



EPRI

ELECTRIC POWER
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EPRI Distributed PV (DPV) Feeder Analysis Project



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UWIG Solar Users Group
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Solar PV Distribution Feeder Impacts Utility Concerns

Voltage

- Overvoltage
- Voltage variations

Equipment Operation

- Feeder regulators
- Load tap changers
- Switched capacitor banks

Demand

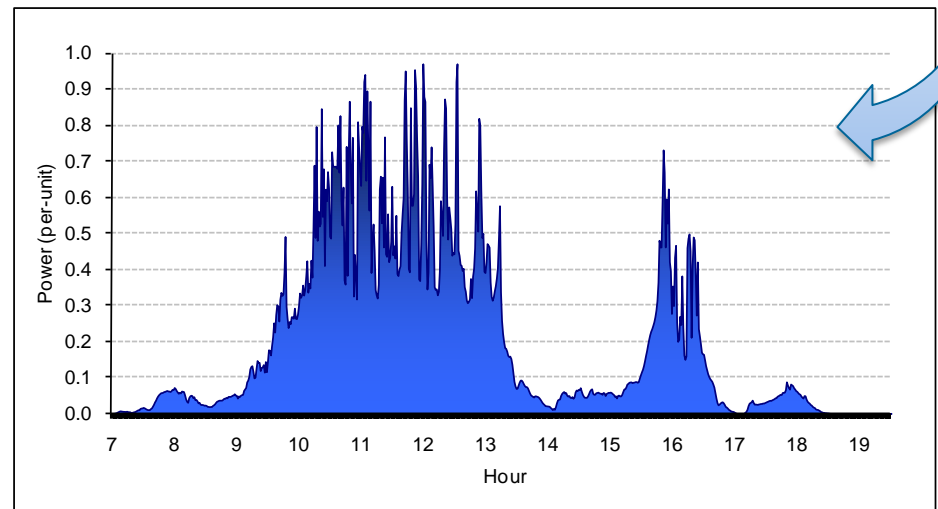
- “Masking” peak demand
- Reducing power factor

System Protection

- Relay desensitization
- Unintentional islanding

Power Quality

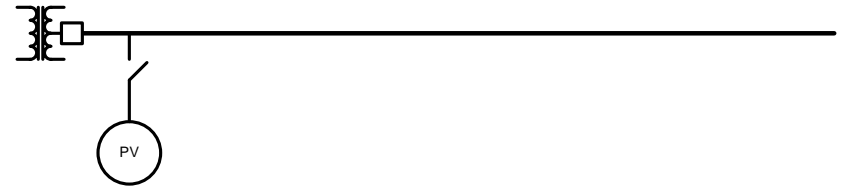
- Harmonics
- Flicker



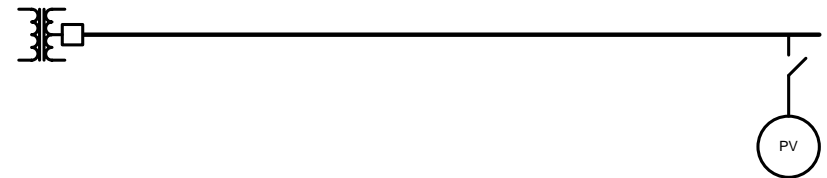
Key Factors that Determine Hosting Capacity

- Size & distribution of PV
- Location of PV
- Feeder topology & characteristics
- Electrical proximity to
 - other PV on feeder
 - Feeder regulation equipment
- Unique solar resource characteristics in the area

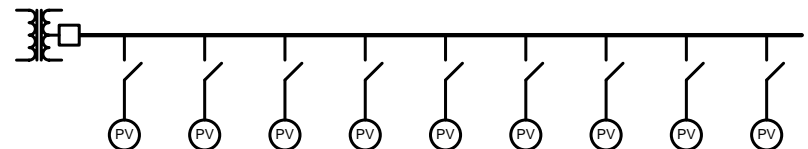
Large Scale PV Near Sub



Large Scale PV @ End Line

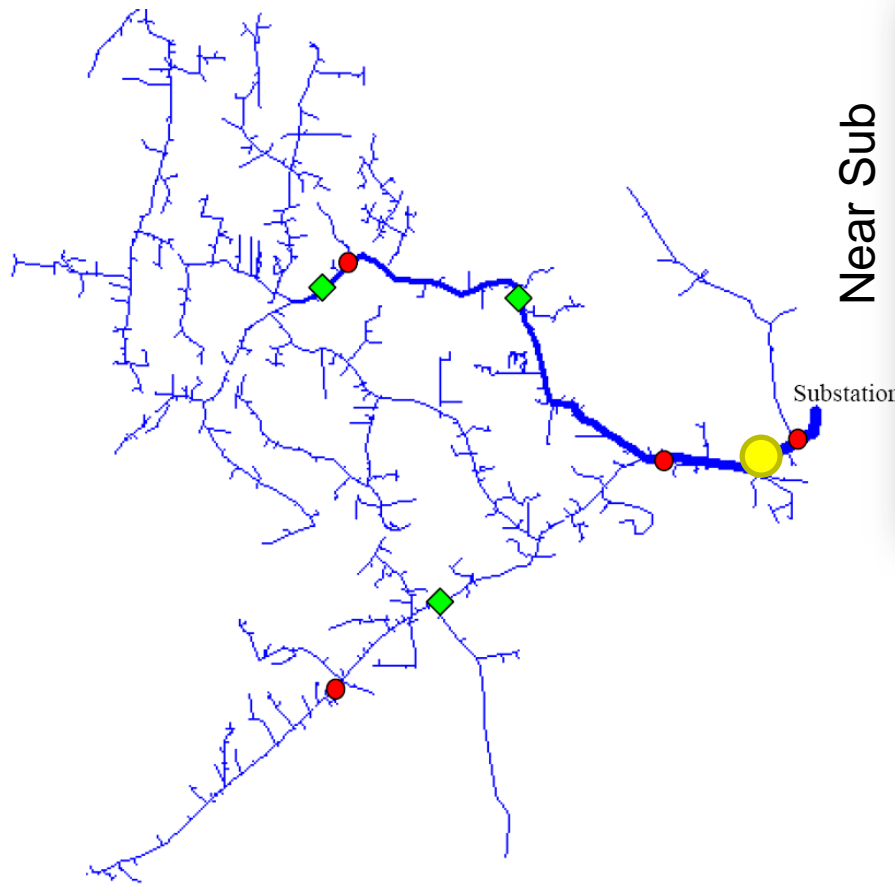


Small-Scale Distributed PV

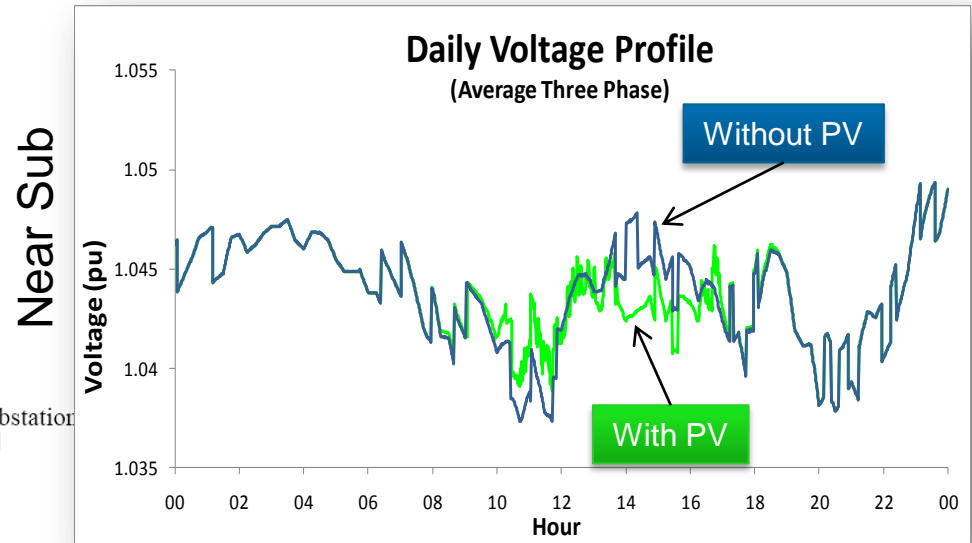


Location, Location, Location...

2MW PV System Near Sub



Capacitors (♦) Regulators (●)

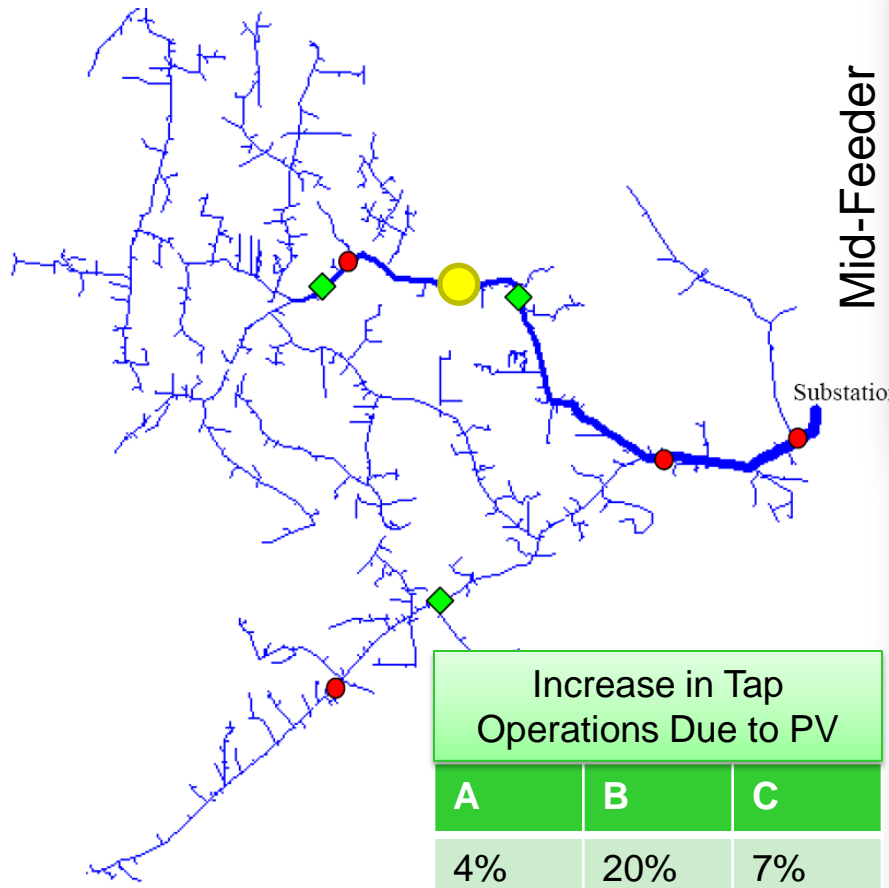


PV Located Near Sub: No Adverse Impact on Regulation Equipment (Substation LTC or feeder regulator)

IEEE Feeder Test Case (based on actual feeder)

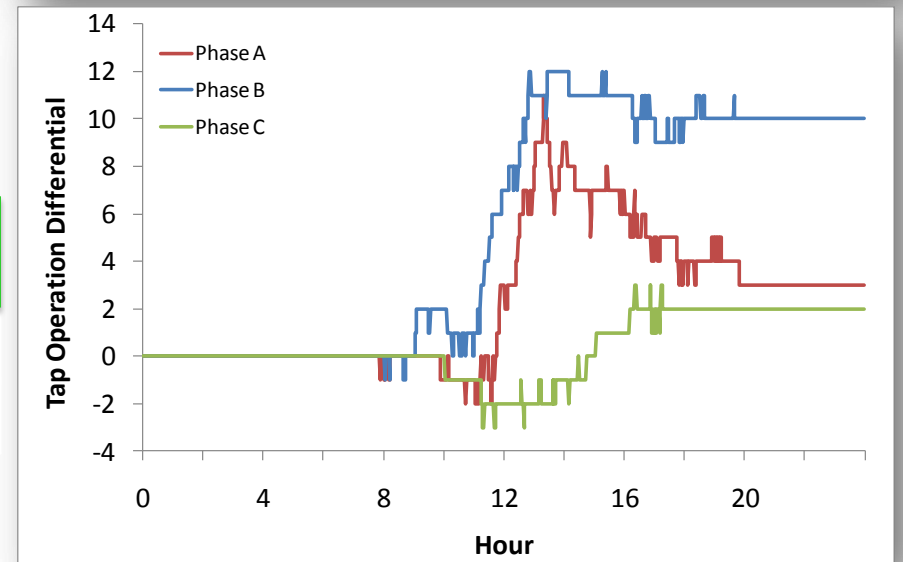
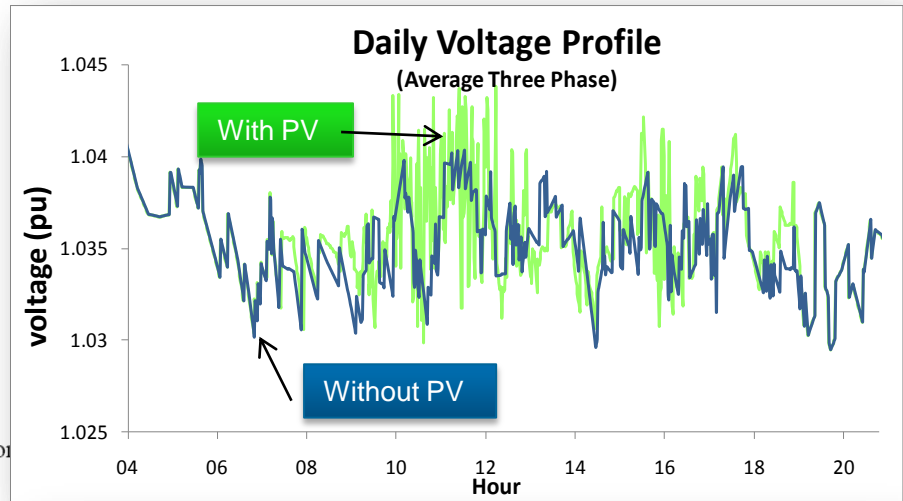
Location....further out from Sub

2MW PV System located Mid-Feeder



Capacitors (●) Regulators (◆)

IEEE 8500 Node Test Case



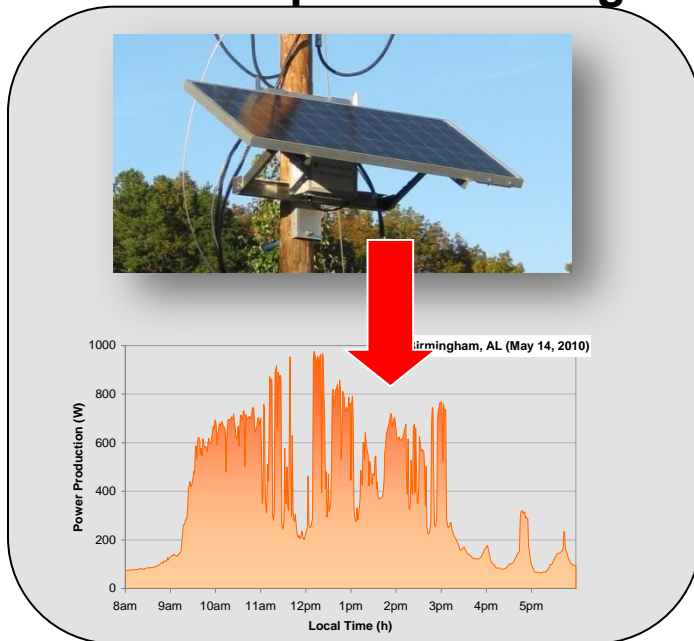
EPRI's Distributed Photovoltaic (DPV) Research

Study on Distributed PV Variability and Distribution System Impacts

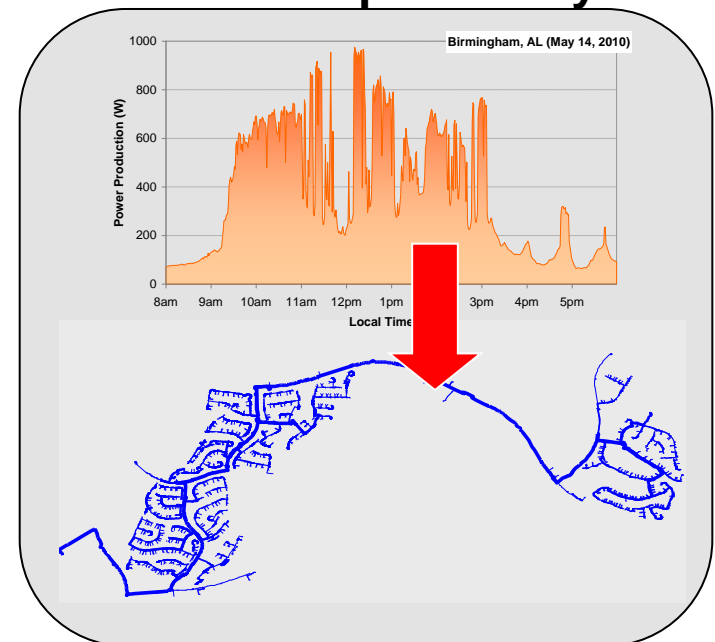
- Industry-wide study
- Launched in mid-2010
- Will continue through 2012
- Looking for 20 utilities, 8 in so far
- 30 to 40 distribution circuits, 26 now
- 250-300 monitoring sites, 180 identified

Two Distinct R&D Projects

PV Output Monitoring



Feeder Impact Analysis

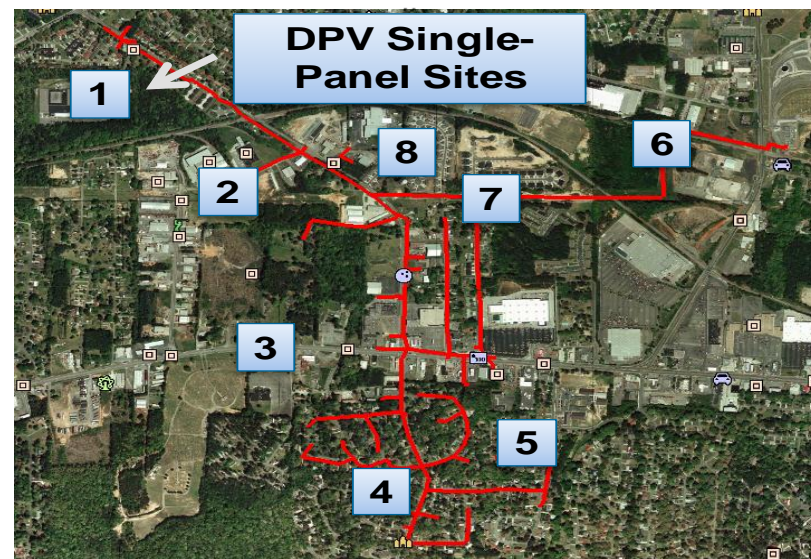
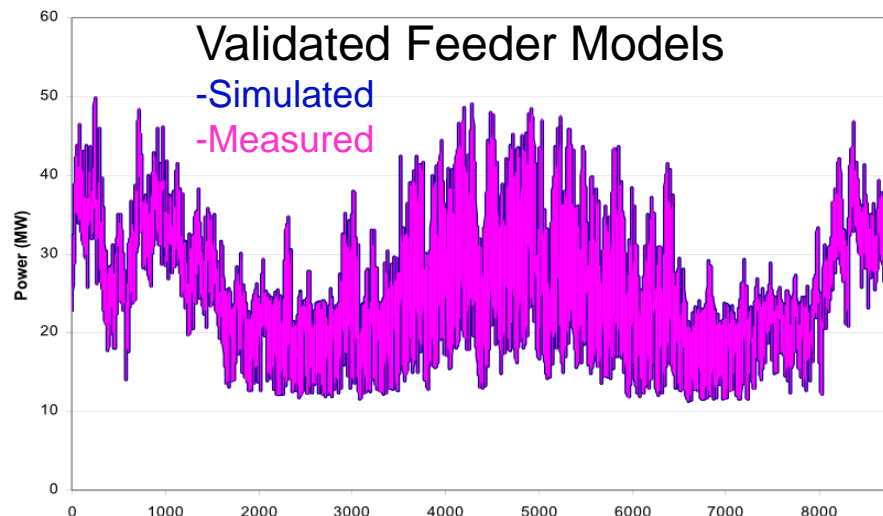


Feeder Impacts Utility Participation (as of 8/11)

Participating Utility (US location)	# of Circuits	Notes
Southeast	3	1 urban, 2 rural
West	5	3 urban, 2 rural
Northeast	2	2 urban
Northeast	3	2 urban, 1 rural
Southwest	4	4 urban
East Coast	2	1 urban, 1 rural
East Coast	2	1 urban, 1 rural
Northeast	2	2 urban
Southeast	1	1 rural
West	2	1 urban, 1 rural
Total	26	17 urban, 9 rural

Modeling for Feeder Analysis

- High fidelity feeder model
 - Multi-phase model
 - Substation to customer meter
 - Validated against measured data
 - Time-varying customer load
 - Distribution regulation and controls
- Time-varying nature of solar PV
 - DPV monitoring data → single panel PV output & irradiance data
 - Utilize best available data
- Allows “what if” analysis of future PV deployment
 - Small, residential distributed throughout feeder
 - Large, centralized commercial



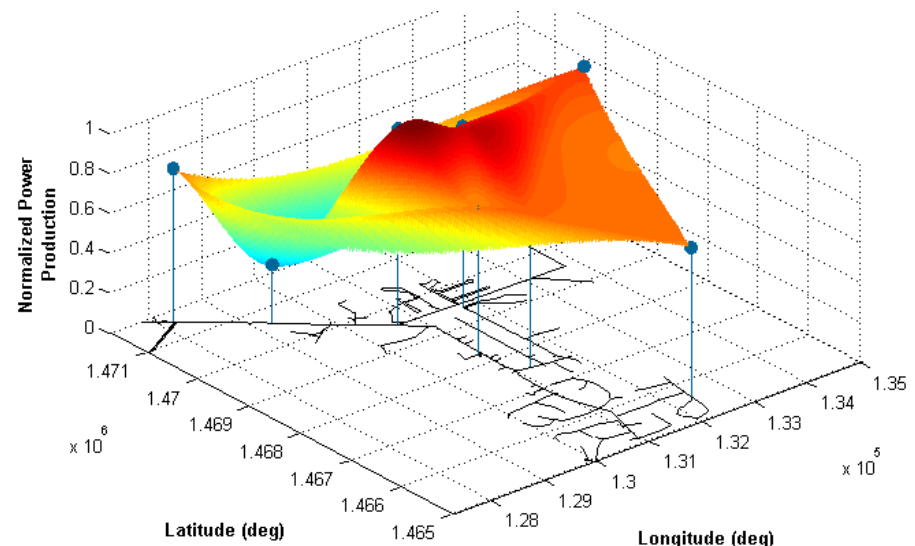
PV Impact Analysis Approach

Steady State Analysis

- Scenarios
 - Stochastic approach using high number of random PV allocations
 - Weighted and/or non-weighted allocations
 - Load
 - Absolute peak and minimum
 - Non-coincident with PV peak
 - Circuit response bounding envelope
 - Solar noon peak and minimum
 - Coincident with PV peak
 - Circuit response probable bounds
 - Regulation Equipment
 - Fixed for base load operation
- Determine circuit response from Zero to full PV output

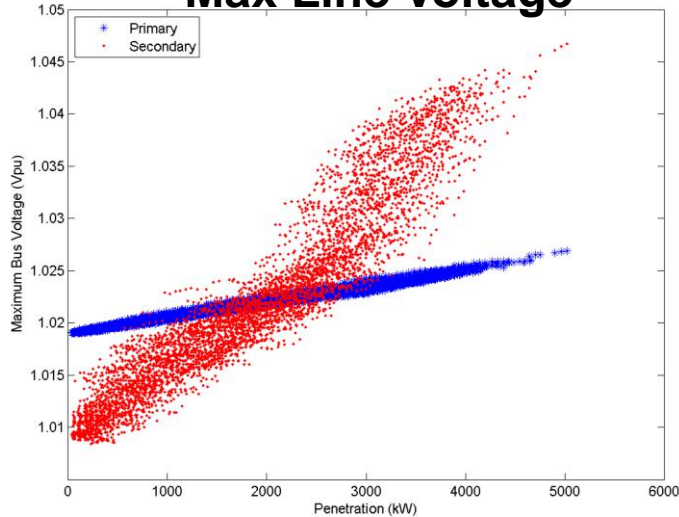
Time Series Analysis

- Scenarios
 - Subset from steady state analysis selected by violation criteria
 - Load and regulation equipment
 - Normal operation protocols
- Determine circuit response from measured PV irradiance data

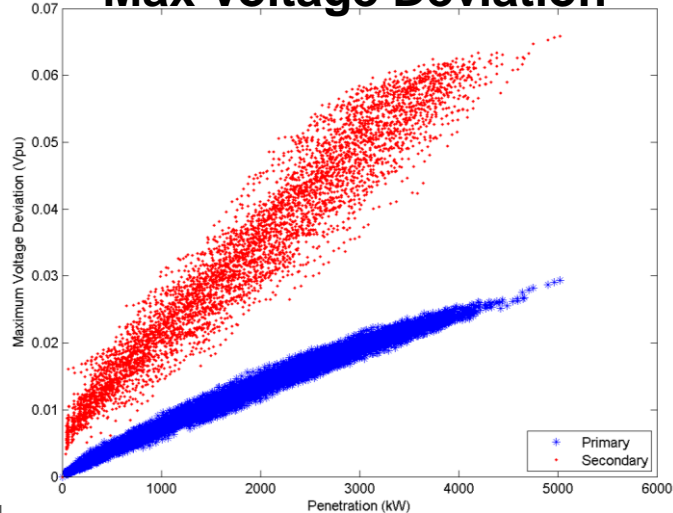


Example Steady-State Results for 1 Circuit

Max Line Voltage

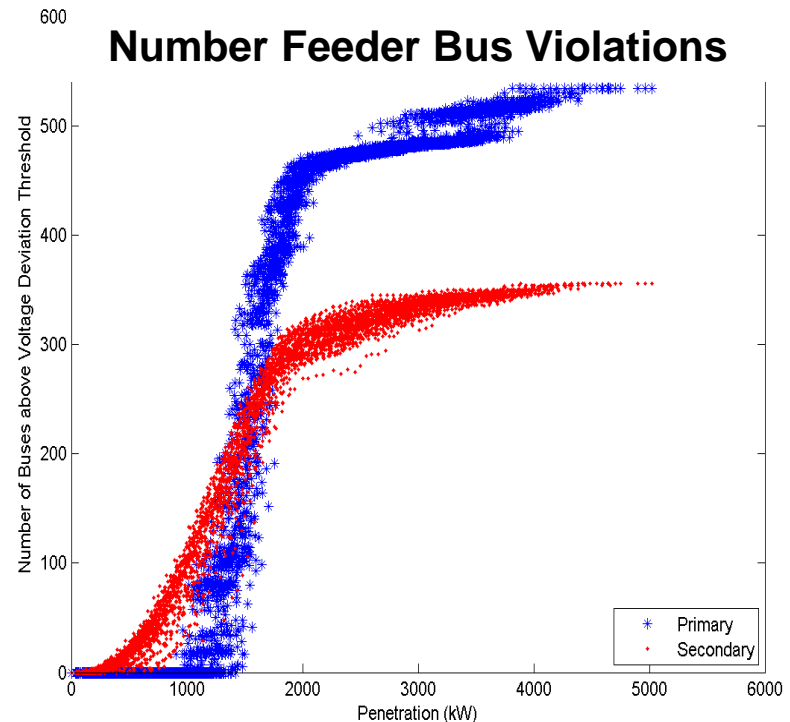


Max Voltage Deviation

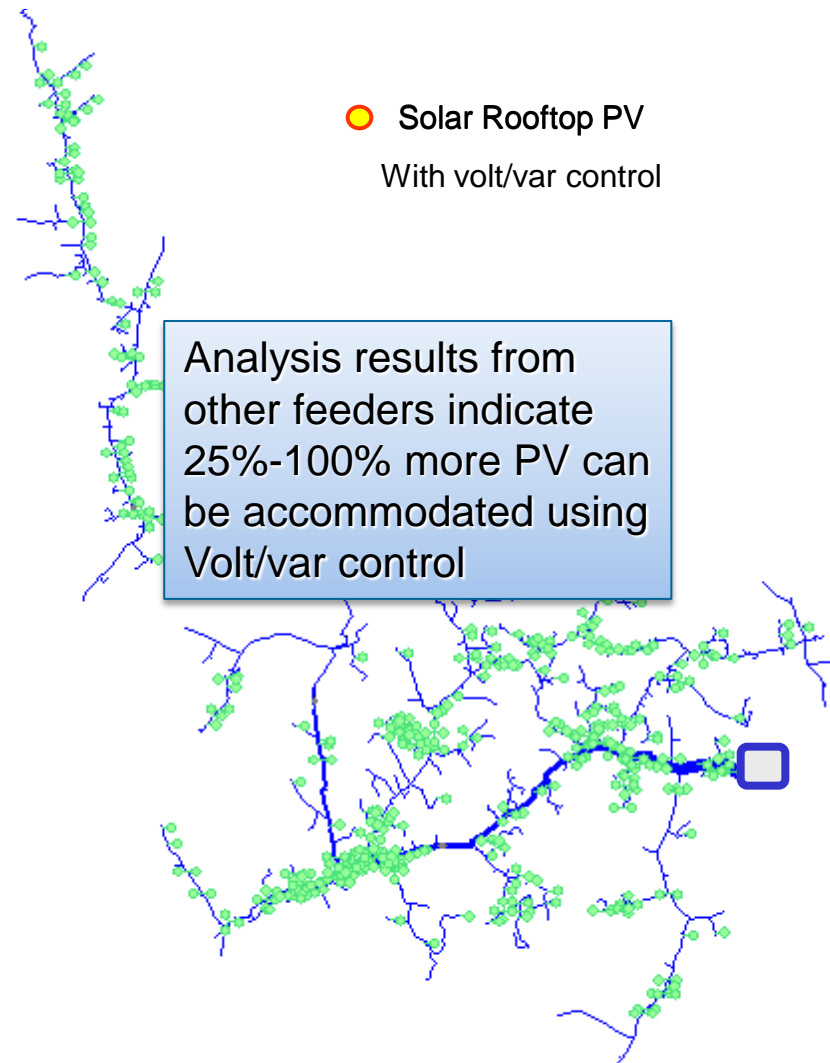
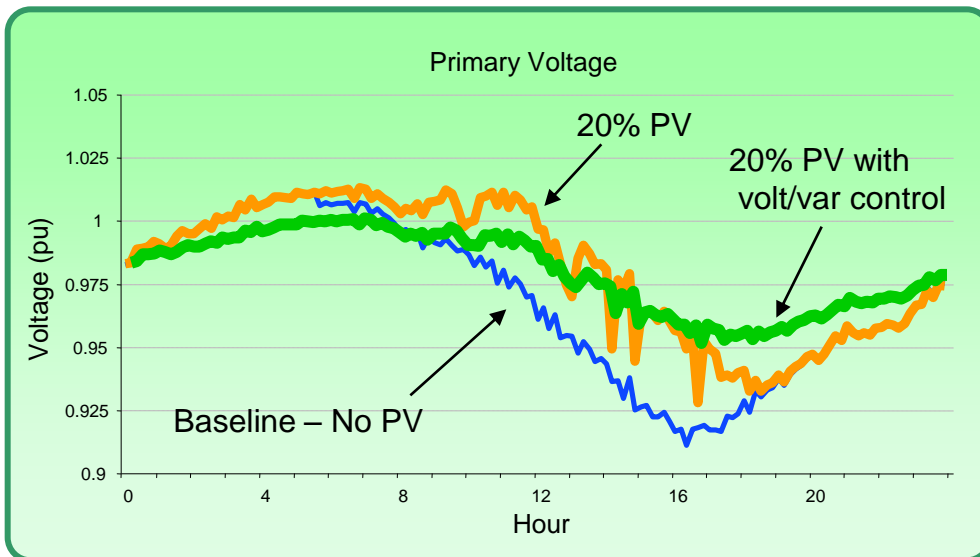
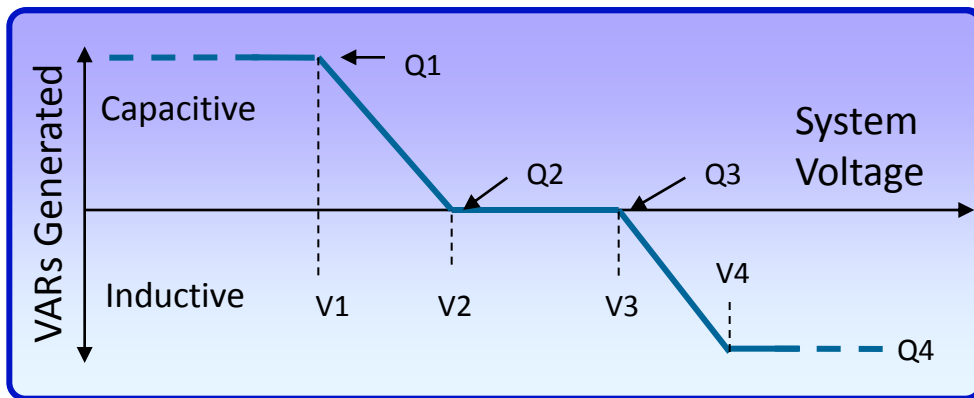


- Boundary Condition Analysis
 - Worst-case conditions
- 1000's of cases on each feeder
 - Small and large scale
 - Random and weighted locations
- Increase penetration until violations occur

Number Feeder Bus Violations



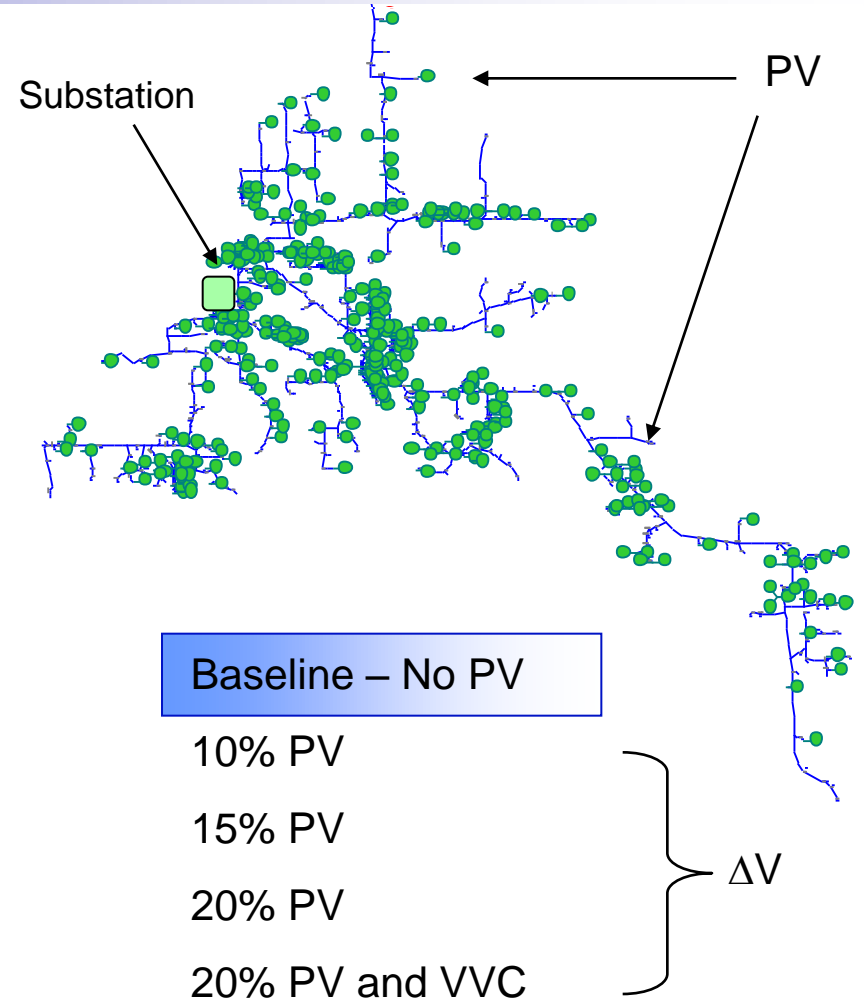
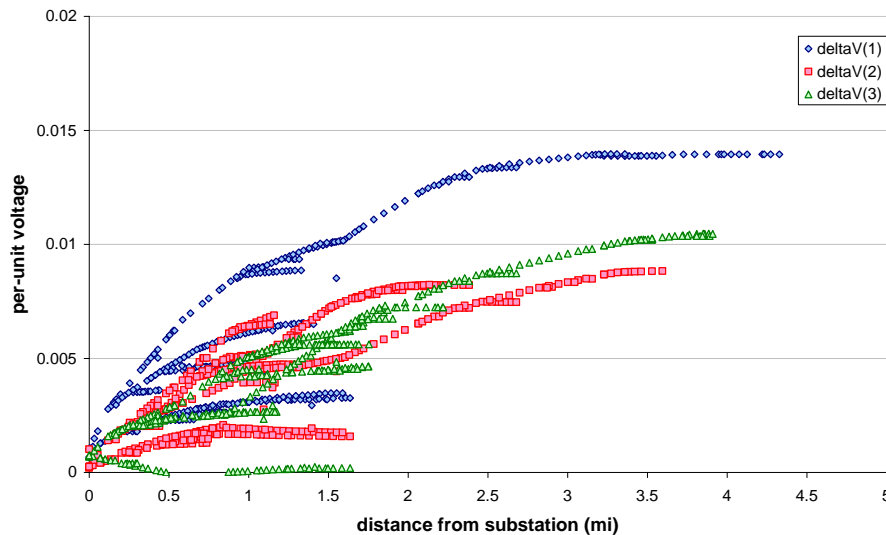
Use of Smart Inverters for Accommodating High-Penetration PV



Steady-State Voltage

- Maximum change in voltage before regulator/LTC/capacitor banks operate
- Considered “worst-case” conditions
- PV at increased penetration until limit exceeded

20% PV with VVC
Voltage Change



Conclusions

- PV penetration level depends upon feeder characteristics
 - Feeder length & regulation, PV location, operating practices, etc.
- EPRI DPV Objective
 - Determine circuit limits for range of feeder types & utility practices
 - Improved methodology for estimating hosting capacity
 - Develop simplified analysis/screening methods
- DPV Feeder Analysis Approach
 - Detailed/validated feeder models
 - Best available PV time series data
 - Standardized analysis methods applied
- Investigate Possible Mitigation Approaches
 - Use of advanced inverter controls

Questions and Discussion

