Enabling High Penetration of Distributed PV through the Optimization of Sub-Transmission Voltage Regulation

Nader Samaan, PhD, PE
Pacific Northwest National Laboratory

UVIG Fall Technical Workshop l
Nashville, TN
October 11, 2017

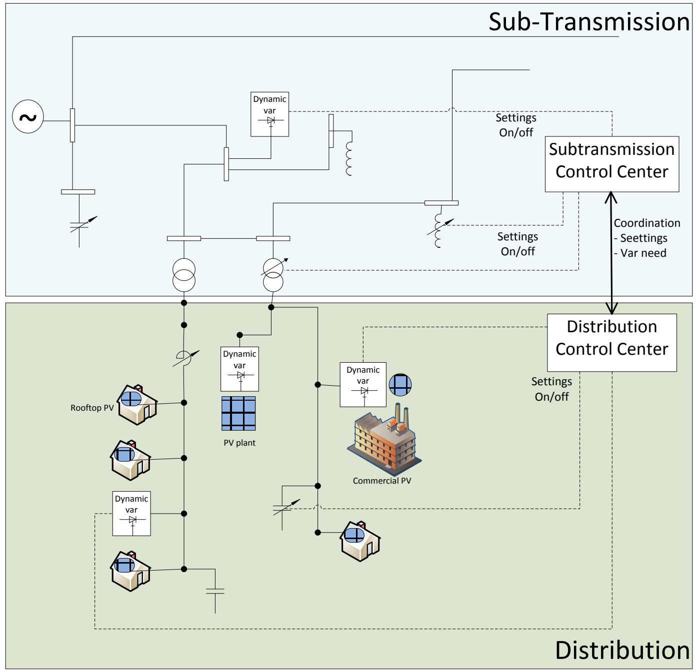
Project Team: Prof Alex Huang (UT),
Prof. Ning Lu (NCSU),
Dr. Yazhou Jiang (GE),
Dr. Greg Smedley (OCC),
Mr. Brant Werts (Duke Energy)

Overview

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

Challenges:

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



Solution:

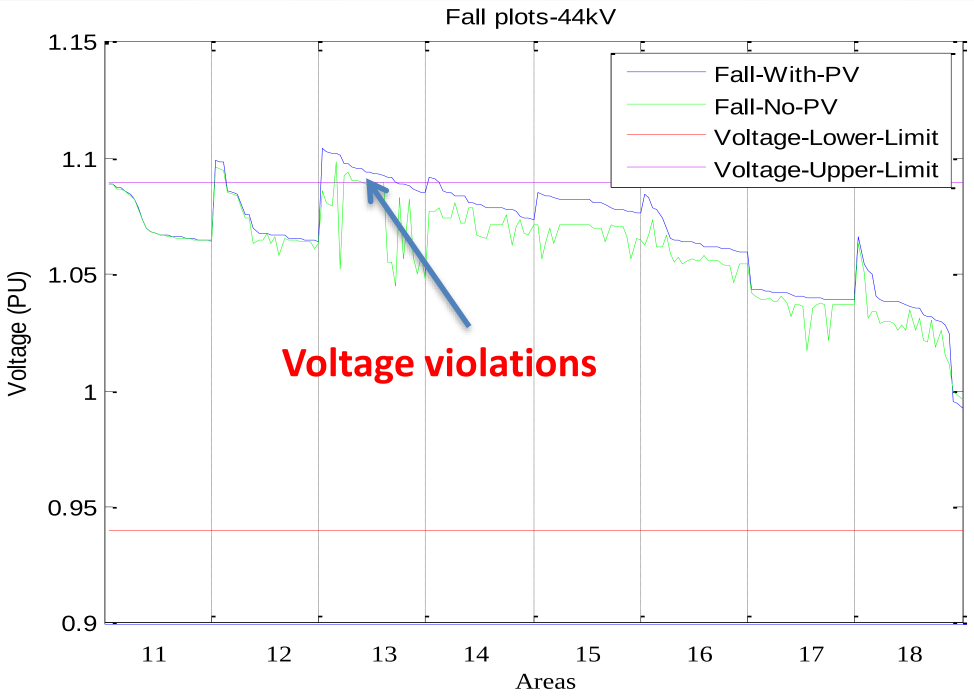
- Develop a Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT)
  - Autonomous & supervisory control via flexible algorithm
  - Co-optimization of distribution and sub-transmission scales
- Develop an Optimal Future Sub-Transmission Volt-Var Planning Tool (OFuST-VPT)
  - Multistage stochastic programs
  - Goal balancing
  - Stage-wide planning evaluation

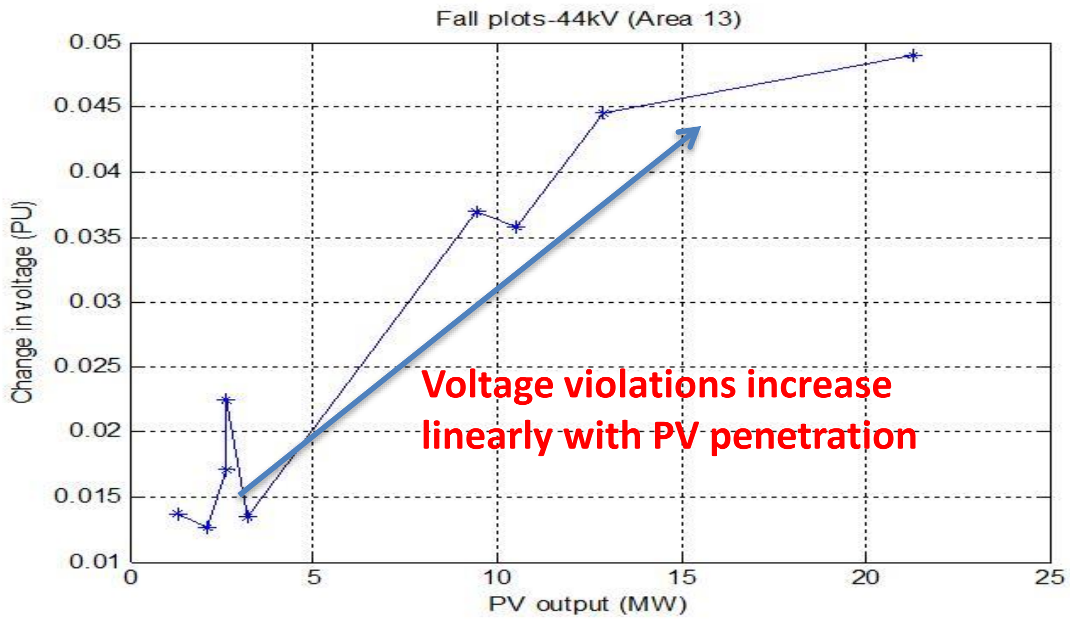
Impact:

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

PNNL Study* Showed Volt/Var Regulation Challenge at Sub-Transmission

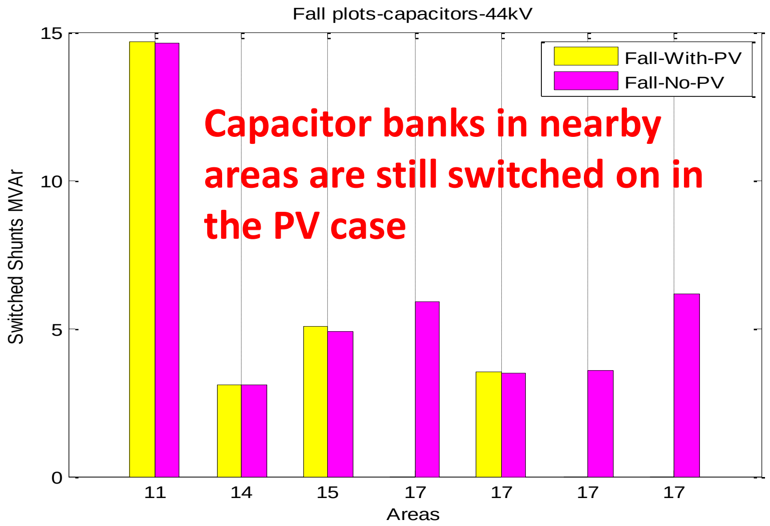
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965





System voltage magnitudes increase almost proportionally when the PV outputs increase

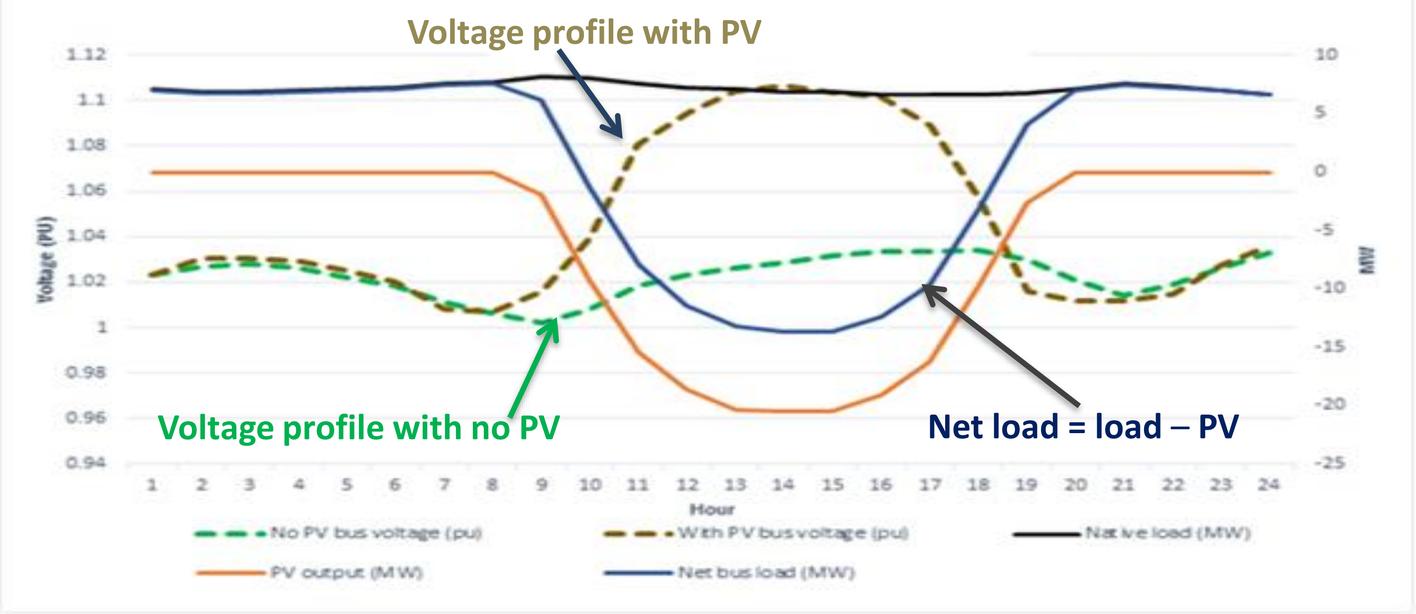
- Under modest penetration of distributed photovoltaics (PVs), controllin overvoltage becomes a challenge at the sub-transmission level
- Voltage regulation challenges at sub-transmission are a barrier for high penetration of PVs. Developers of new PV projects target interconnection to sub-transmission 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)



March 9th

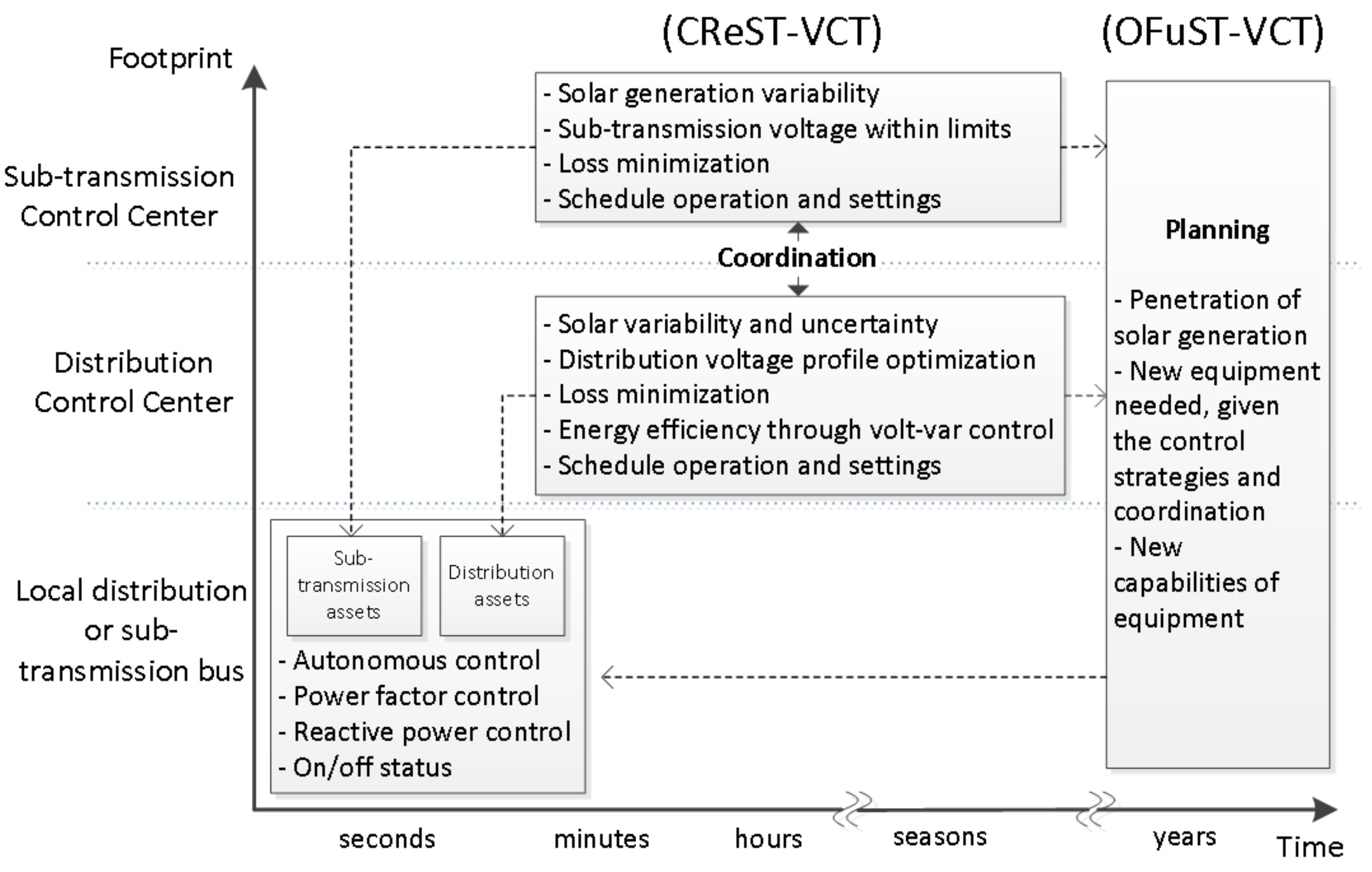
Low Load Day

July 24th

High Load Day

Under low load condition and high PV penetration, there is a potential for over-voltage problems

Project Objectives

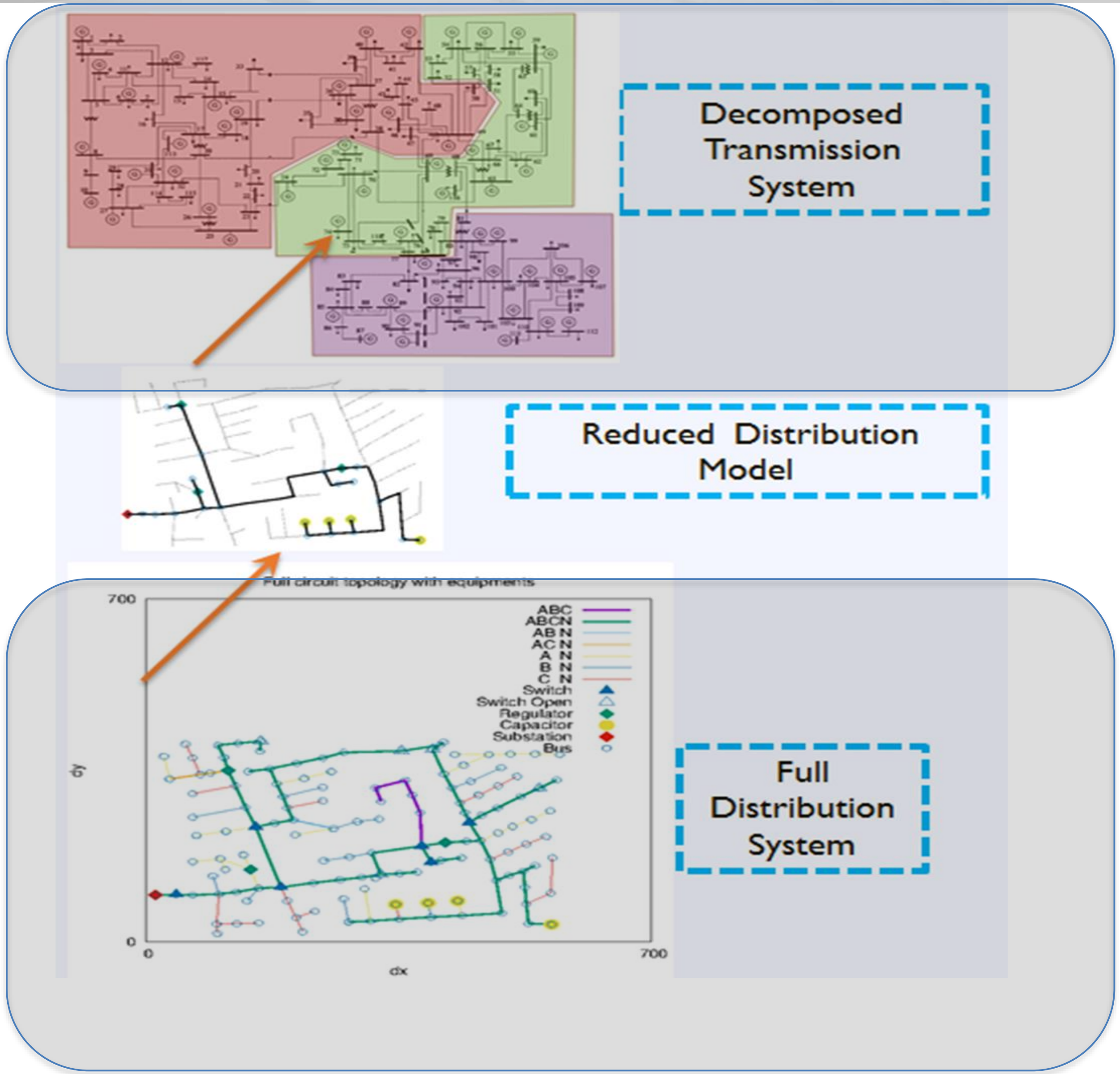


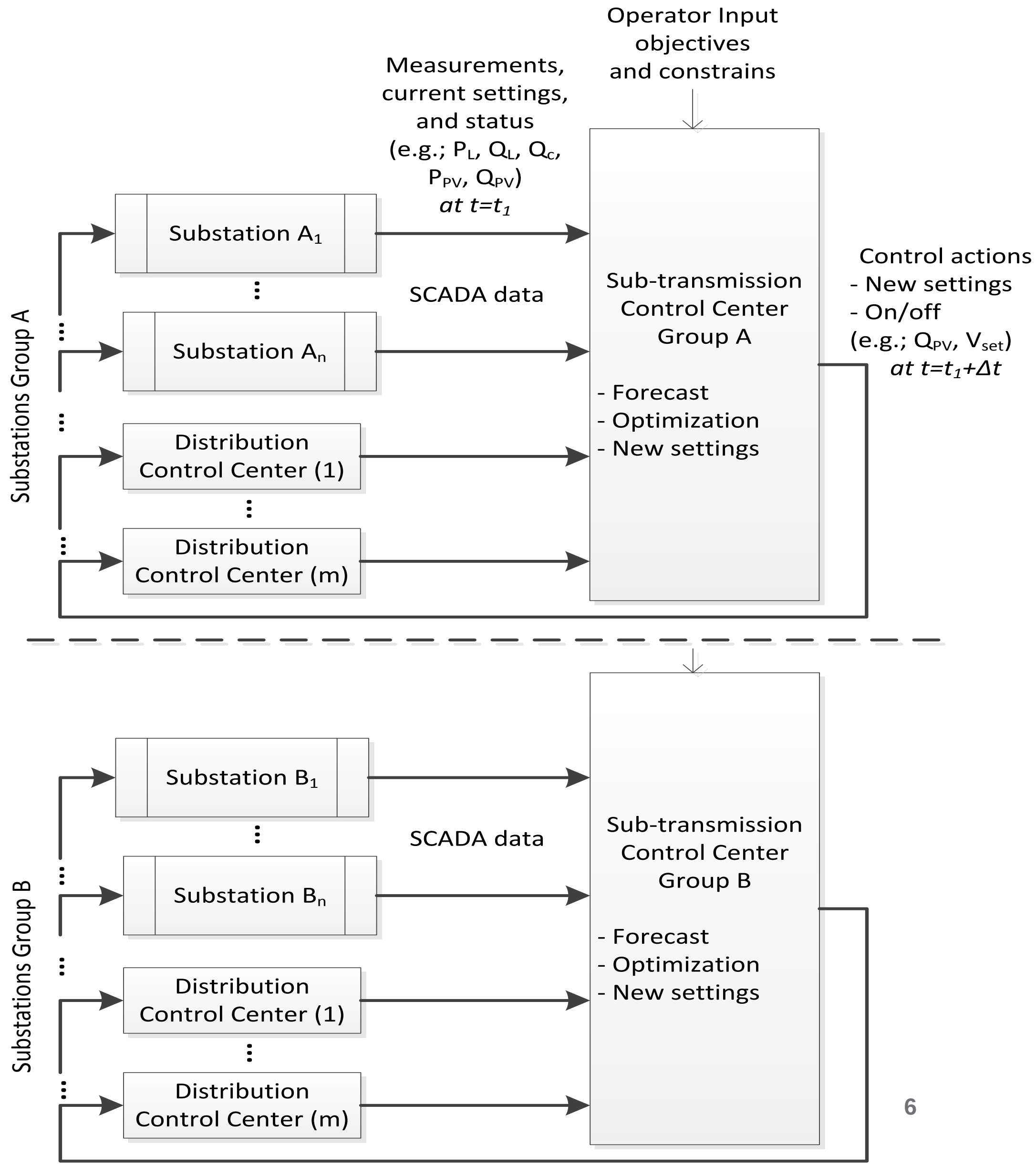
- **Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT)**
- **Optimal Future Sub-Transmission Volt-Var Planning Tool (OFuST-VPT) for short- and long-term planning**

Key Milestones & 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

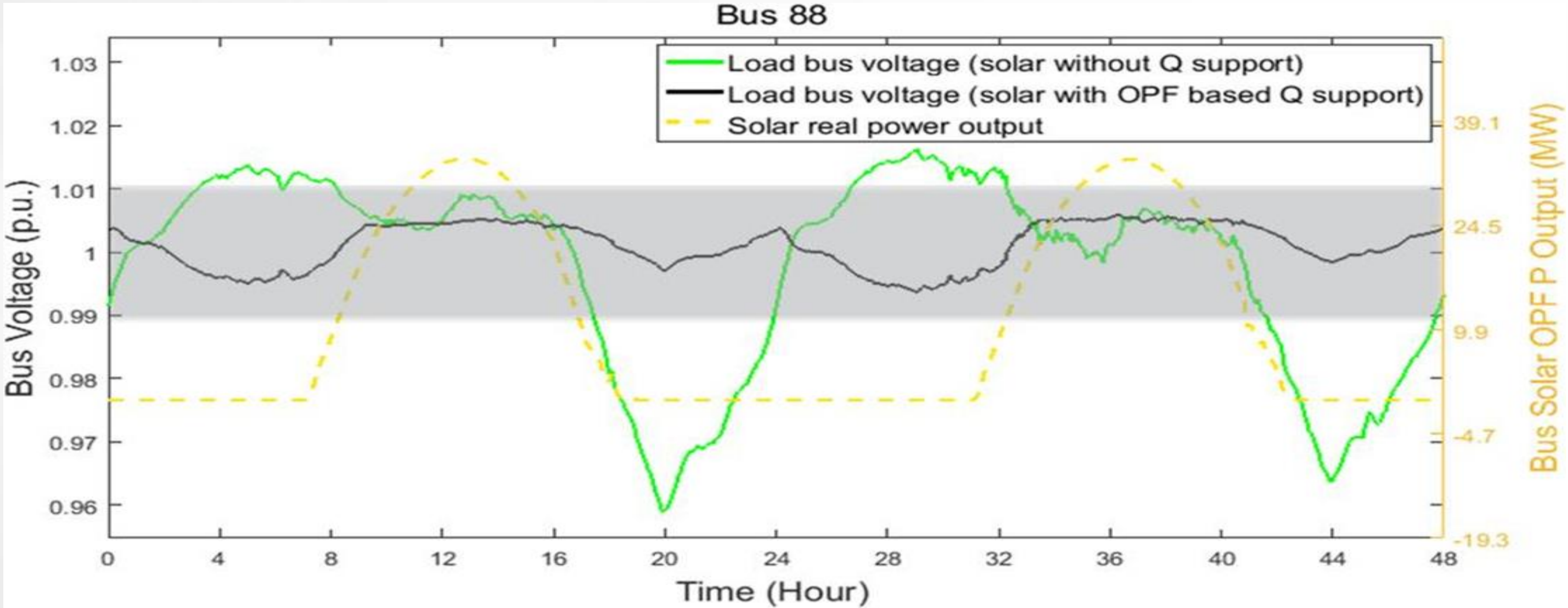
Scalability of the Solution: Co-Optimization of Transmission and Distribution Voltage





Project Progress

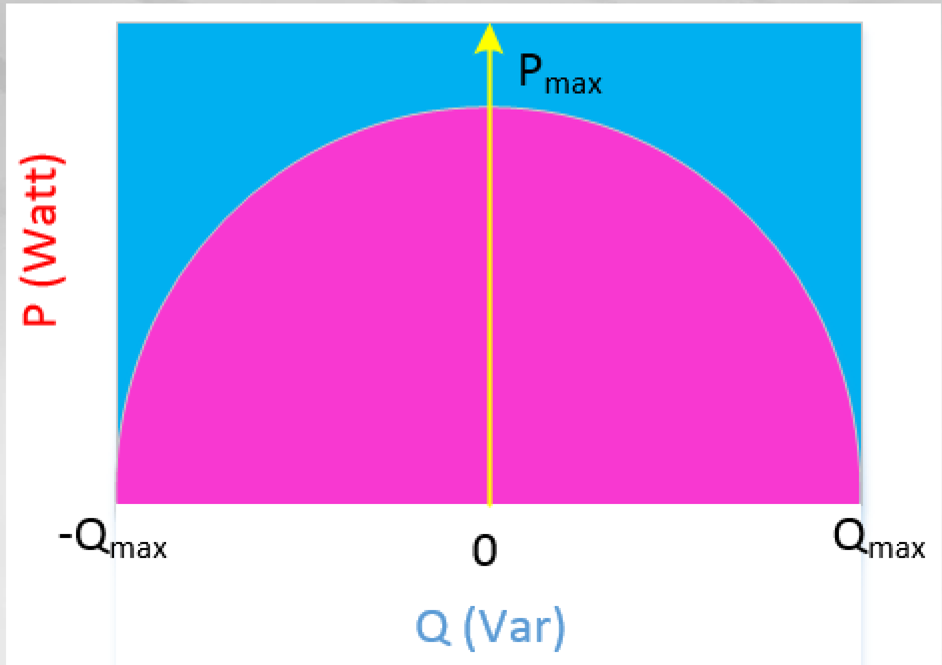
- Demonstrated CReST-VCT on IEEE 118-bus transmission test system IEEE coupled with IEEE123-node distribution test system
- Completed advanced synchronous generator-capable PV inverter control models and integrated them into CReST-VCT
- Developed and tested, via simulation, load-side control options for full IEEE 123-node system in OpenDSS
- Wrote white paper summarizing characteristics of reactive power compensation devices to be modeled in CReST-VCT
- Finalized prototype of distribution system model reduction tool



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 power/reactive required from demand response
  - Real power curtailment from PV

Improved PV Inverter Active and Reactive Constraint Model



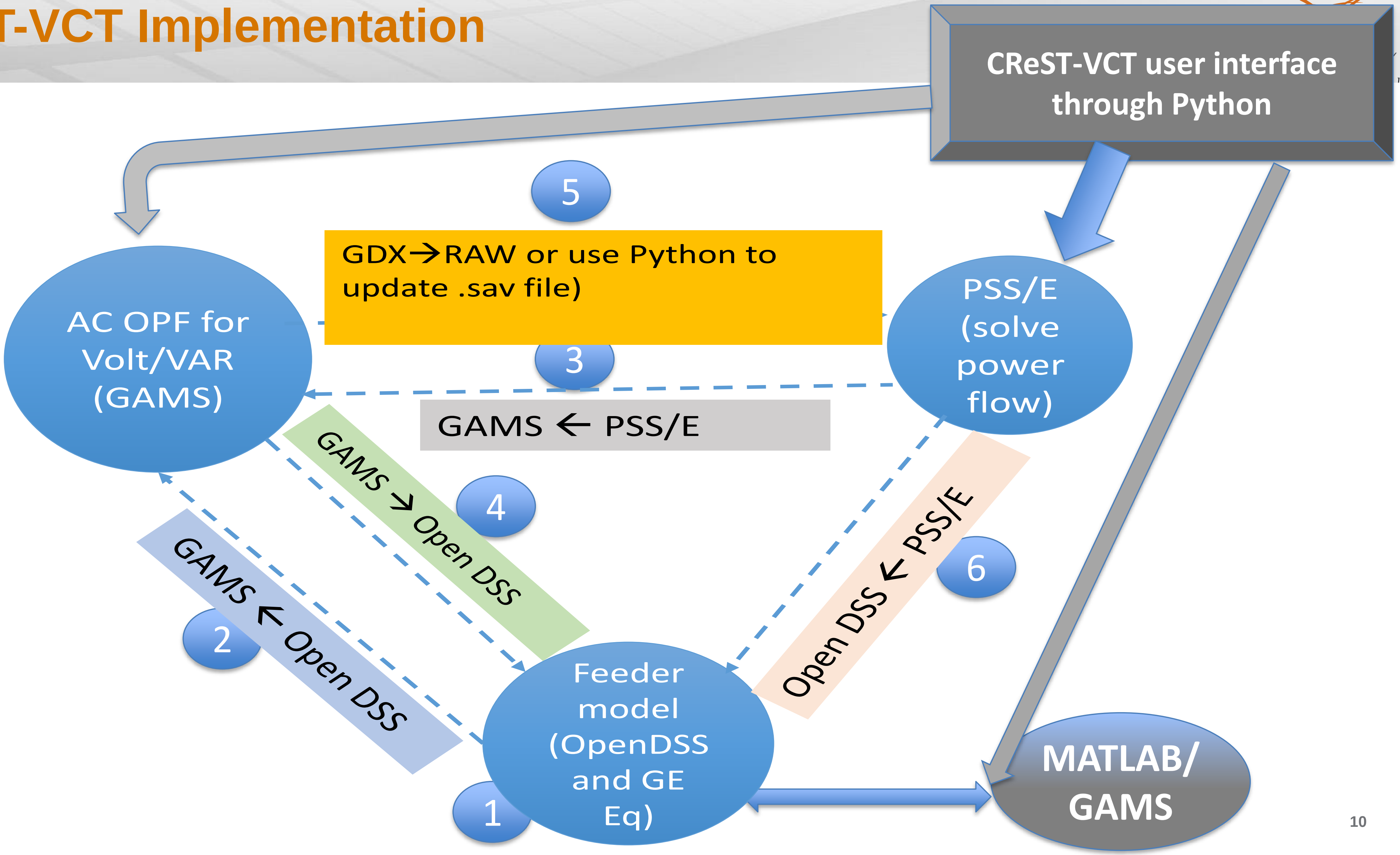
$$\frac{P^2}{P_{max}^2} + \frac{Q^2}{Q_{max}^2} \leq 1$$

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

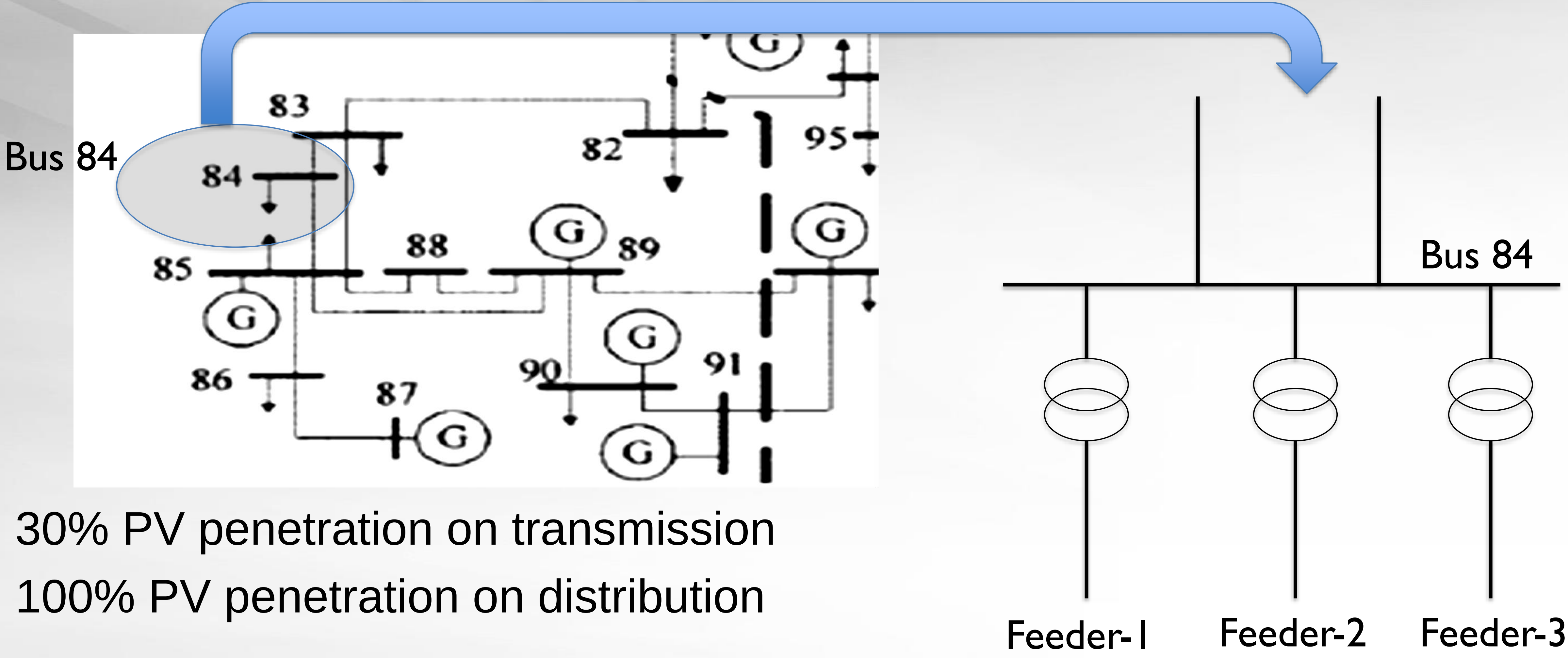
k is the **improved factor** for reactive power constraint, 1.1 for a normal **IGBT-based** PV inverter

- *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 PF, and Volt-Var). We are using constant *Q* that comes from the optimization engine.

CReST-VCT Implementation



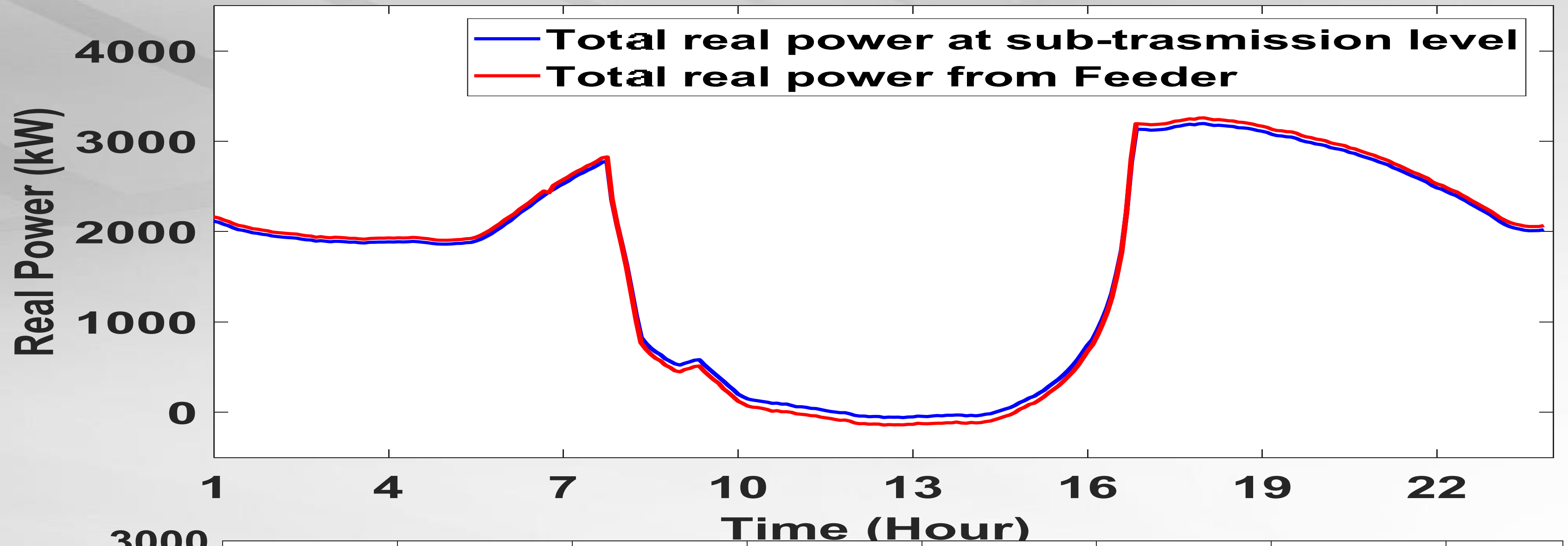
Simulation Scenario – 3 IEEE 123-Node Feeders Connected to Bus 84 of the IEEE 118-Bus System

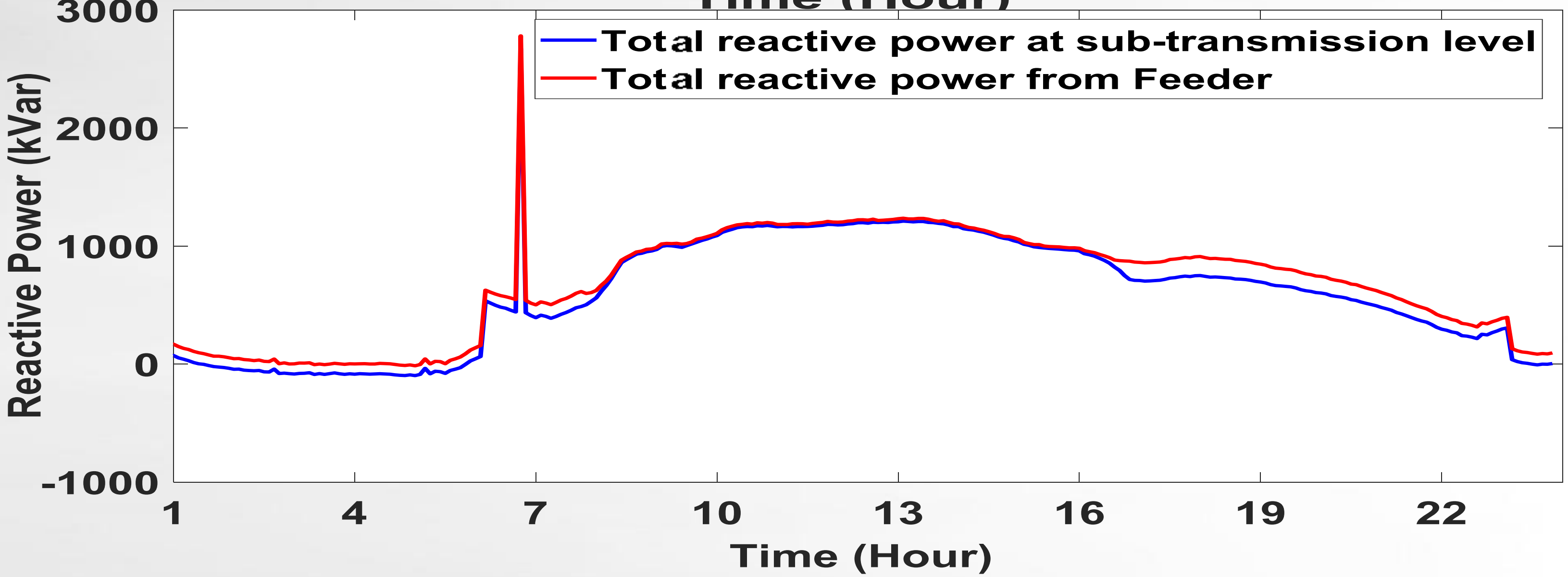


- 30% PV penetration on transmission
- 100% PV penetration on distribution

Real and Reactive Power (Transmission vs. Distribution)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*





Distributed PV is able to meet reactive power requirements to support sub-transmission voltage.

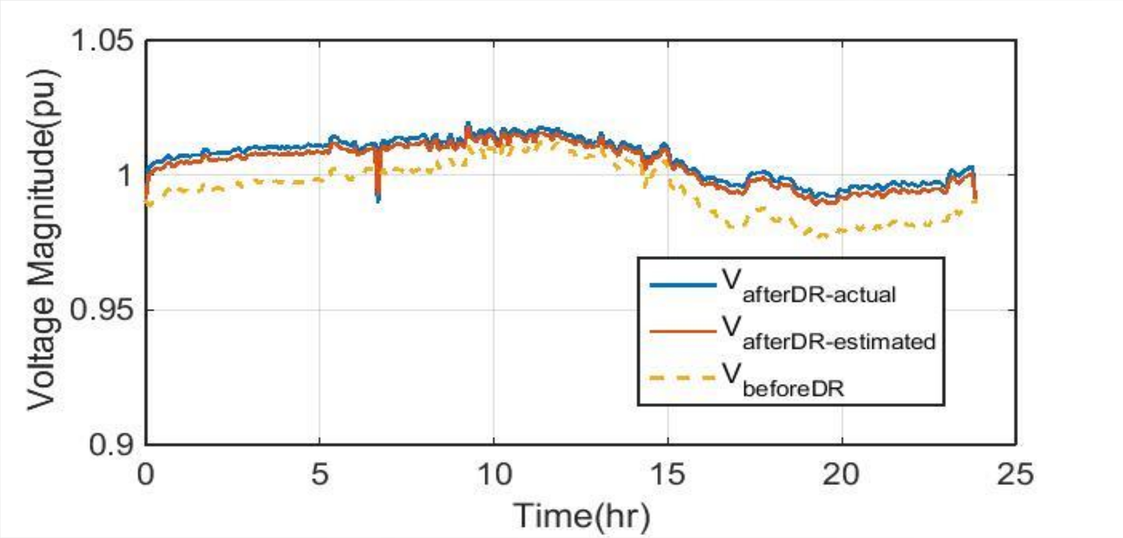
Optimizing Distribution Voltage while Meeting Required Sub-Transmission Support

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

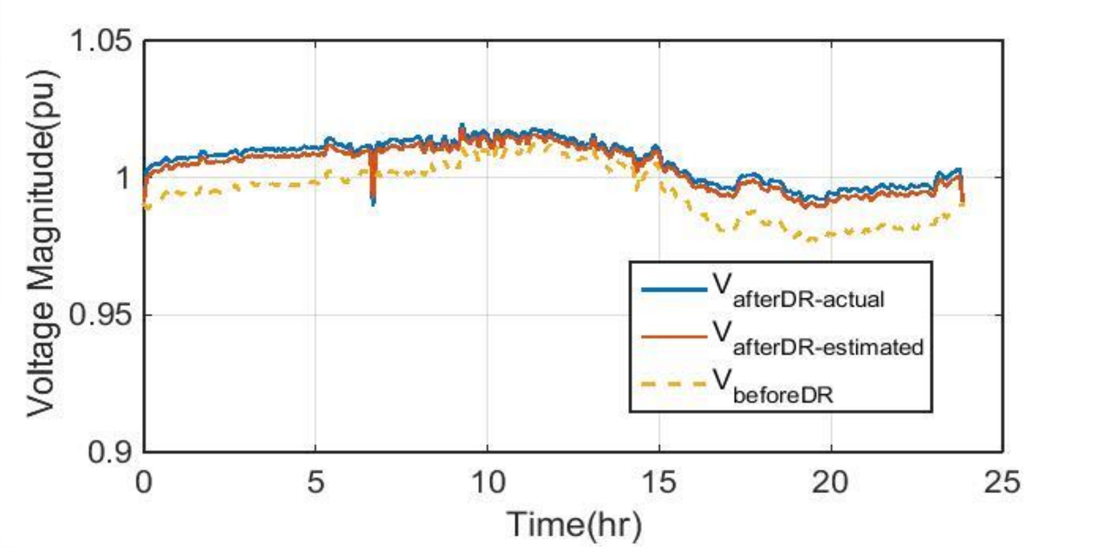
A voltage-load sensitivity matrix (VLSM)-based voltage control/optimization scheme was developed to improve distribution voltage profiles under high solar penetration while meeting required sub-transmission support.

Voltage statistics for all the nodes

Maximum voltage (pu)	Minimum voltage (pu)
1.0328	0.9598

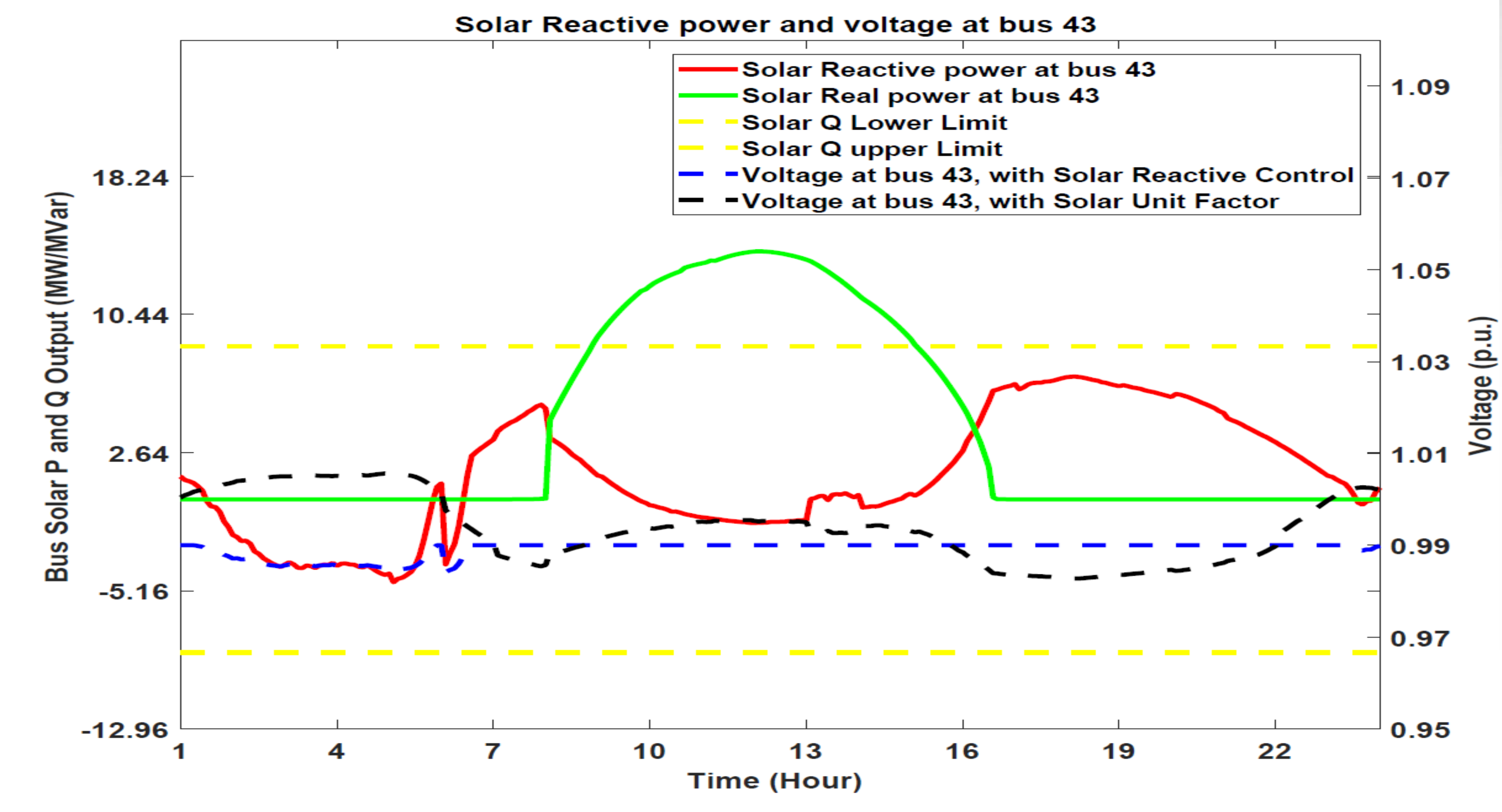


Voltage profiles at node 11 phase A



Voltage profiles at node 65 phase C

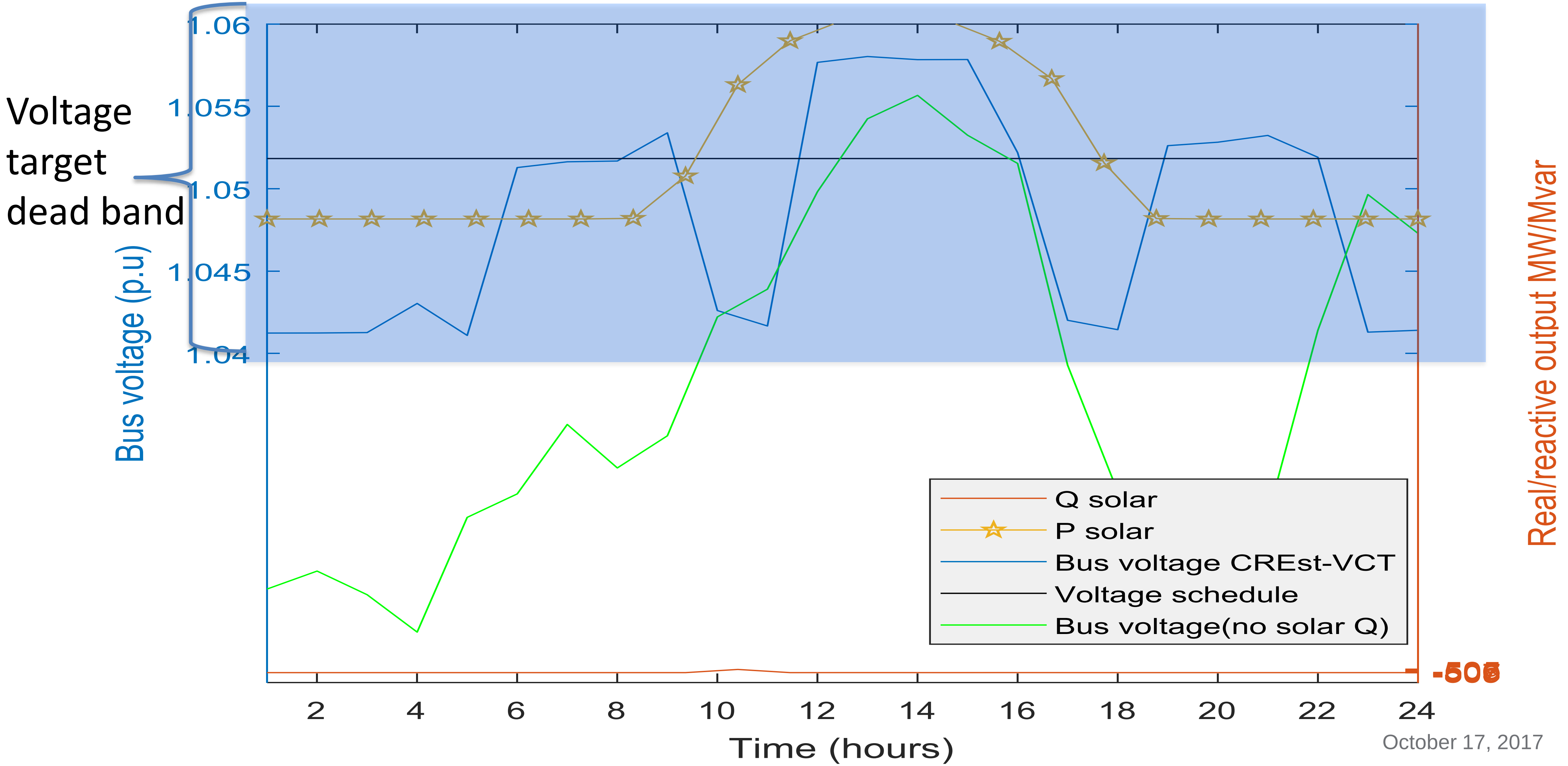
Voltage Profiles at another Substation (PV at Unity PF vs. PV Providing Reactive Power Support)



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

Preliminary Hourly Simulation Results on Duke Carolinas System under High PV Penetration

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965



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 to stabilize voltage fluctuations caused by high PV penetration and intermittent PV outputs.
- PV inverter models for active power and reactive power regulation have been developed and validated.
- Preliminary results show volt/var optimization at sub-transmission can be achieved by taking advantage of reactive power capabilities of distributed PV smart inverters.
- Voltage profiles are co-optimized on both sub-transmission and distribution levels.
- The proposed tool would enable higher PV penetration without negative impact on the power grid.

Acknowledgment

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

- This study is funded by the U.S. Department of Energy (DOE) SunShot Initiative as part of SunShot National Laboratory Multiyear Partnership (SuNLaMP)
- The project team wants to especially thank Mr. Jeremiah Miller, Dr. Guohui Yuan, Dr. Kemal Celik, and Ms. Rebecca Hott from the Systems Integration Subprogram at DOE's SunShot Initiative for their continuing support, help, and guidance.

Questions?

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Thanks!
- Contact Information:

- Nader Samaan, Ph.D., P.E.
- Sr. Power Systems Research Engineer
- Electricity Infrastructure Group
- Pacific Northwest National Laboratory
- P.O. Box 999, MSIN J4-90
- Richland, WA 99352
- Phone: (509) 375-2954 (W)

- Email: nader.samaan@pnnl.gov