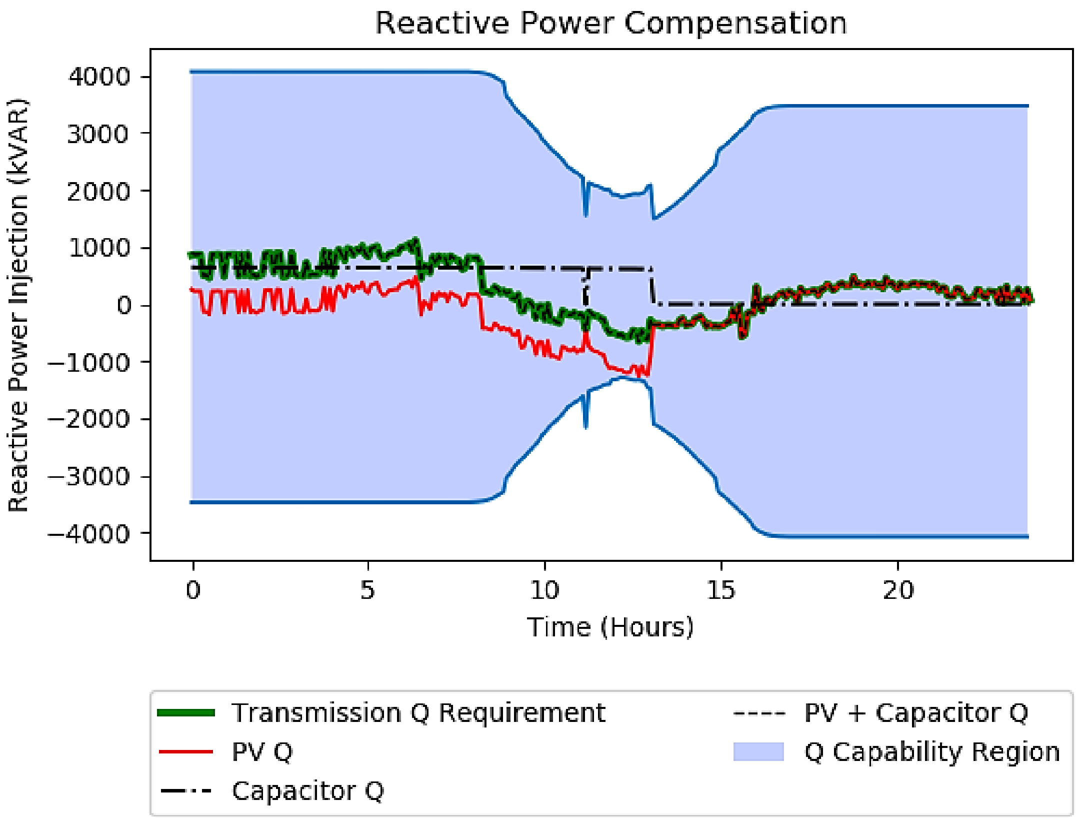
Voltage deviation distribution for all subtransmission load buses for one full winter week at 5-min resolution

Overvoltage problems (red line) have been eliminated (blue line).

Aggregated reactive power from distributed PV (red line, lower graph) is able to maintain the target substation voltage (blue line, upper graph).

Optimizing Distribution Voltage while Meeting Required Subtransmission Support

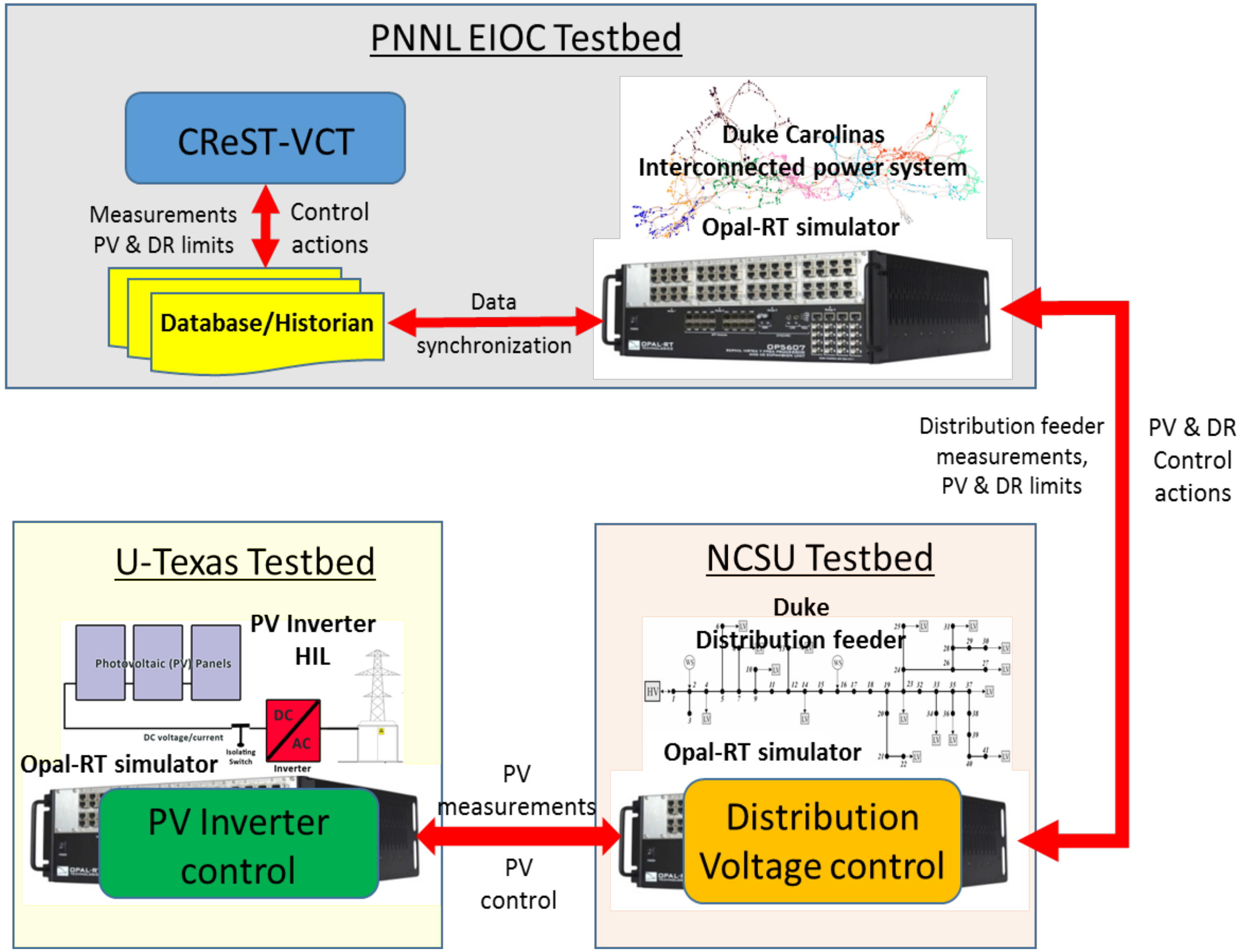




- ✓ Voltage-Load Sensitivity Matrix (VLSM) control algorithm successfully controls distribution system voltages.
- ✓ VLSM control algorithm successfully meets transmission requirements for reactive power.

PNNL – NCSU – UT Hardware-in-the-Loop Demonstration

- Three hardware-in-the-loop (HIL) test systems have been developed to test the performance of
  - CReST-VCT developed at PNNL
  - Distribution voltage control based on PV control and demand response at NCSU
  - PV control with smart inverters at UT-Austin
- An integrated HIL test system have been developed using an Opal-RT facility at each site via a selected communication protocol.



PNNL – Duke Energy – OCC – GE Field Validation

After discussions between PNNL and Duke Energy regarding the Year 3 demonstration, the following options are currently being considered:

A. PNNL will use historical operation data for Duke Energy system
   - Validate that our simulation model is able to calculate voltage profiles at different substations as observed from actual data.
   - Apply CReST-VCT and show how voltage profiles could be improved with PV inverters providing reactive support.

B. PNNL will import Duke Energy day-ahead dispatch, load, and solar forecast data to perform the following:
   - Use CReST-VCT to predict hourly reactive power dispatch for a solar plant connected to one of the substations to meet a certain voltage profile.
   - The owner of the PV plant will apply these values in real time.
   - Actual measurements will be compared with day-ahead predicted values.

Conclusions

- A Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT) has been developed to optimize the use of
  - reactive power control devices and
  - PV smart inverters.
- PV inverter models for active and reactive power regulation have been developed and validated.
- Preliminary results show volt/var optimization at subtransmission can be achieved by taking advantage of reactive power capabilities of distributed PV smart inverters.
- Voltage profiles are co-optimized on both subtransmission and distribution levels.
- The proposed tool would enable higher PV penetration without negative effects on the power grid.

Acknowledgments

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- The project team wants to especially thank Mr. Jeremiah Miller, Dr. Guohui Yuan, and Dr. Kemal Celik from the Systems Integration Subprogram at DOE's SunShot Initiative for their continuing support, help, and guidance.

Questions?

Thanks!

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Project publications: https://www.researchgate.net/project/Enabling-high-penetration-of-distributed-PV-through-the-optimization-of-sub-transmission-voltage-regulation

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