Distribution System Control and Automation

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What do we mean by distribution system control and automation?

***Distribution Automation (DA):** Uses sensors and switches with advanced control and communications technologies to automate feeder switching; voltage and equipment health monitoring; and outage, voltage and reactive power management.*[1]

DA provides benefits to utilities and customers promising:

- Shorter outages
- Improved system resilience during extreme weather
- More optimal equipment maintenance
- More efficient use of line crews
- Improved integration of distributed energy resources (DERs) and modern loads (e.g., EVs)

[1] Distribution Automation: results from the smart grid investment grant program, DOE, Sept. 2016.

Spectrum of DA – Simple Systems to Complex System of Systems

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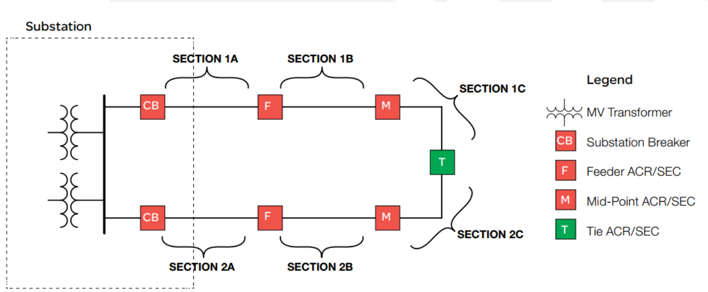
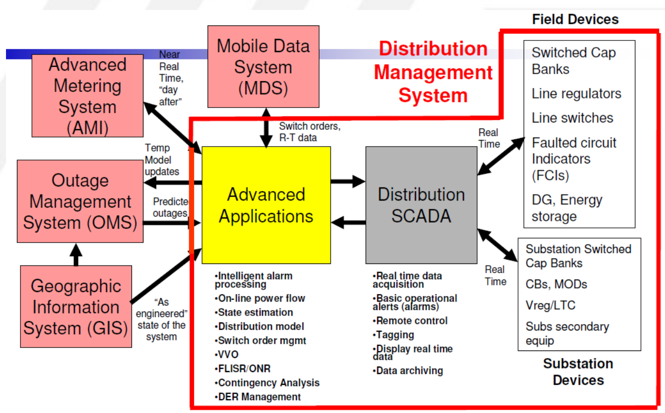
Simple – Loop Recloser Automation



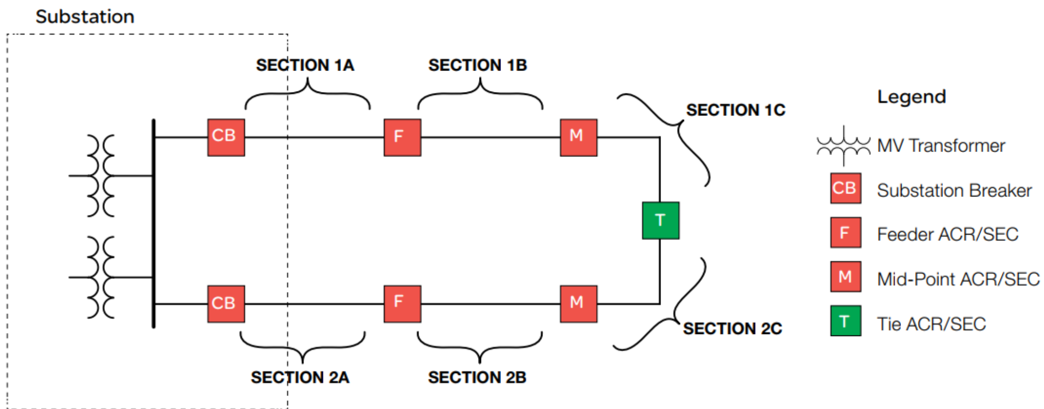
- Usually serve a single function
- Equipment controlled is bound locally
- Relative number of potential operating scenarios is limited/reasonable

Complex - Advanced Distribution Management System (ADMS)



- Serves many functions (co-optimization)
- Equipment controlled is vast and varied
- Systems are seamlessly integrated

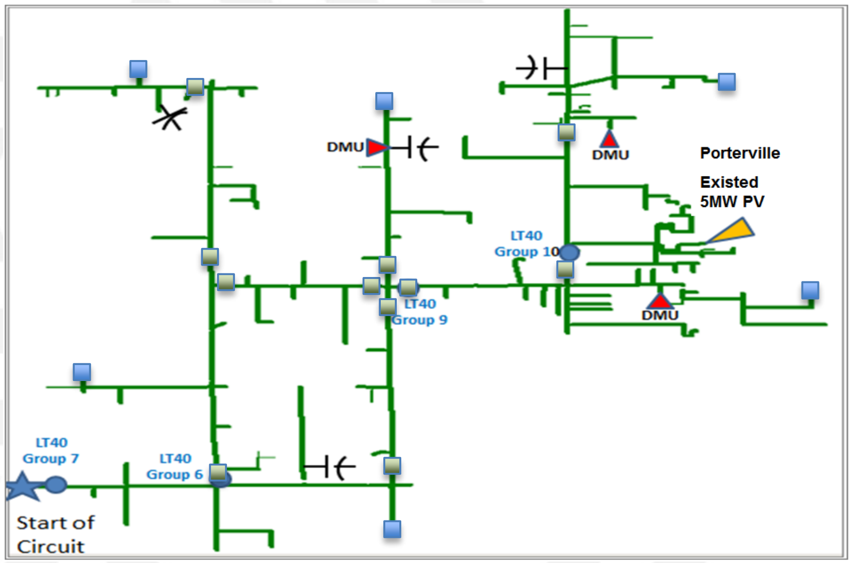
DA Example: Loop Recloser Automation



Goal: decrease outage duration/impact

Operation: Two adjacent feeders are upgraded with controllable reclosers/circuit breakers including an automatic "tie" recloser. Following a fault the line section containing the fault is identified and the circuit is reconfigured to provide power to the most customers possible until the fault can be cleared by line crews. System operates autonomously.

DA Example: Automatic Reconfiguration



Goal: decrease outage time, balance substation load, manage voltage profiles, etc.

Operation: Sections of the circuit are connected to adjacent feeders

DA Example: Conservation Voltage Reduction (CVR)

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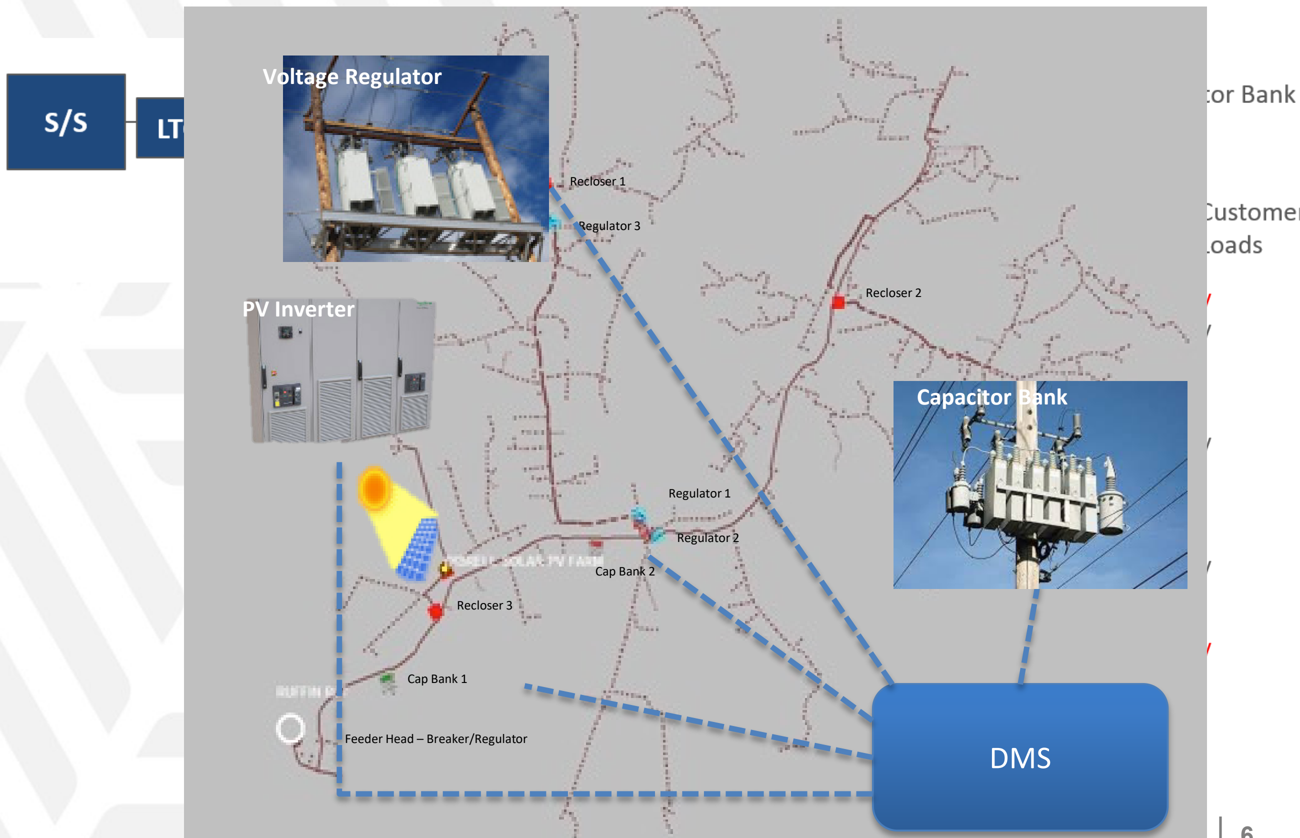
***Conservation Voltage Reduction (CVR):** A voltage reduction scheme that flattens and lowers the distribution system voltage profile to reduce overall energy consumption.*

- Works best with circuits with high shares of resistive loads
- Normally performed by flattening the system voltage using capacitor banks and/or voltage regulators and lowering the voltage by controlling a substation Load Tap Changer (LTC)



DA Example of Value: CVR at AEP

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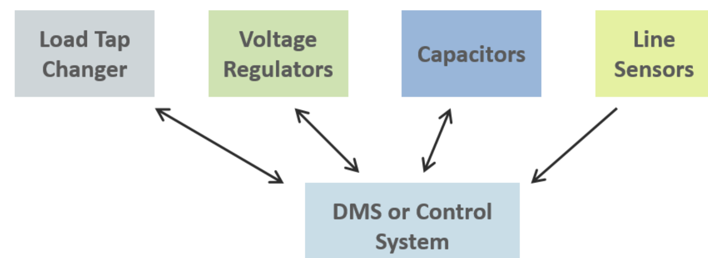
AEP's CVR Objectives:

- Apply data from end-of-line sensors to automatically control line voltage regulators and load tap changers at substation feeder head
- Coordinate capacitors to keep power factor of the substation transformer near unity (manage substation efficiency)



Near-real-time feedback loop enables optimized operation of these components.

Results Averaged across 11 Circuits	Initial Results	Potential Customer Savings (estimated for a 7 MW peak circuit with 53% load factor)	
Customer Energy Reduction	2.9%	943 MWh/year	$75,440 (at $.08/kWh)
Peak Demand Reduction	3%	210 kW	Defer construction of peaking plants

Figure courtesy of Joe Paladino, DOE

DA Example of Value: CVR Business Case at Dominion Virginia Power

- Dominion VA Power's Objective: Using Advanced Metering Infrastructure (AMI) as voltage sensors to enable CVR
- Value Determination: Of the multiple value streams the enablement of CVR provided the highest overall value.
- This project is a good example of the value stacking capability of DA/DMS.

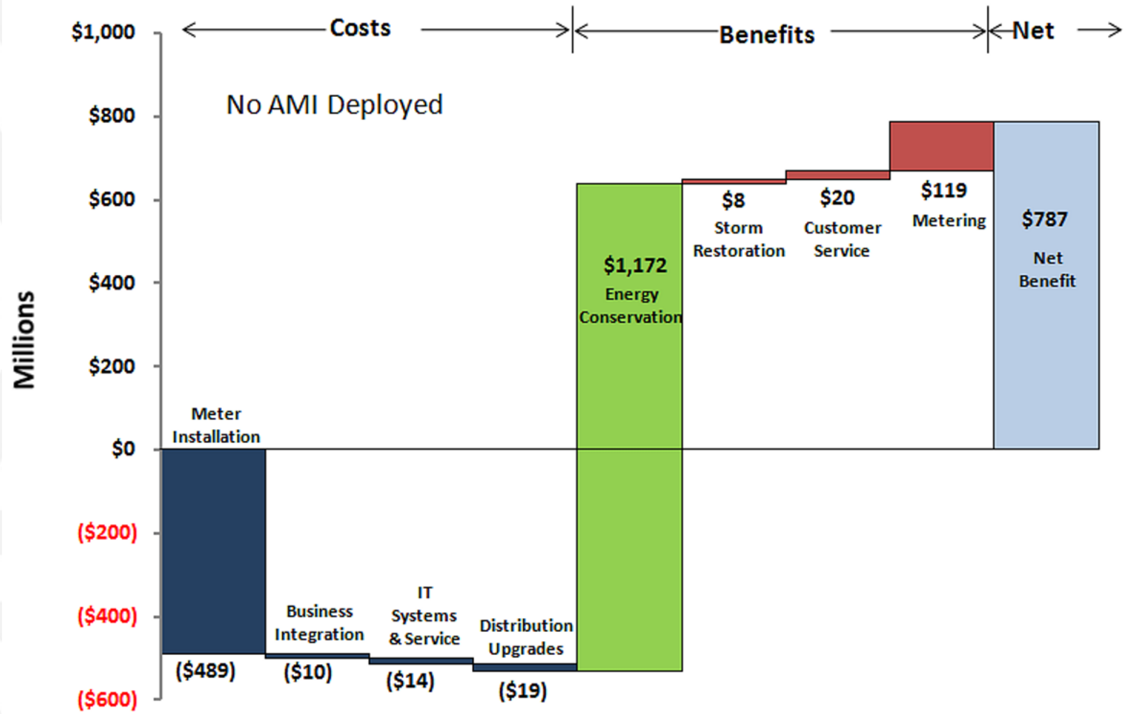


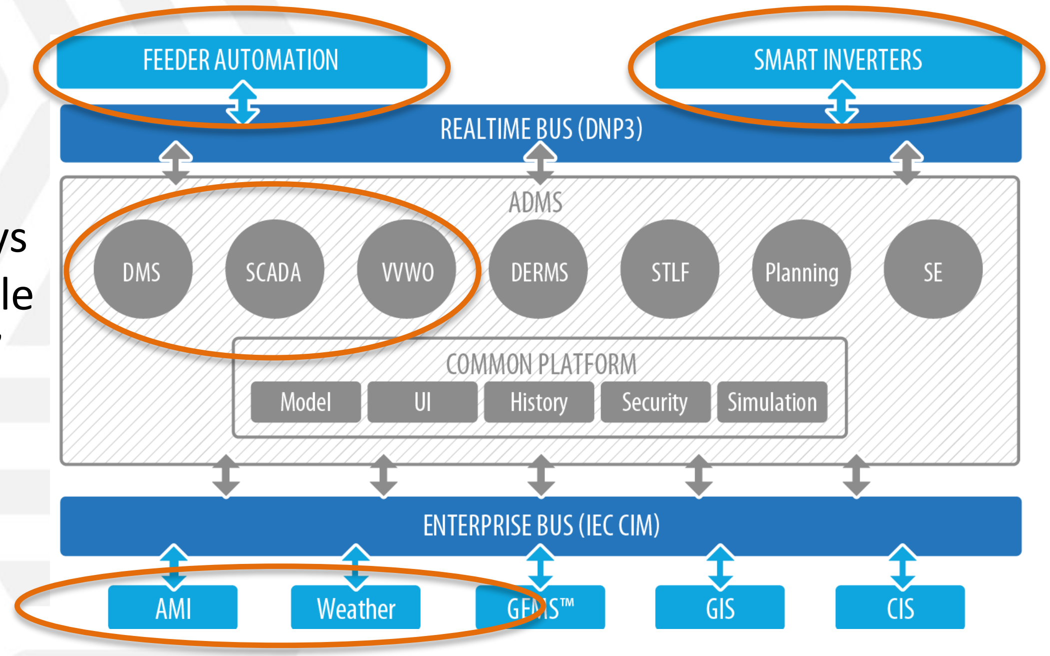
Figure courtesy of Joe Paladino, DOE

Advanced Distribution System Management Systems (ADMS)

- The "Whole Enchilada"
- Consist of a seamlessly integrated "system of systems"
- Typically sharing common platform
- Data used for management is used for other analytics, and data from other systems (e.g., billing) is leveraged for control and optimization.
- Application-wise: You're limited only by your imagination.

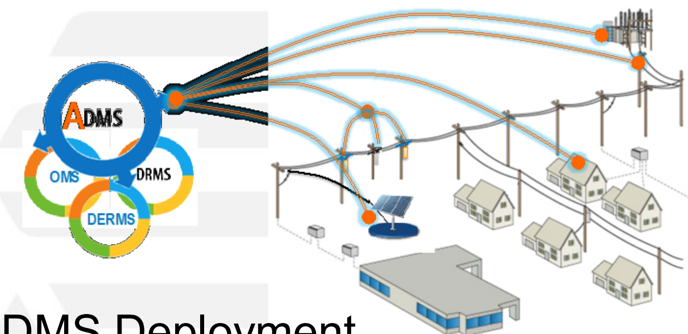
Connects to real hardware

Deploys multiple "apps"



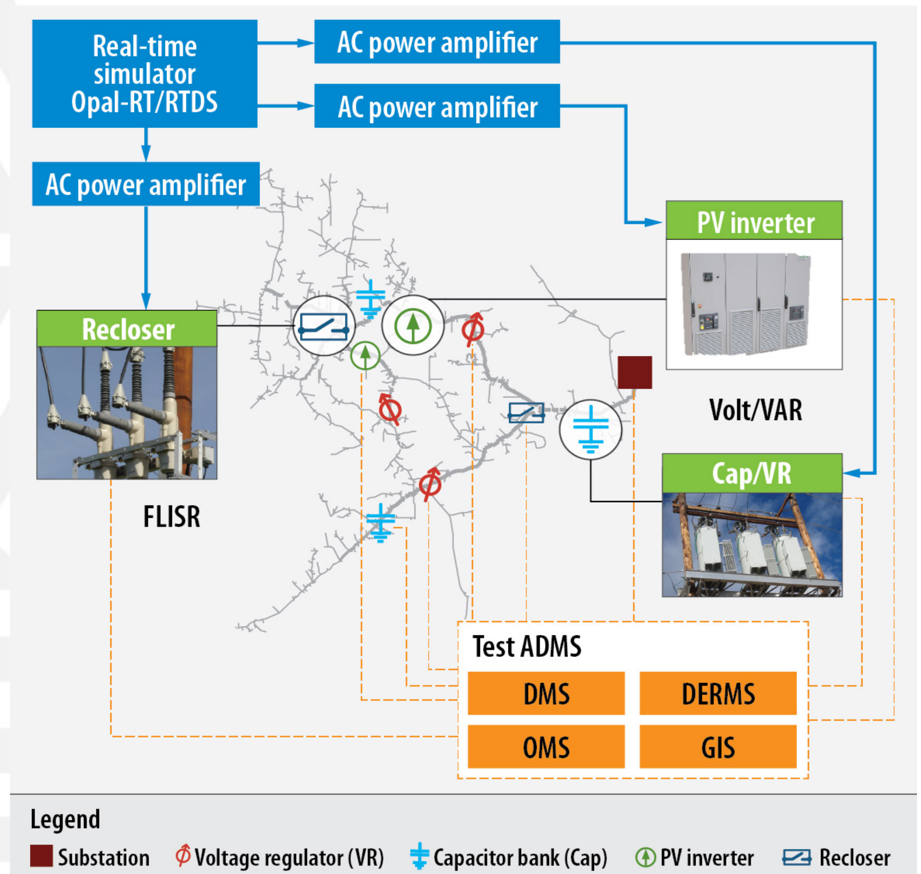
Connects to multiple data sources

NREL's ADMS Testbed



Actual ADMS Deployment

- Tools to model large scale distribution systems for evaluating ADMS applications
- Integrate distribution system hardware for power hardware-in-the-loop (PHIL) experimentation
- Develop advanced visualization capability



Distribution Control and Automation – Path Towards Increased Resilience

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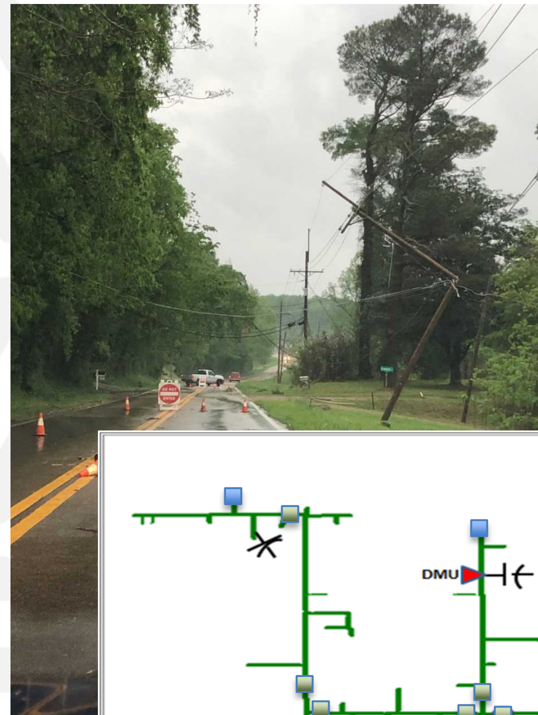
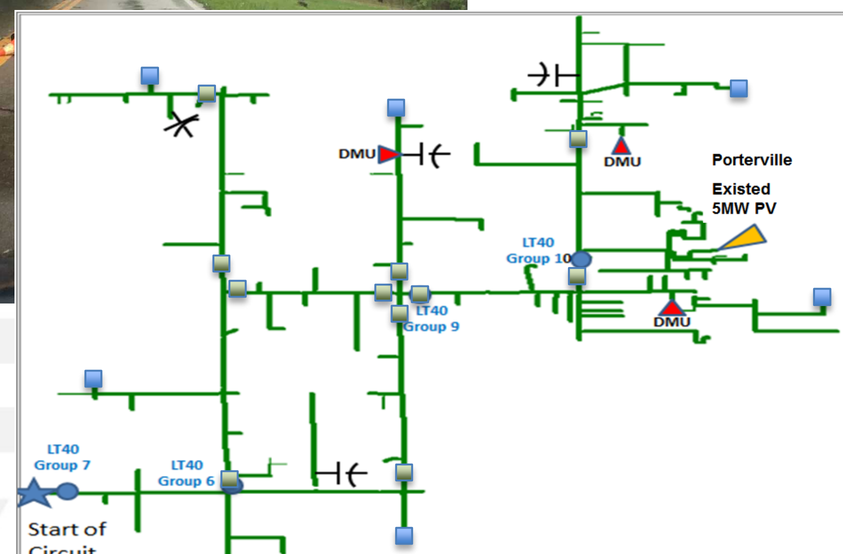
Enables better operational decisions (visibility and control)

- Data is integrated into one system (see the whole picture).
- There is much more data to inform decisions (think AMI, more remotely operated switches with voltage measurements, fault indicators, etc.).
- There are far more potential options due to greater flexibility of the system (think circuit reconfiguration, controllable demand response, etc.).

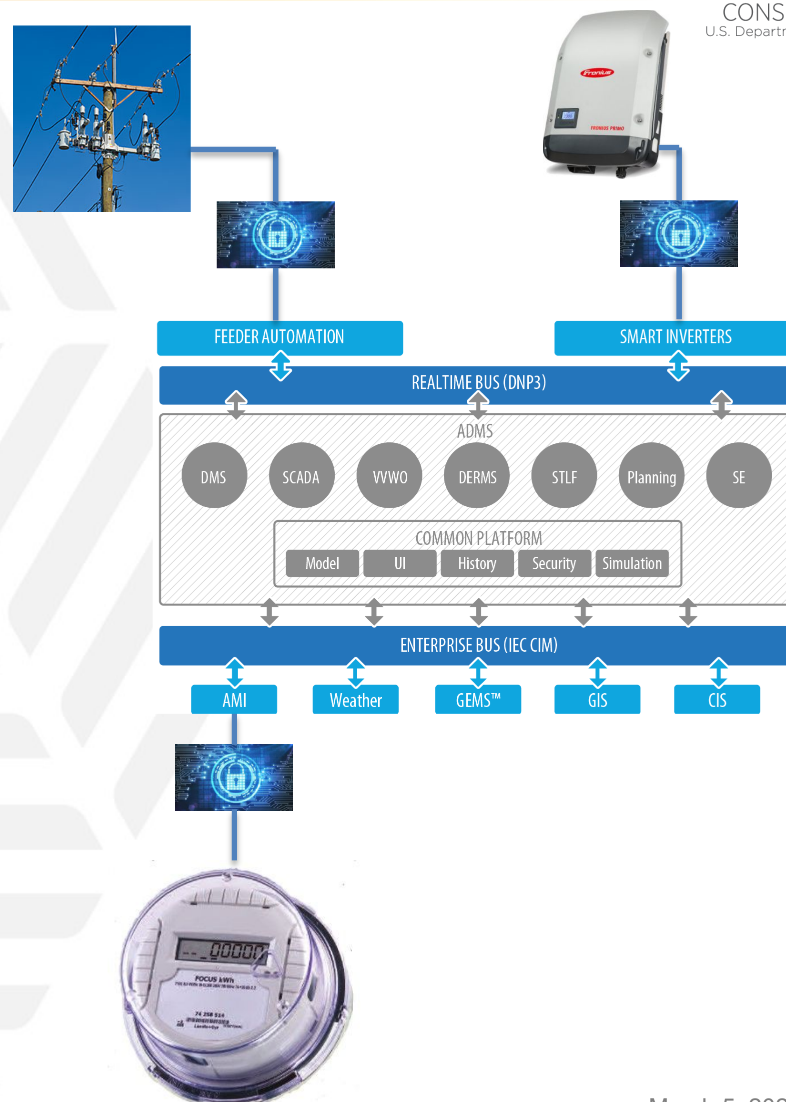




Cybersecurity Considerations

Actionable data and controllability require a “double-ended” cybersecurity approach.

- Operational decisions could be erroneous if incoming data is corrupted.
- More controllable equipment in the field opens more potential vulnerabilities (utility and customer owned).
- Physical underlying realities can serve as a check on corrupt data or malicious control commands.



ADMS Case Study

Case Study: Feeder Voltage Using Advanced Inverters and a DMS

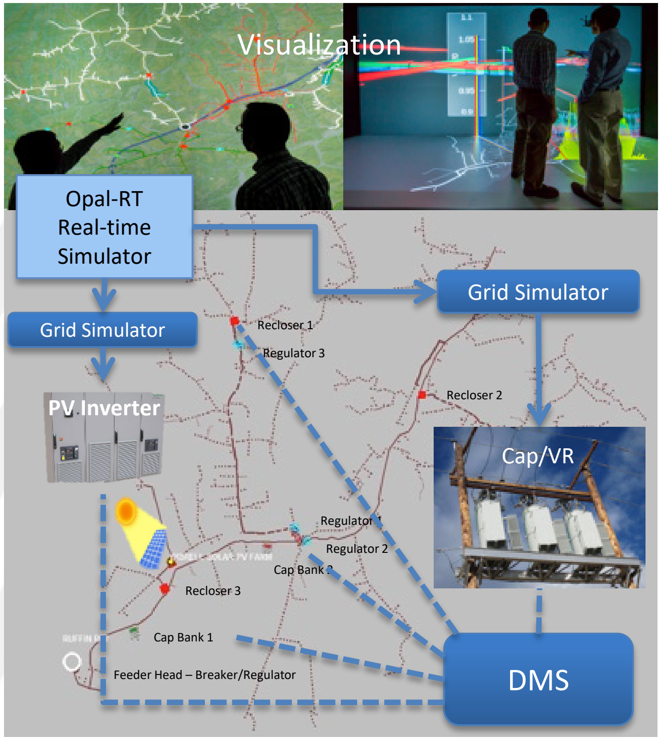
Objective:

Understand advanced inverter and distribution management system (DMS) control options for large (1–5 MW) distributed solar photovoltaics (PV) and their impact on distribution system operations for:

- Active power only (baseline);
- Local autonomous inverter control: power factor (PF) ≠1 and volt/VAR (Q(V)); and
- Integrated volt/VAR control (IVVC)

Approaches:

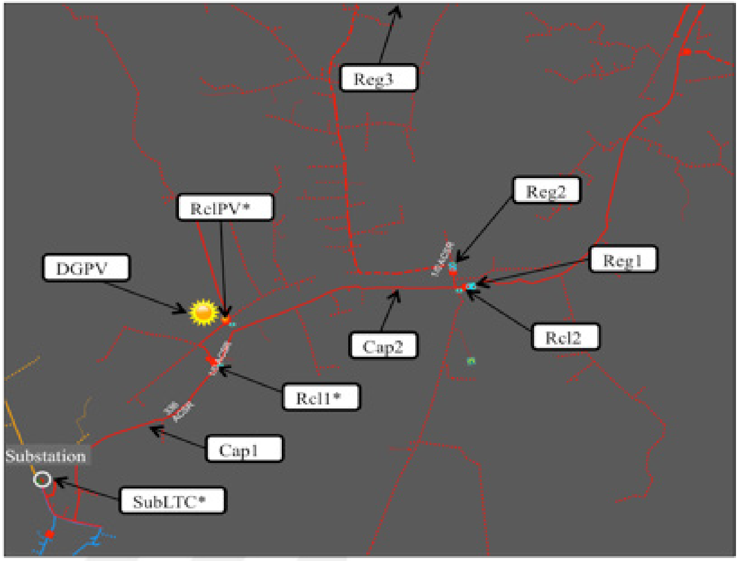
- Quasi-steady-state time-series (QSTS)
- Statistics-based methods to reduce simulation times
- Cost-benefit analysis to compare financial impacts of each control approach



Palmintier, B., Giraldez, J., Gruchalla, K., Gotseff, P., Nagarajan, A., Harris, T., ... Baggu, M. (2016). Feeder Voltage Regulation With High Penetration PV Using Advanced Inverters and a Distribution Management System: A Duke Energy Case Study (NREL Technical Report No. NREL/TP-5D00-65551). Golden, CO: National Renewable Energy Laboratory.

Study System Characteristics

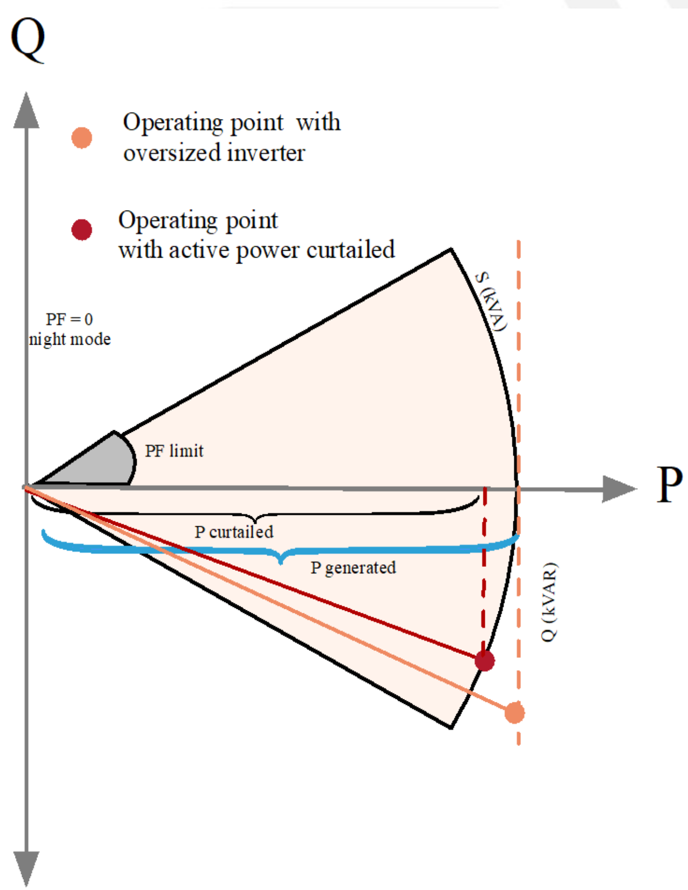
Feeder Characteristics	
Substation primary/secondary voltage (kV LL)	44/13.5
Substation transformer (MVA/%X)	10/6.84
Feeder head gang-operated regulators, set of three (kVA/%X)	250/6.25 (each)
Feeder head X/R	4.25
P(Est. Native)$_{annual\ avg}$ (MW)	1.71
P(Est. Native)$_{peak}$ (MW and date)	5.26 (Jan. 30, 2014)
P(Measured)$_{annual\ avg}$ (MW)	0.678
P(Measured)$_{min}$ (MW)	-3.72
Capacitor Banks (number/total kVAR)	2/900
Line Regulator groups	1x3-phase, 2x2-phase
PV Plant Characteristics	
Commission date	March 2013
Plant rating (MW$_{DC}$/MW$_{AC}$)	6.4/4.8
PV recloser X/R	1.82
Distance to substation (overhead line miles)	1.75



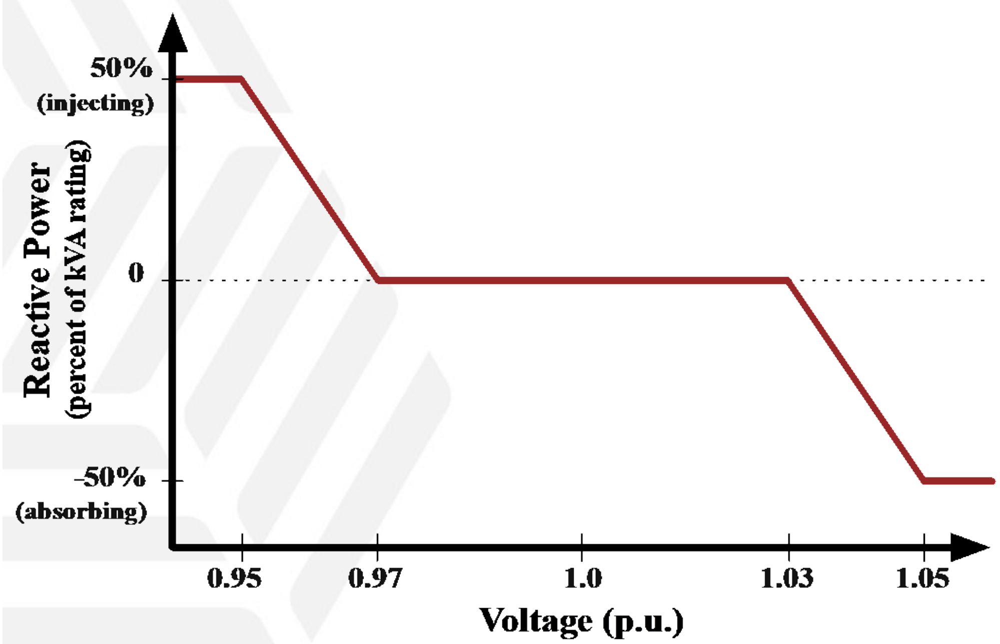
- Cap1: A 450-kVAR (150 kVAR per phase) VAR-controlled capacitor with temperature override. Cap2: A three-phase 450-kVAR capacitor (always disconnected unless controlled otherwise by IVVC)
- Reg1: A set of three single-phase 167-kVA regulators with a voltage target of 123 V (120 V base)
- Reg2: A set of two single-phase 114-kVA regulators on phase B and phase C with a voltage target of 123 V
- Reg3: A second set of two single-phase 76.2-kVA regulators on phase B and phase C with a voltage target of 124 V

Local Control Modes for the PV Inverter

Constant Power Factor Set Point



Volt/VAR Curves



Simulation Scenarios Developed to Show Value of Increasingly Complex ADMS

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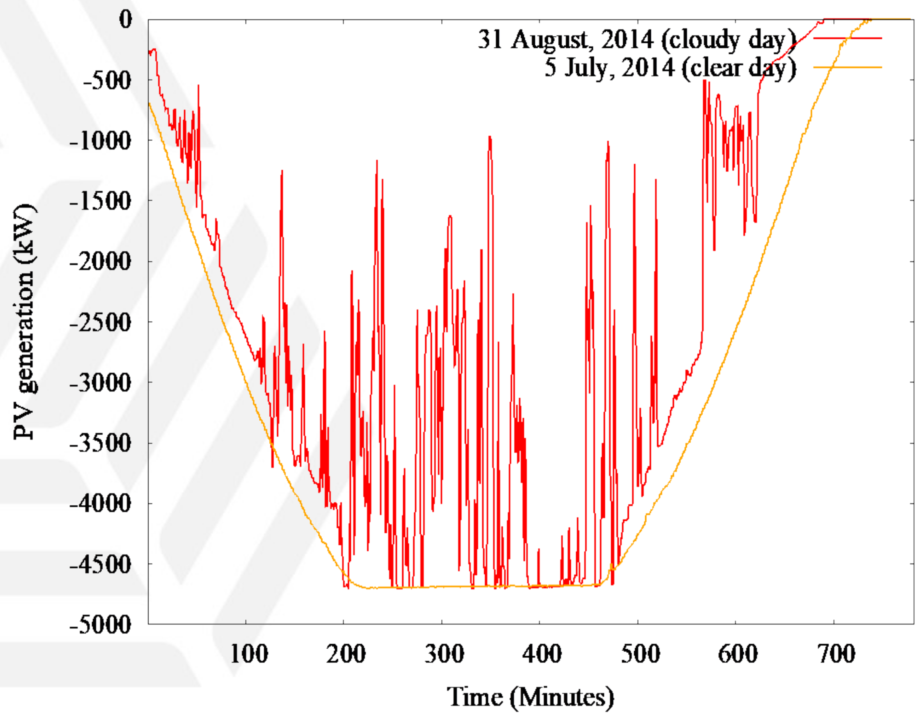
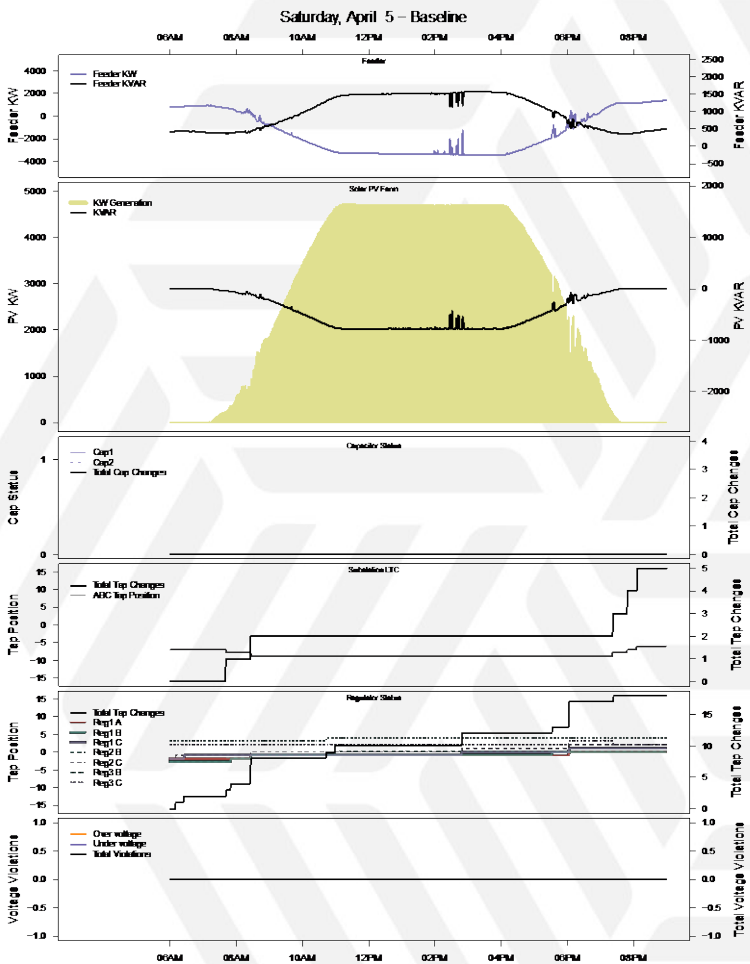
Control Scenarios Evaluated:

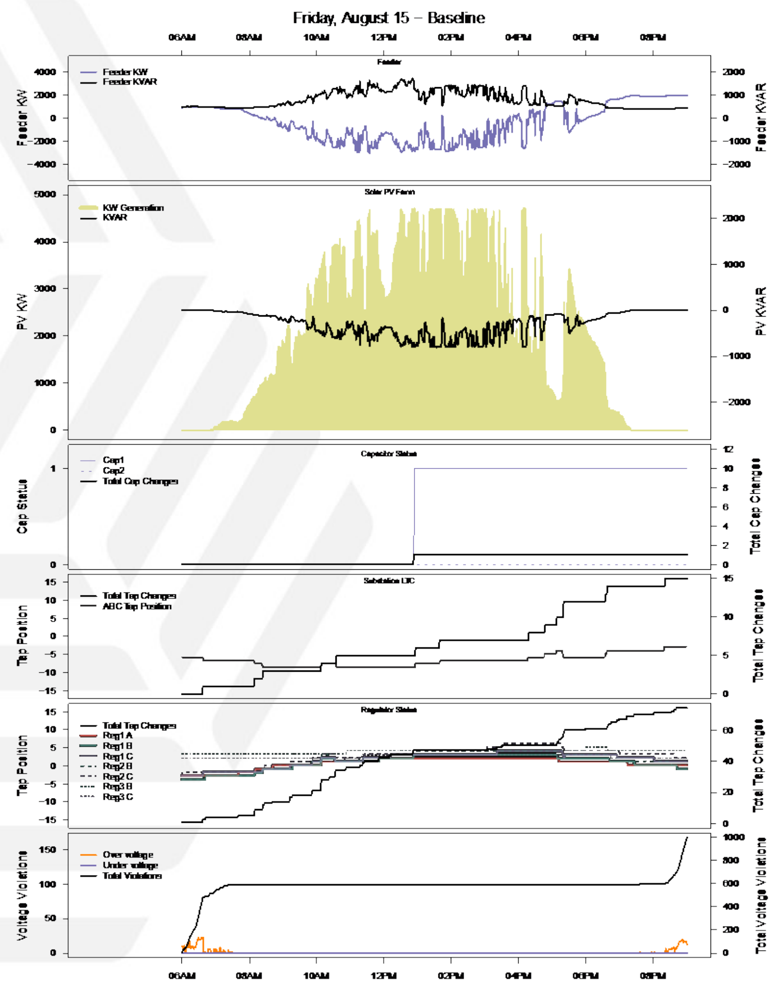
- Baseline (no control)
- Local PV Control (PF = 0.95)
- Local PV Control (Volt/VAR)
- Legacy IVVC* (Exclude PV)
- IVVC with PV @ PF 0.95
- IVVC (Central PV Control)



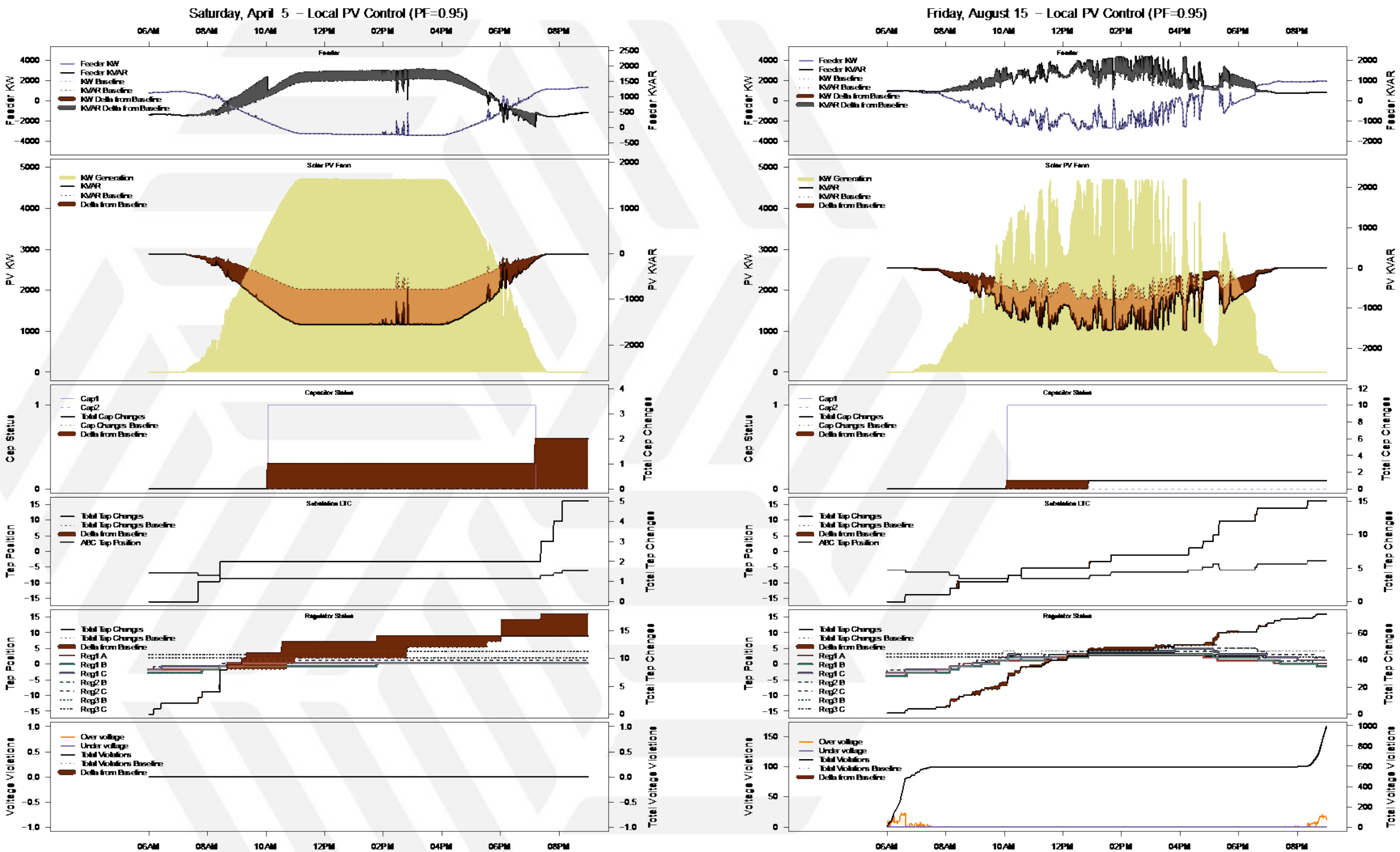
*IVVC = Integrated volt/var control, i.e. VVO

Baseline Results

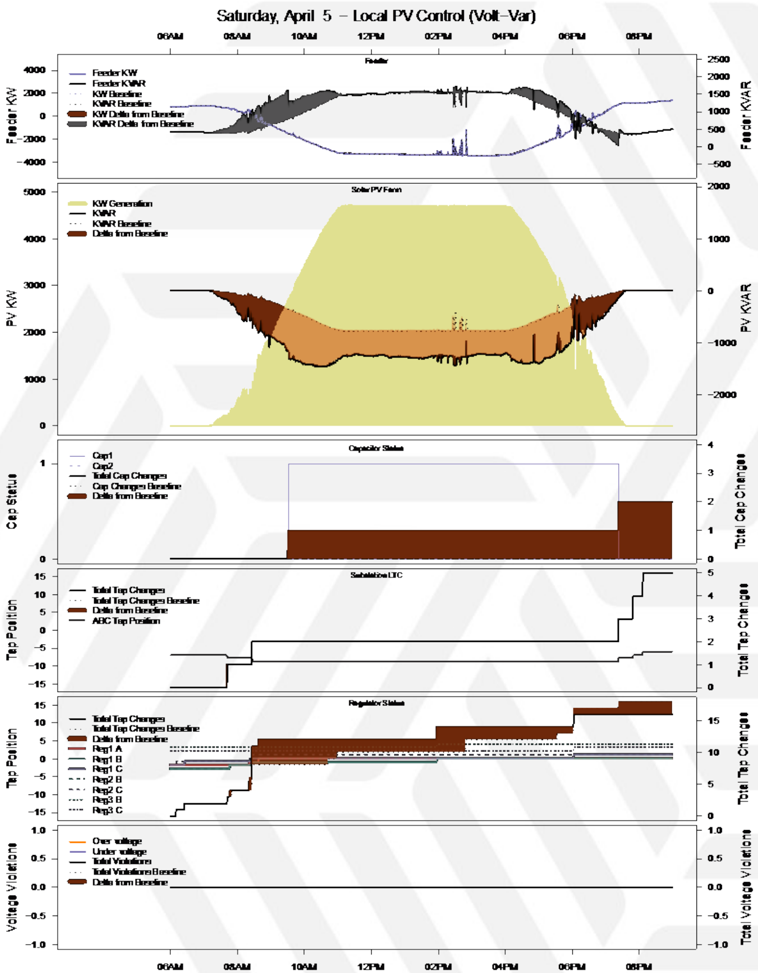


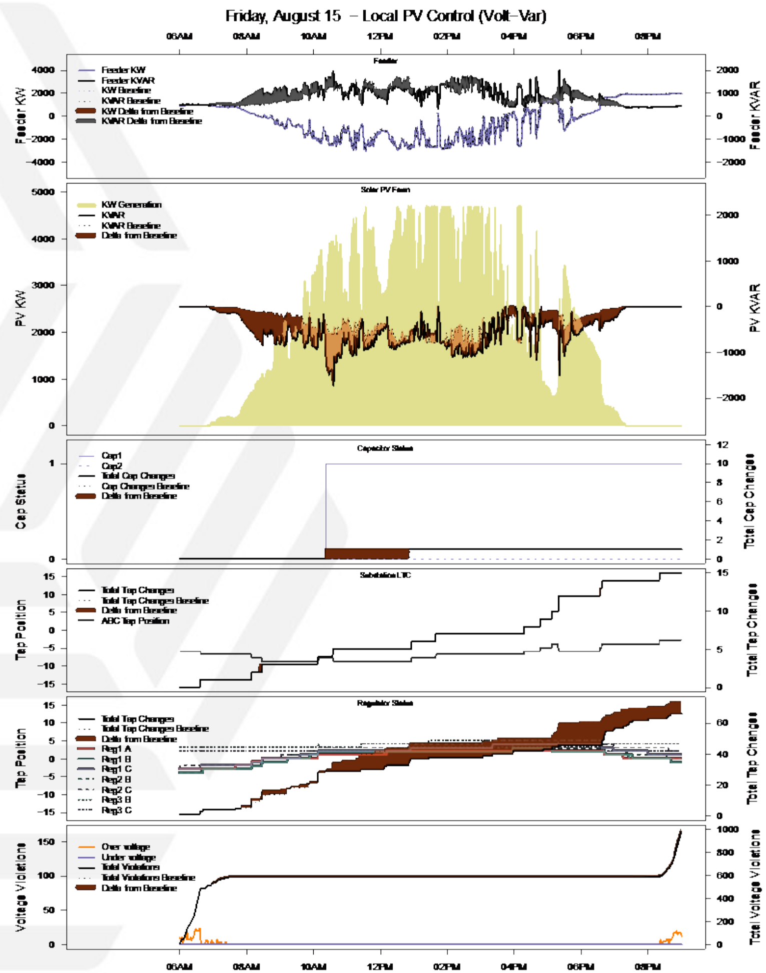


Autonomous Local Control

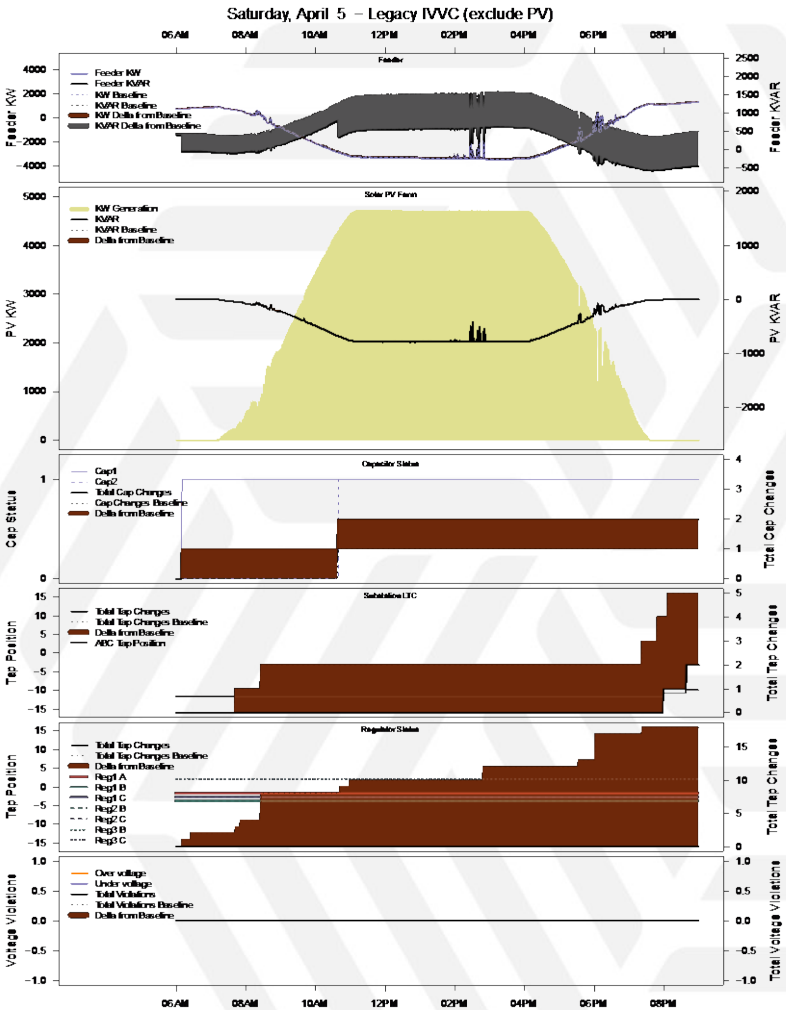


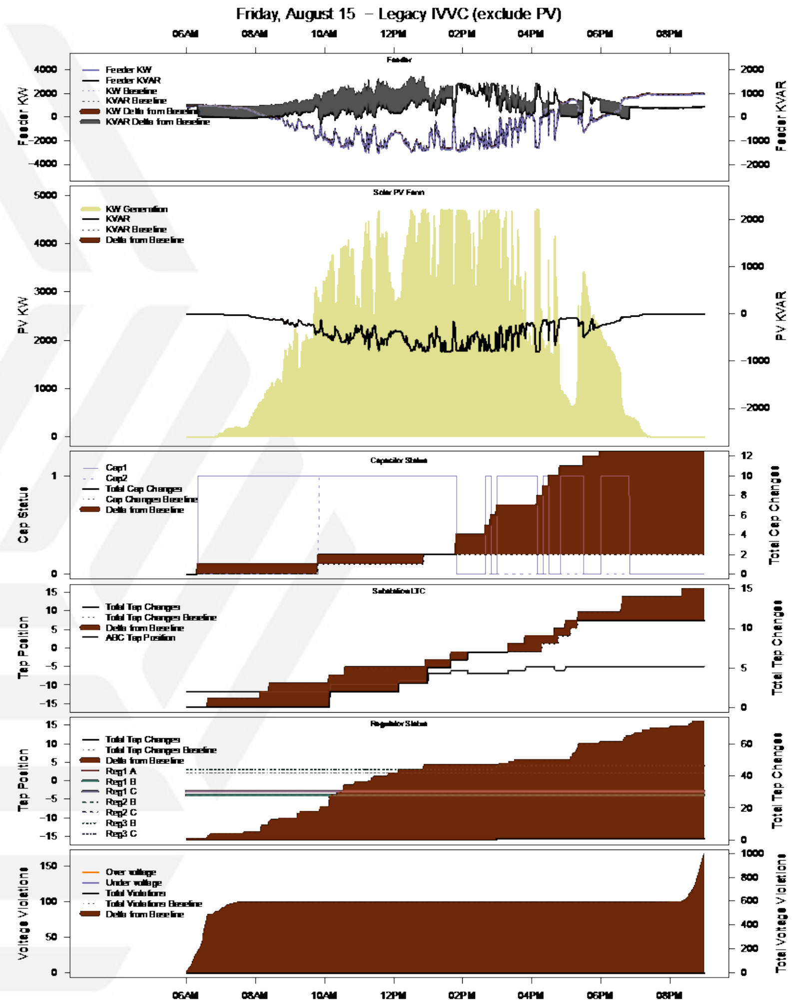
Local Volt/VAR Control





Legacy DMS Integrated Volt/VAR Control with LTC, VR and Caps Only





Integrating Advanced Inverters into IVVC

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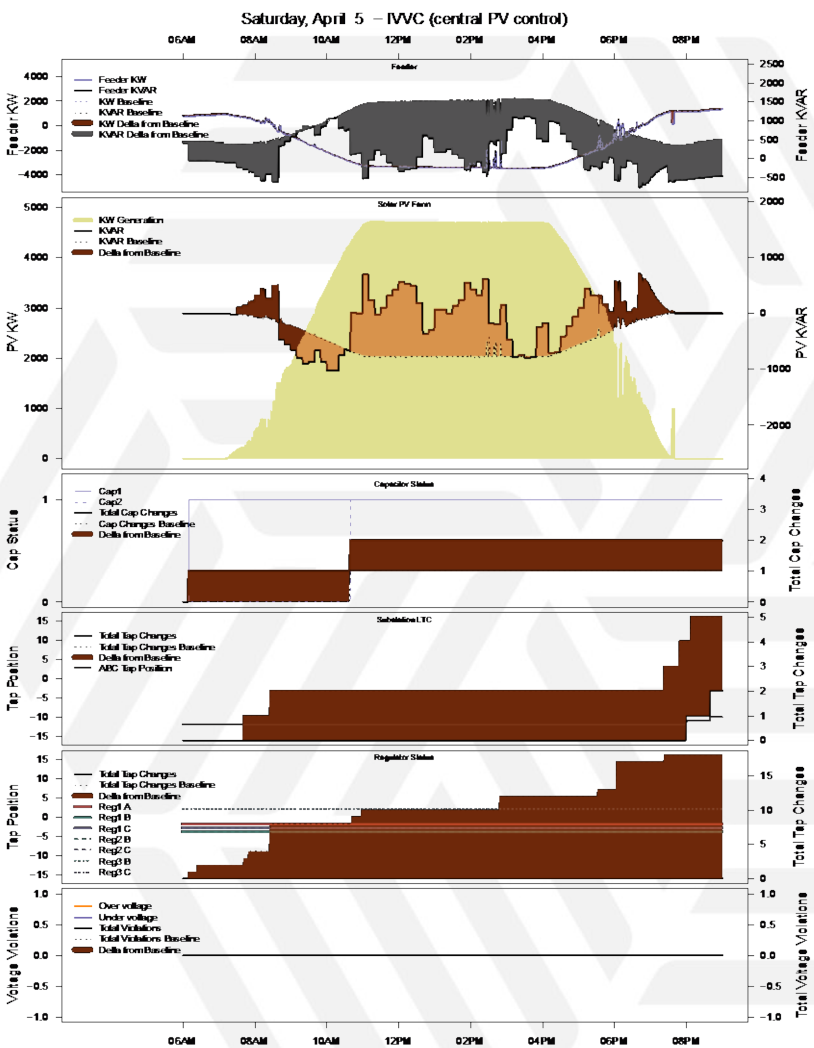

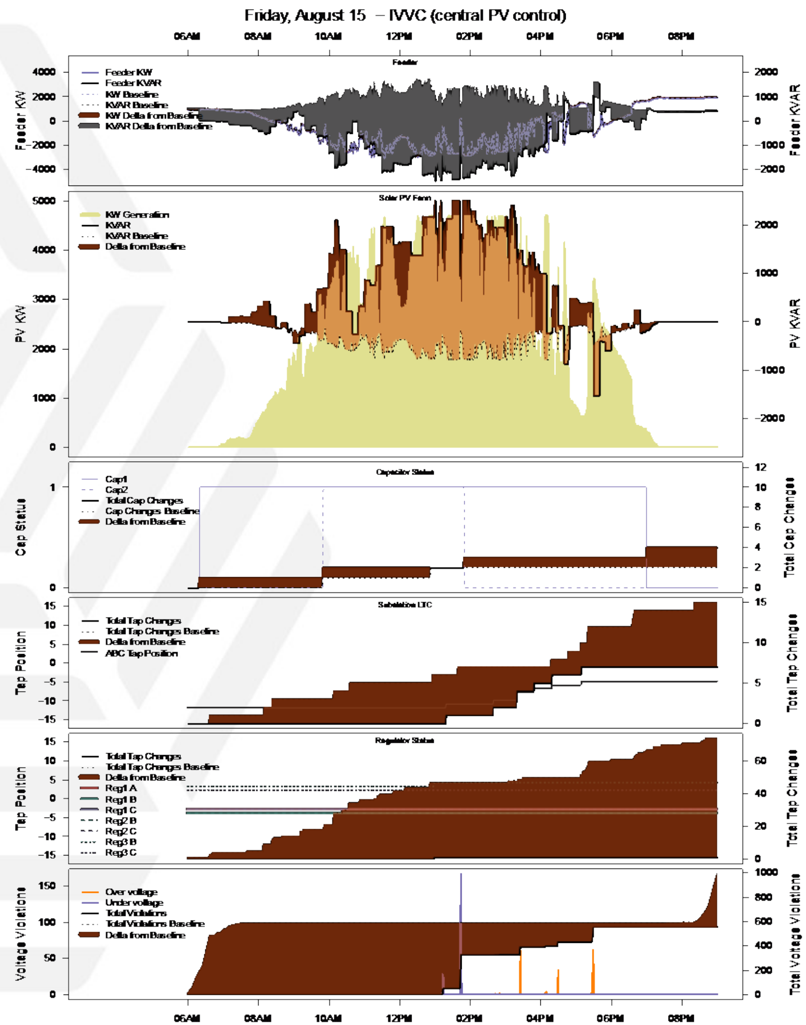

Summary Comparison of Annualized Scenarios

		IVVC Control				Annualized Equipment Operations				Voltage Challenges	
Scenario	PV Mode	LTC	Regulators	Capacitors	PV	LTC	Regulators	Capacitors	Total	Over	Under
Baseline	Default	-	-	-	-	5,043	19,160	125	24,328	1.47%	0.00%
Local PV Control (PF = 0.95)	PF=0.95	-	-	-	-	5,063	19,943	505	25,511	1.48%	0.00%
Local PV Control (Volt/VAR)	Q(V)	-	-	-	-	5,087	19,857	541	25,485	1.44%	0.00%
Legacy IVVC (Exclude PV)	Default	Y	Y	Y	-	2,869	2,943	1,863	7,675	0.02%	0.00%
IVVC with PV (PF = 0.95)	PF=0.95	Y	Y	Y	-	2,498	1,888	1,409	5,795	0.01%	0.00%
IVVC (Central PV Control)	IVVC for reactive power	Y	Y	Y	Y	2,312	2,698	1,151	6,161	0.05%	0.02%

Case Study: Conclusion

- This work Illustrates the potential for coordinated control of voltage management equipment, such as the central DMS-controlled IVVC, by:
  - Providing substantial improvement in distribution operations with large-scale PV systems
  - Reducing regulator operations
  - Decreasing the number of voltage challenges
- The preliminary cost-benefit analysis (not detailed in this presentation) showed operational cost savings for the IVVC scenarios that were:
  - Partially driven by reduced wear and tear on utility regulating equipment
  - Dominated by the use of CVR/demand reduction objective
- Work is needed in the area of integrating advanced inverters as controllable resources into IVVC optimization strategies.
  - Event triggered operation of DMS IVVC
  - Power factor set point in place of reactive power set point

Thank you

Questions?