Pacific Northwest NATIONAL LABORATORY

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

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Challenges for Distribution Planning, Operational and Real-time Planning Analytics

DOE SETO SI Workshop

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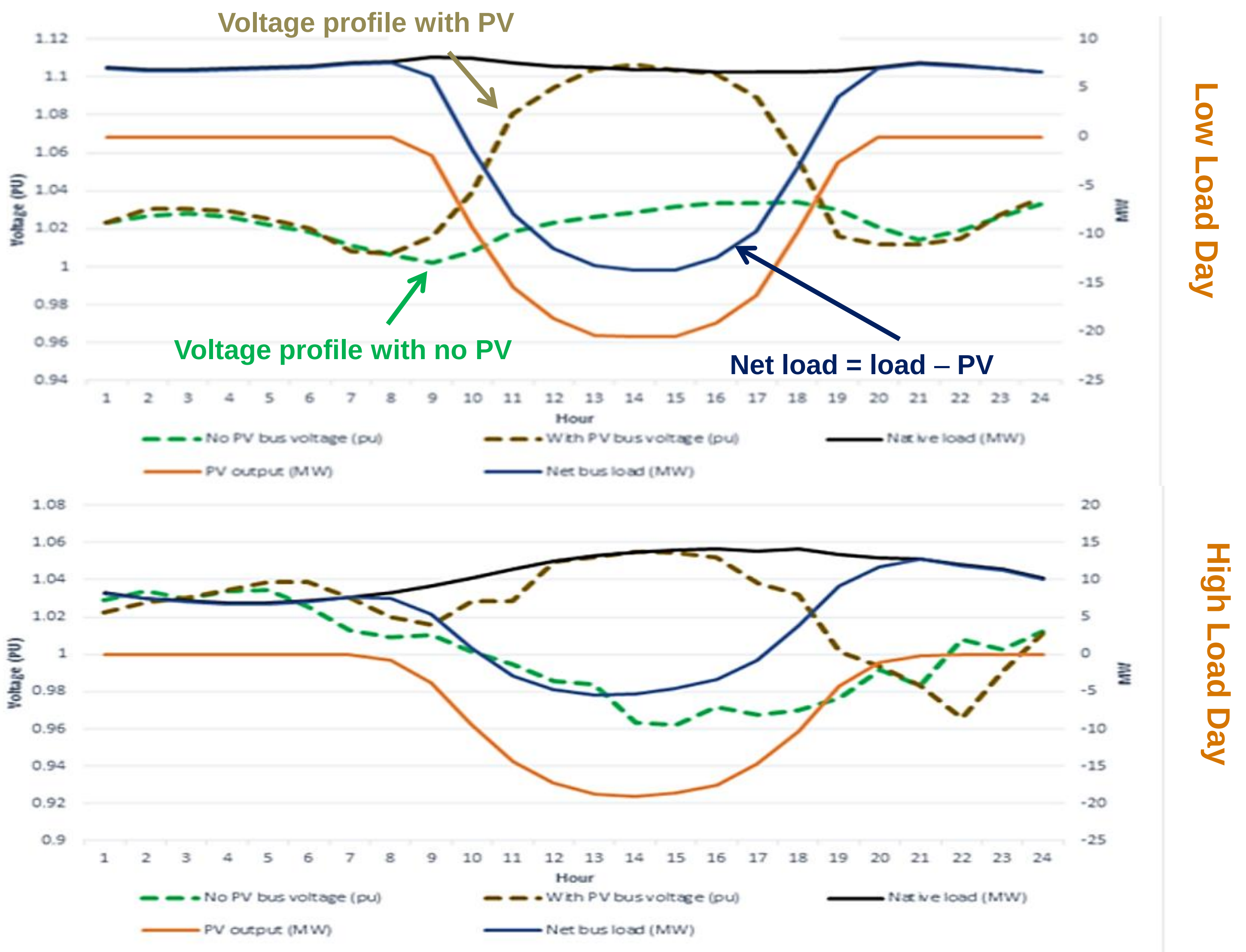
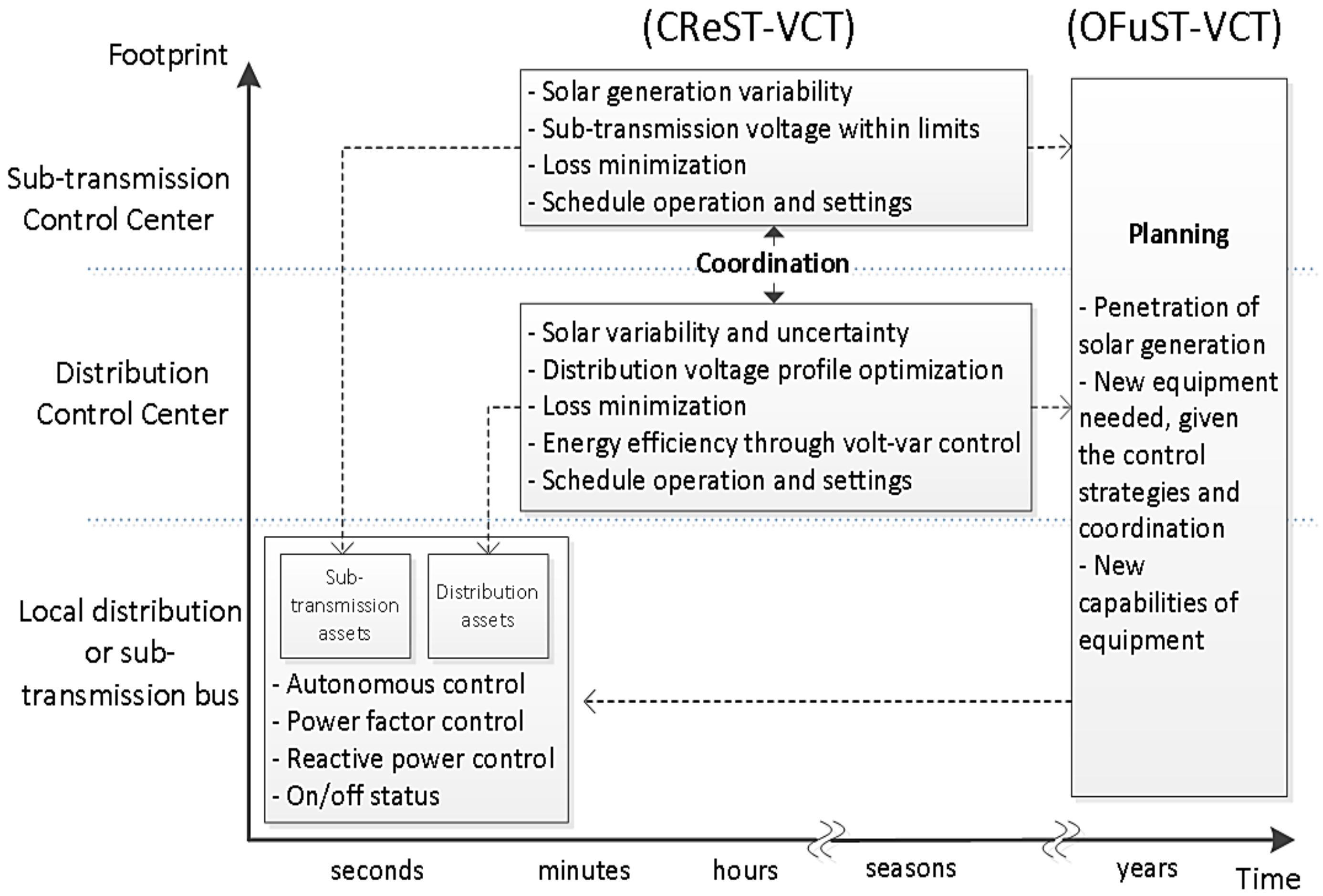
Substation Voltage Profile Comparisons under High PV Penetration (Low vs. High Load)



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

Project Objectives

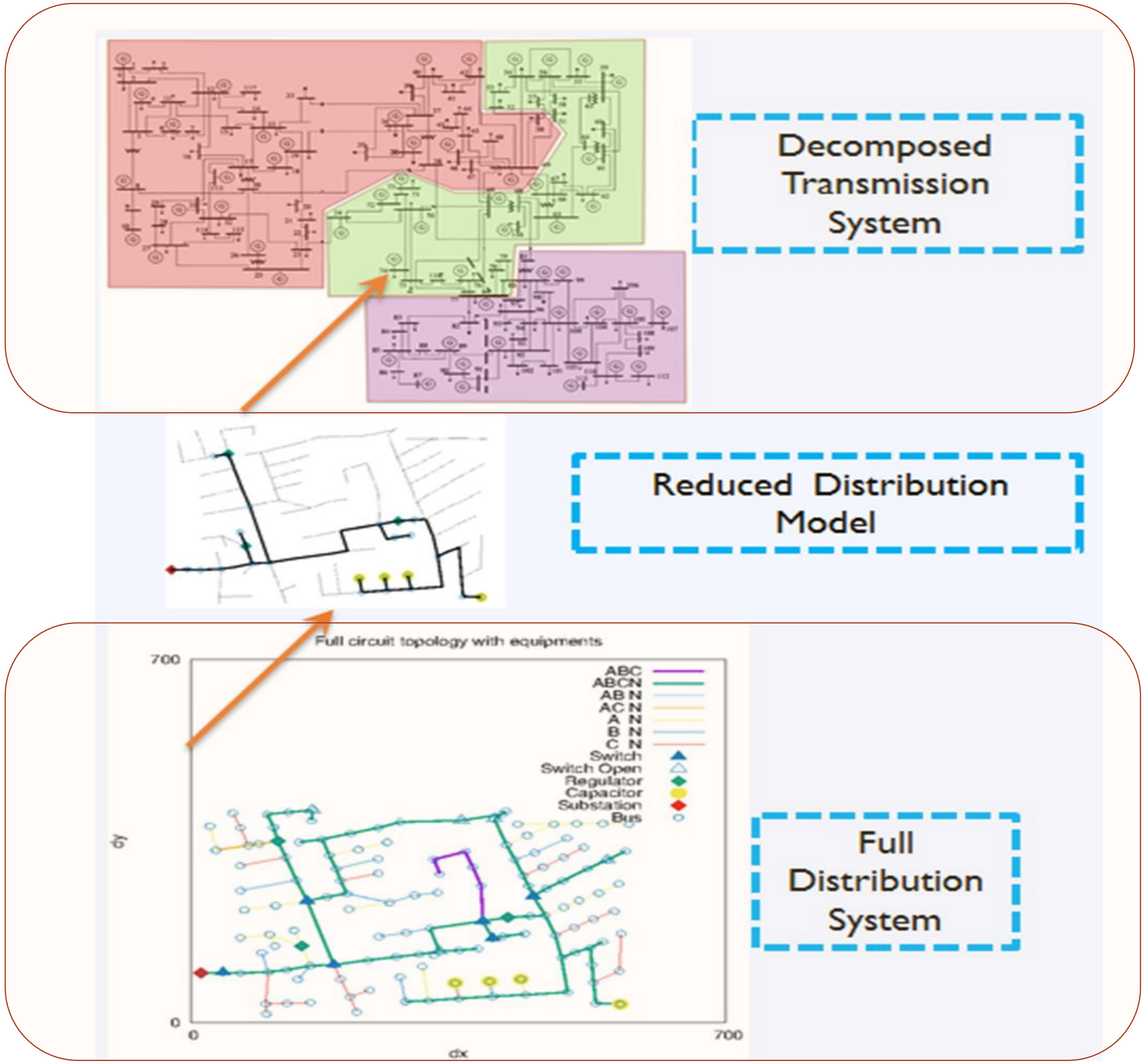


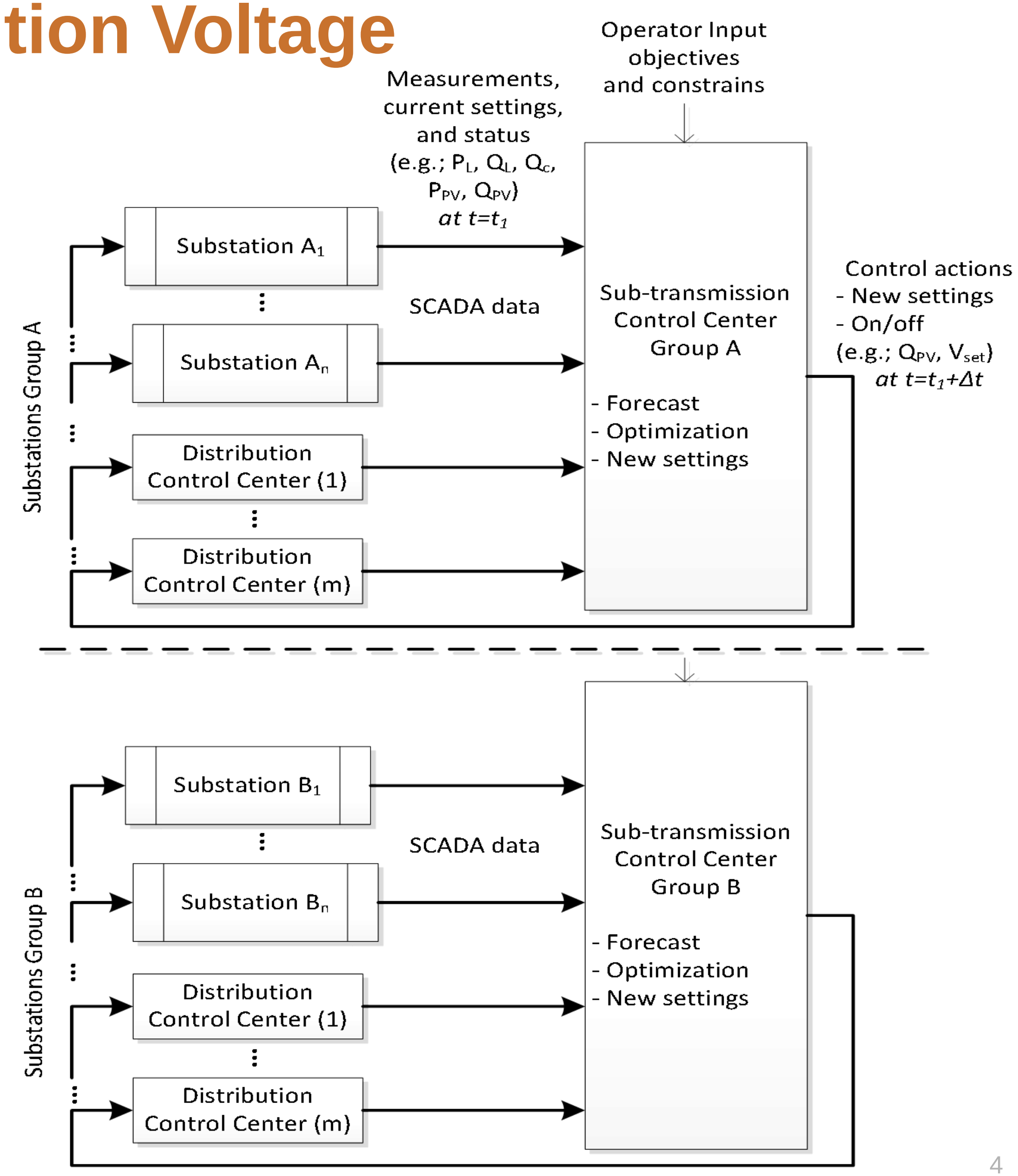
- Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT)
- Optimal Future Sub-Transmission Volt-Var Planning Tool (OFuST-VPT) for short- and long-term planning

Key Milestones and Deliverables

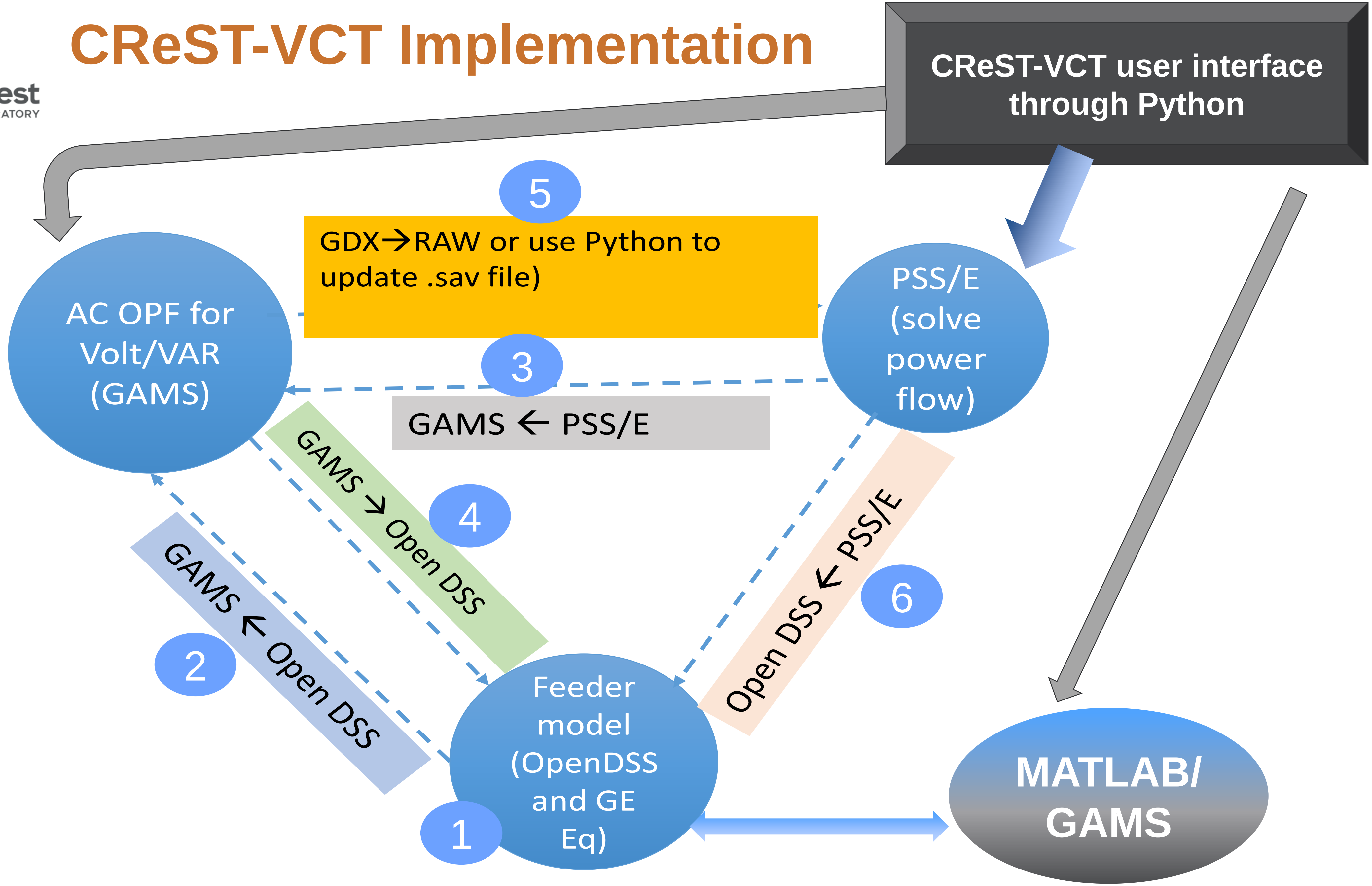
Year 1	Stand-alone prototype of CReST-VCT
Year 2	Simulation demonstration of CReST-VCT and prototype of OFuST-VPT
Year 3	Field demonstration of CReST-VCT, industry outreach, final report, and the codes for the two tools

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



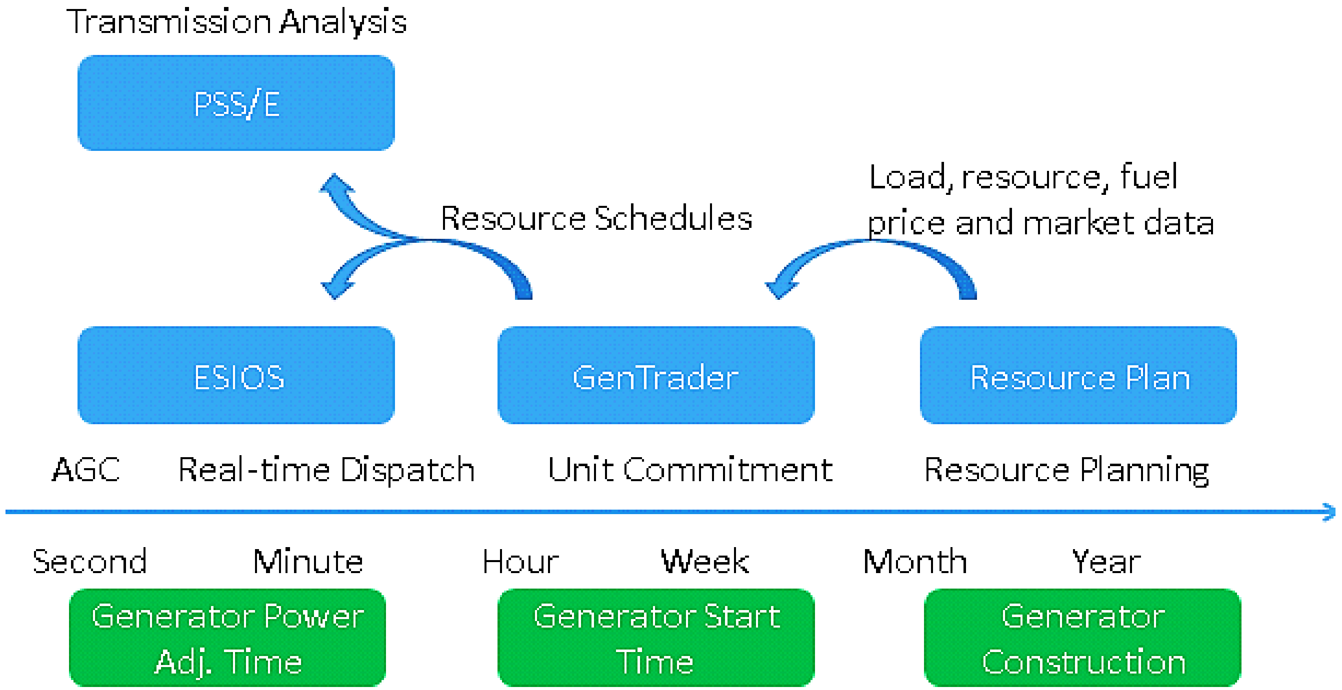


CReST-VCT Implementation



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 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

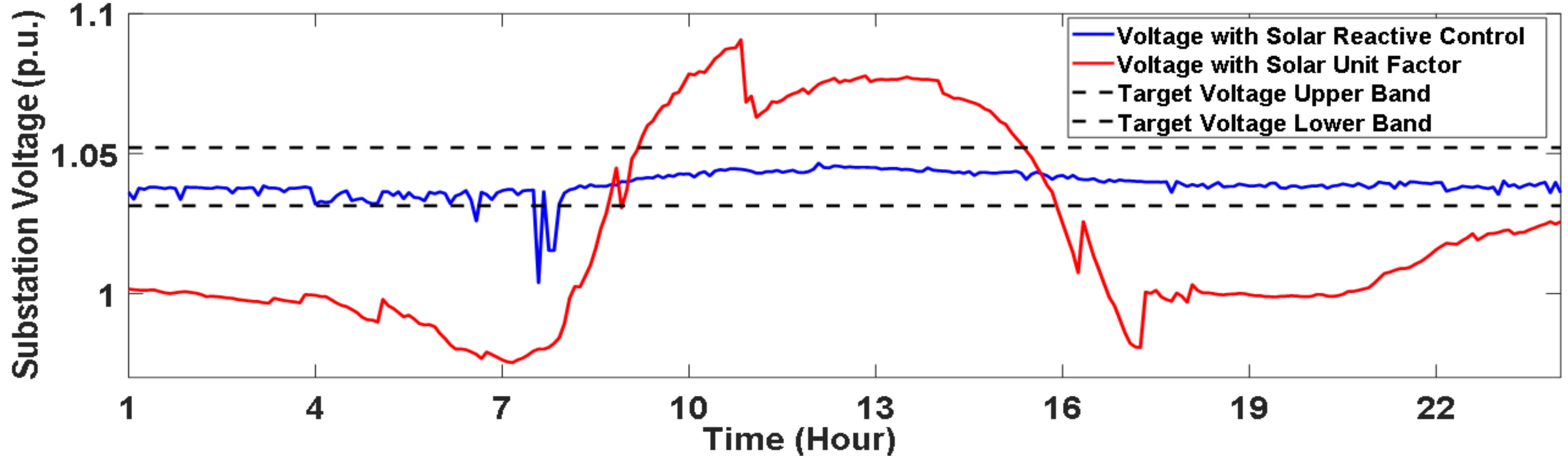
PV Disaggregation at Distribution Feeders

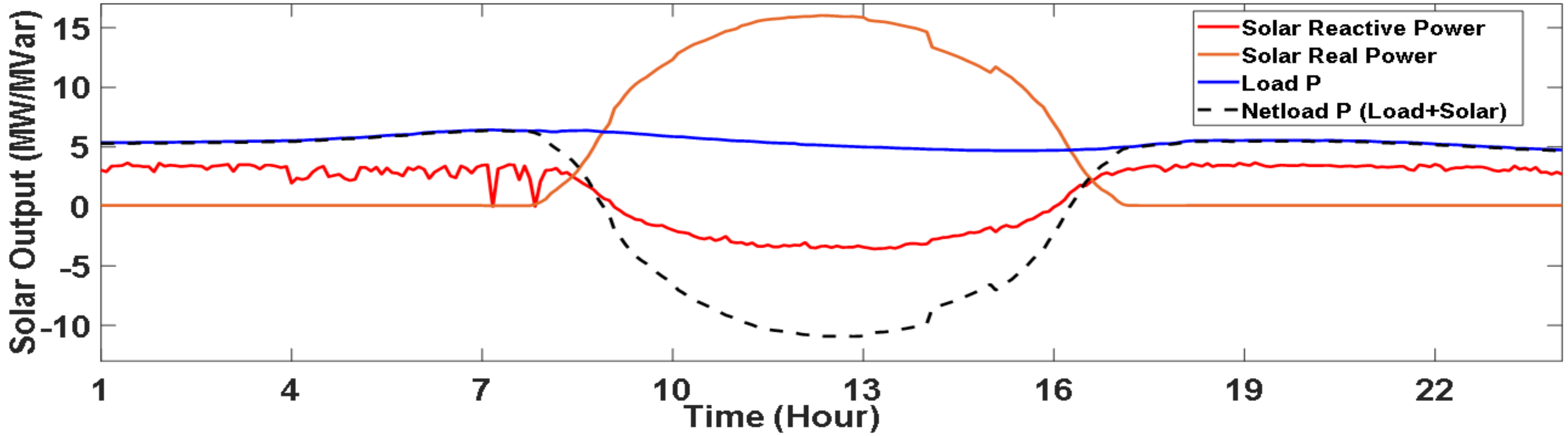
Feeder Model Conversion, Validation, and Data Preparation

- 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

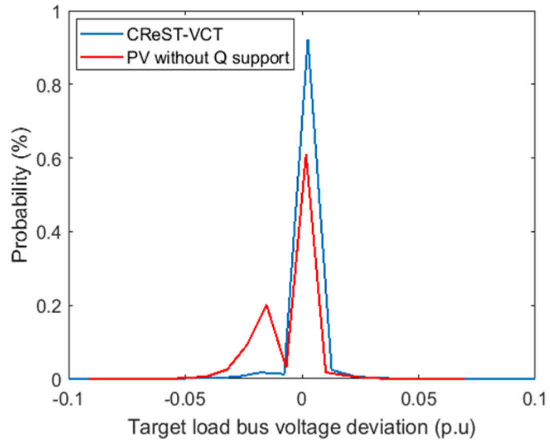
Feeder Name	Number of utility scale PV	Utility scale PV capacity (kW)	Number of residential PV	Residential PV capacity (kW)	Total PV capacity (kW)
R 1201	3	3,157	0	0	3,157
R 1202	0	0	325	1,624	1,624
R 1203	1 (existing)	5,000	0	0	5,000
G 1202	1	5,000	0	0	5,000
G1203	1	5,000	665	4,825	9,825

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





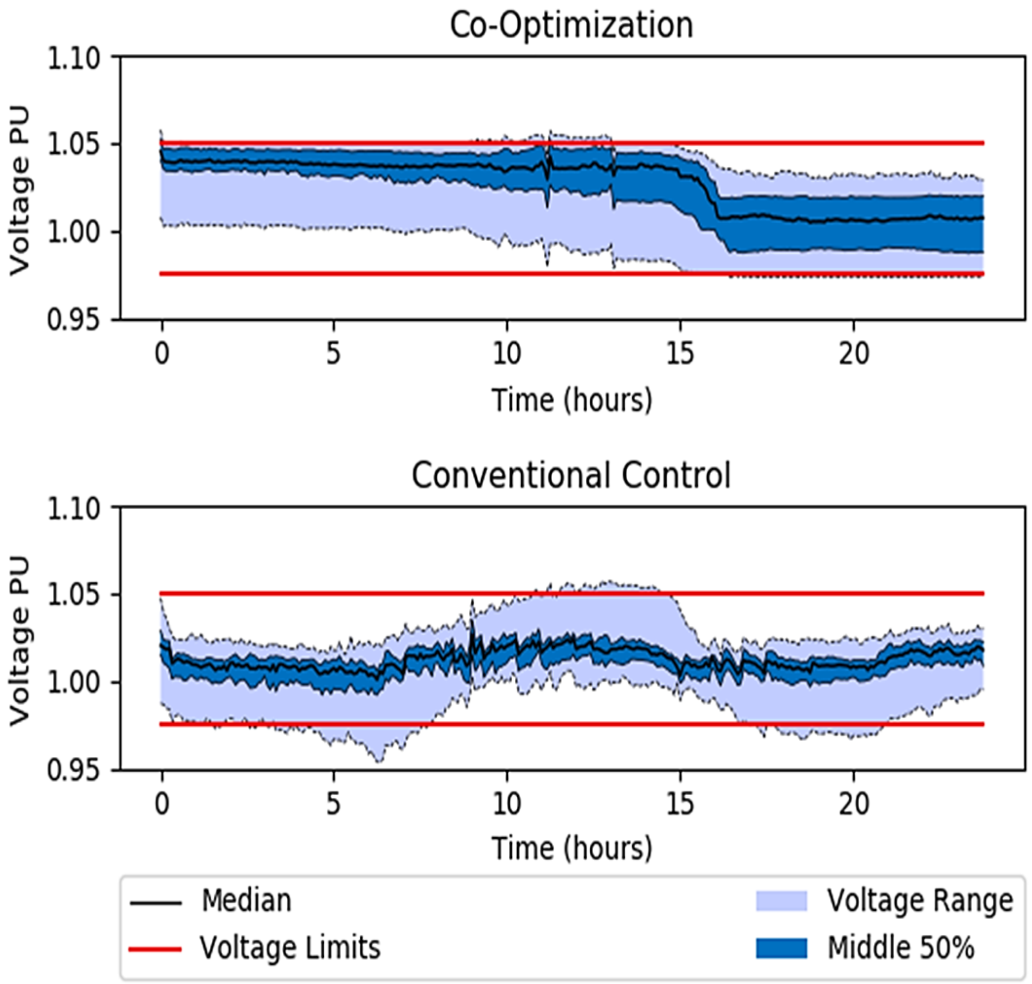
Aggregated reactive power from distributed PV (red line, lower graph) is able to maintain the target substation voltage (blue line, upper graph).

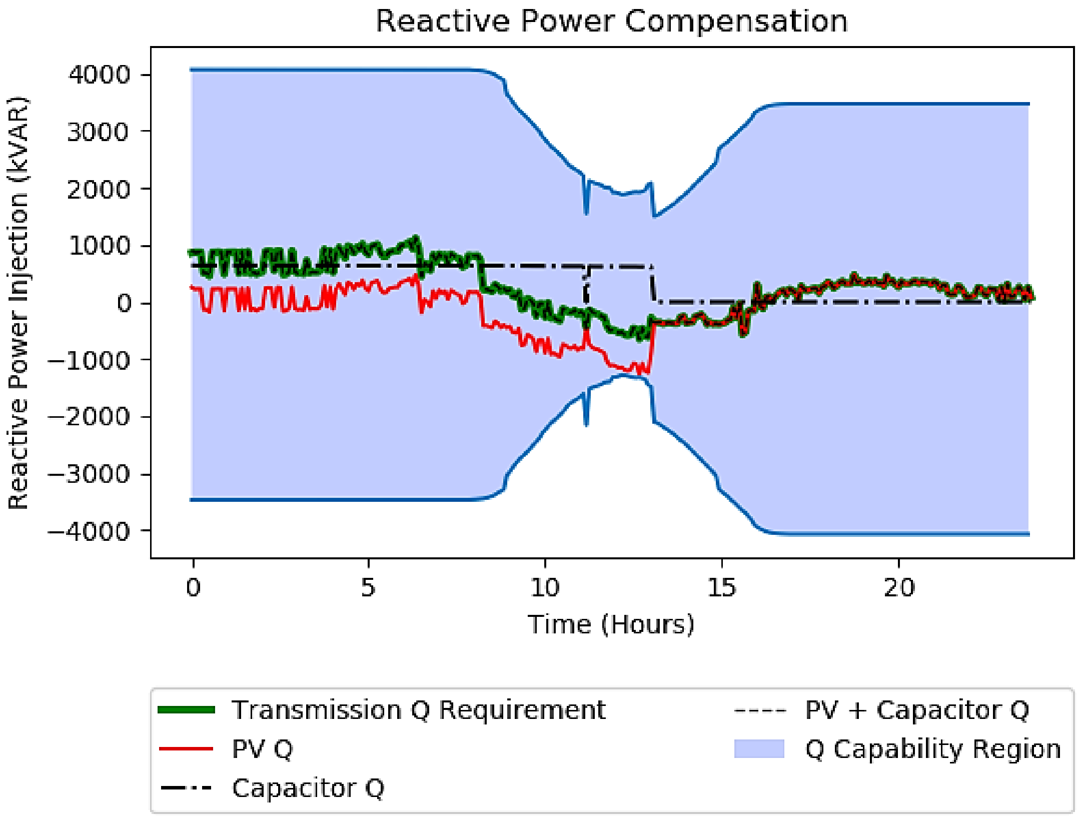


Voltage deviation distribution for all subtransmission load buses for one full winter week at 5-min resolution

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

Optimizing Distribution Voltage while Meeting Required Subtransmission Support

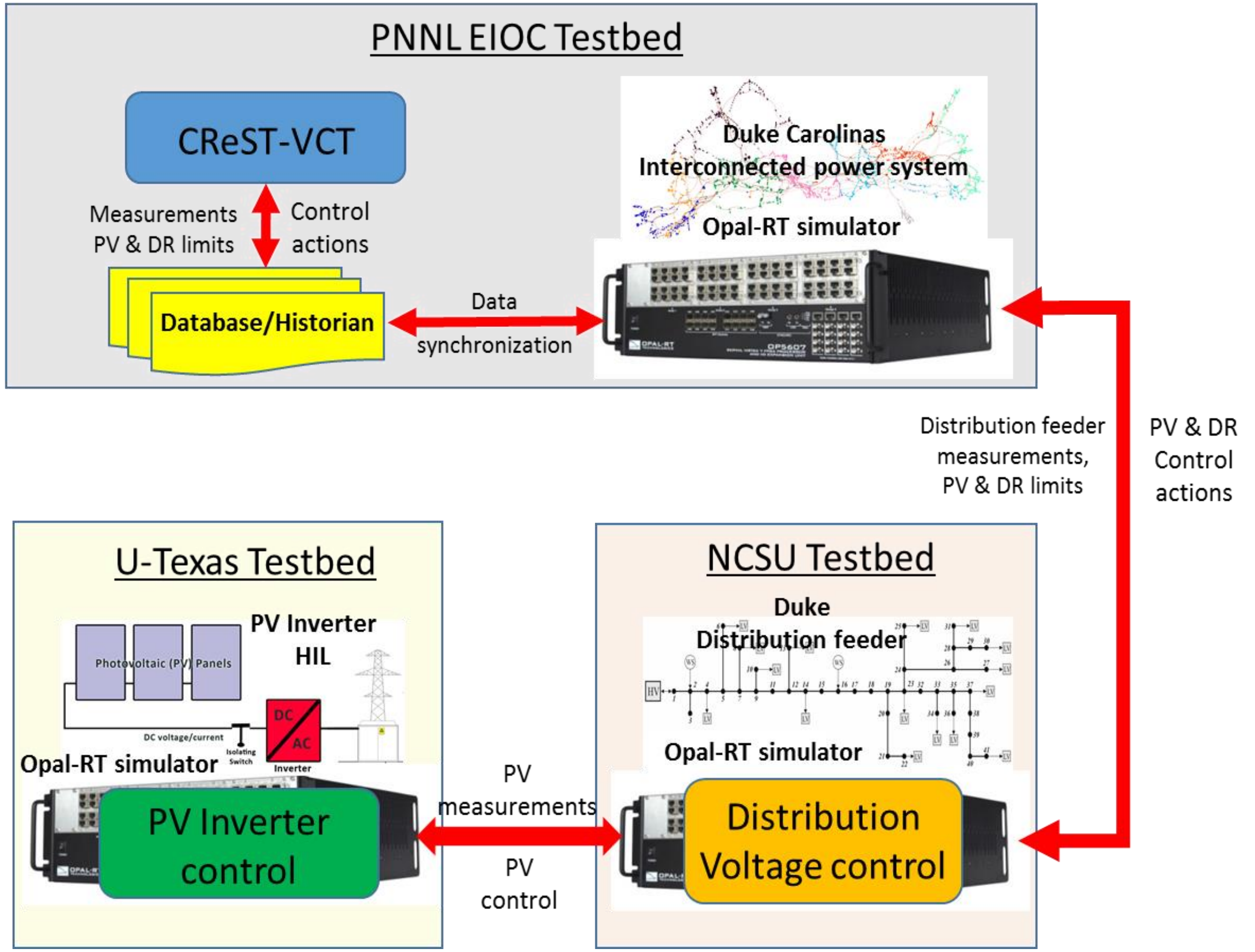




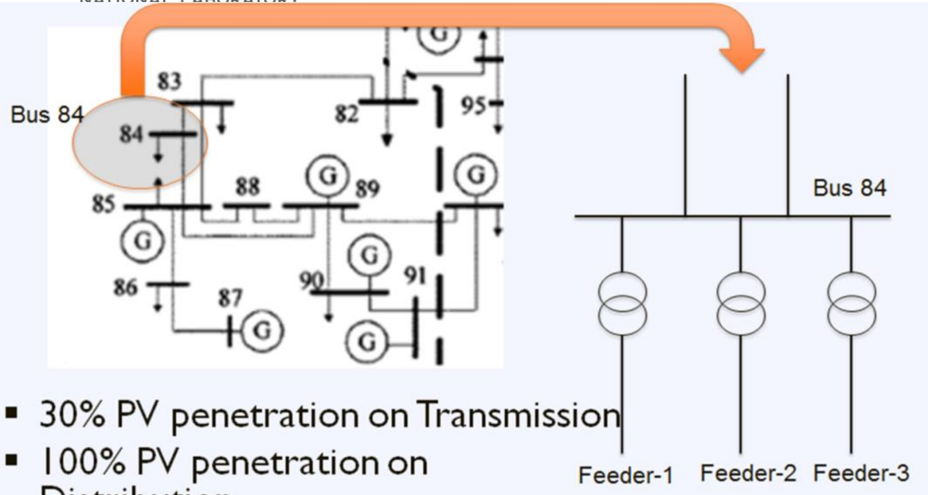
- ✓ Voltage-Load Sensitivity Matrix (VLSM) control algorithm successfully controls distribution system voltages.
- ✓ VLSM control algorithm successfully meets transmission requirements for reactive power.

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

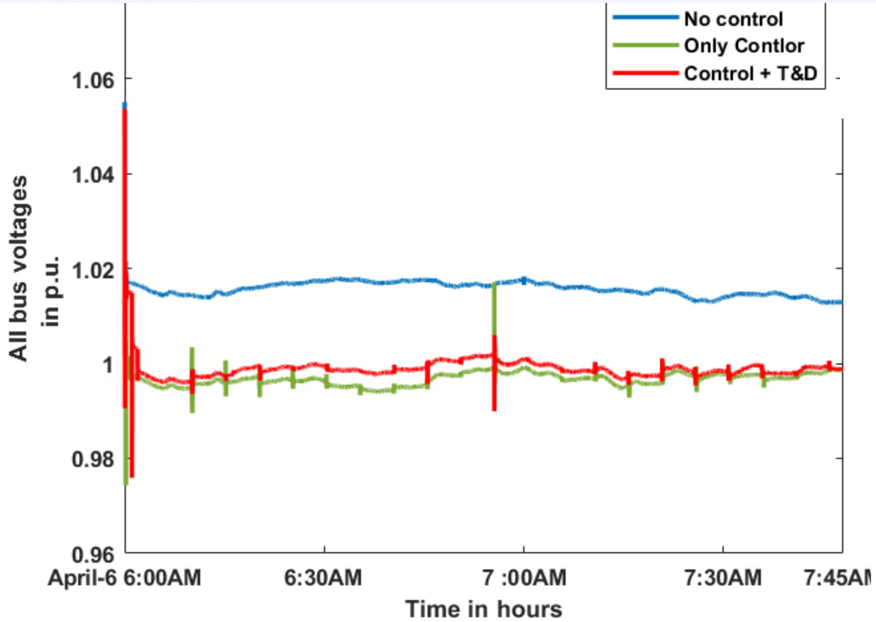
- Three hardware-in-the-loop (HIL) test systems have been developed to test the performance of
  - CReST-VCT developed at PNNL
  - Distribution voltage control based on PV control and demand response at NCSU
  - PV control with smart inverters at UT-Austin
- An integrated HIL test system have been developed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

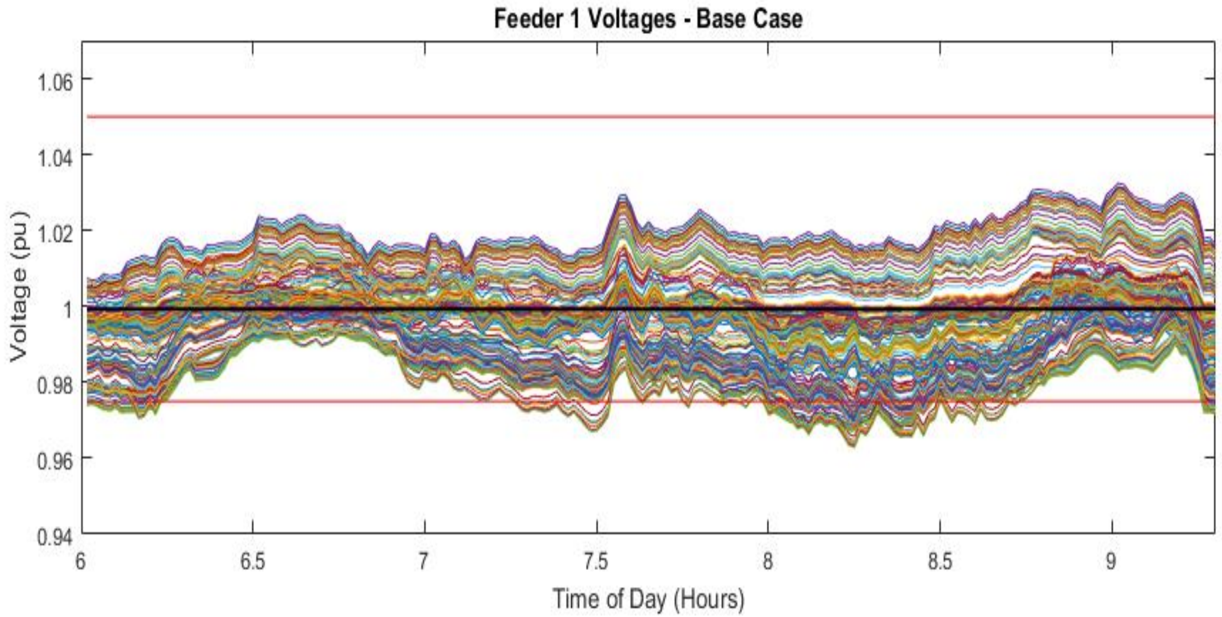


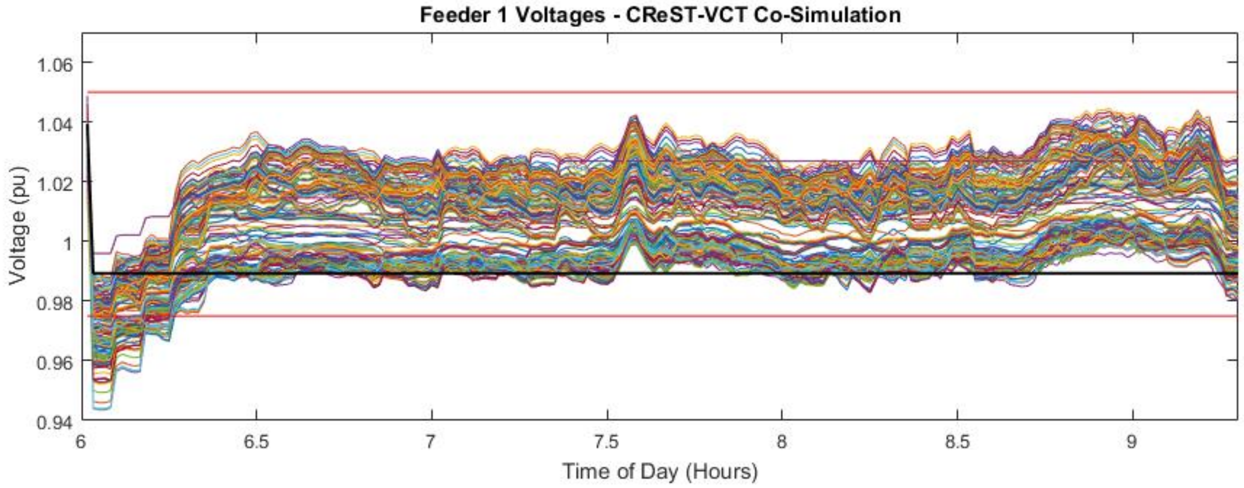
Transmission-Distribution Control Coordination HIL Simulations



- 30% PV penetration on Transmission
- 100% PV penetration on Distribution







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.

Questions?

Thanks!

Contact Information

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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