SAND2016-5524C

Advanced Inverter Controls to Dispatch Distributed PV Systems

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Presented at the 43rd PVSC Conference in Portland, OR
6/8/2016

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Topics of today's talk:

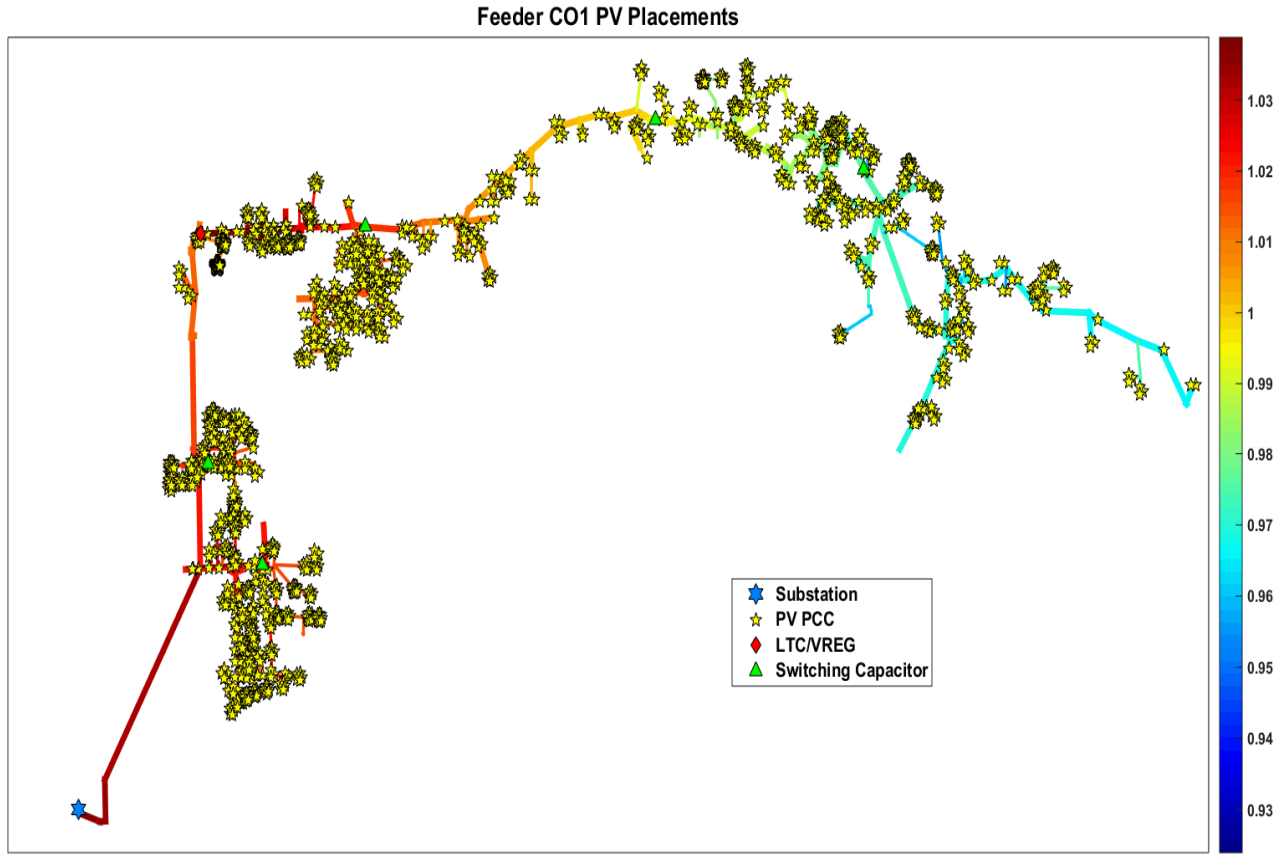
- Motivation
- Advanced Inverter Controls
- Control Tuning
- Simulation Results
- Reactive Power Support
- Summary of Findings

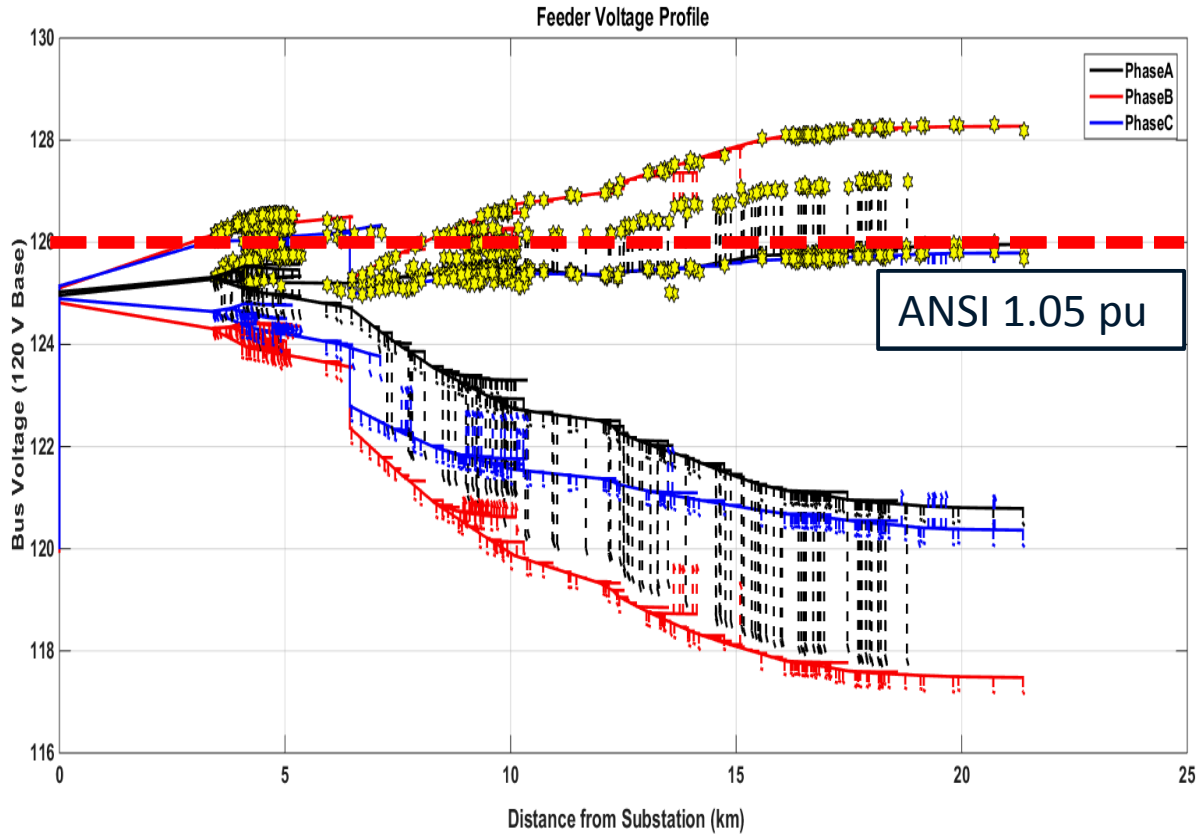
Motivation

Motivation

- There will eventually be a limit in distributed, rooftop PV installations: **capacity reached** or **everyone has one**
- **Voltage rise** is already cited as a **capacity limit** in distribution feeders with high penetration of PV generation
- Does this mean **not everyone** can have a PV system on their roof?
- Can we use advanced inverter controls to mitigate voltage violations caused by **ubiquitous** PV systems?

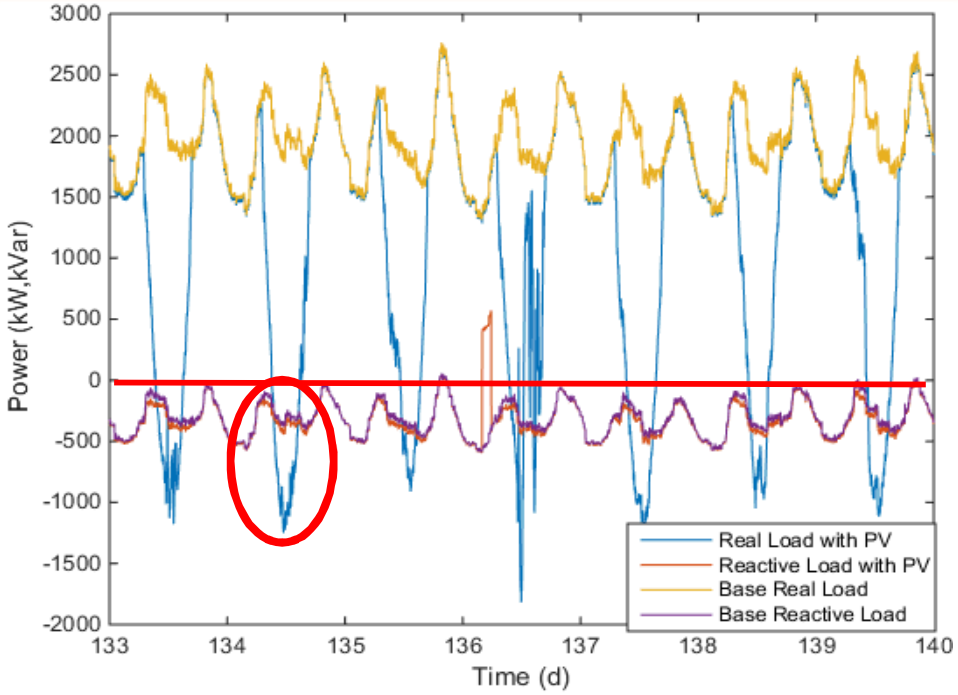
Motivation

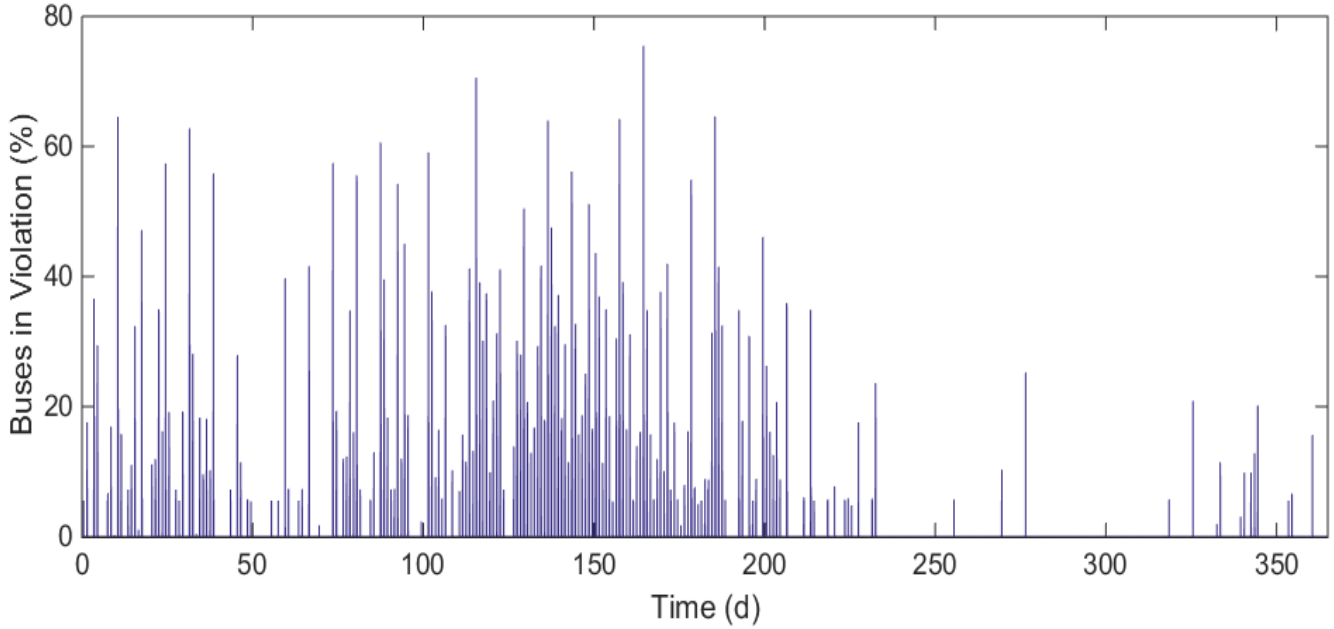




- PV systems placed at each load in feeder
- Sized to 60% of local peak load

Motivation





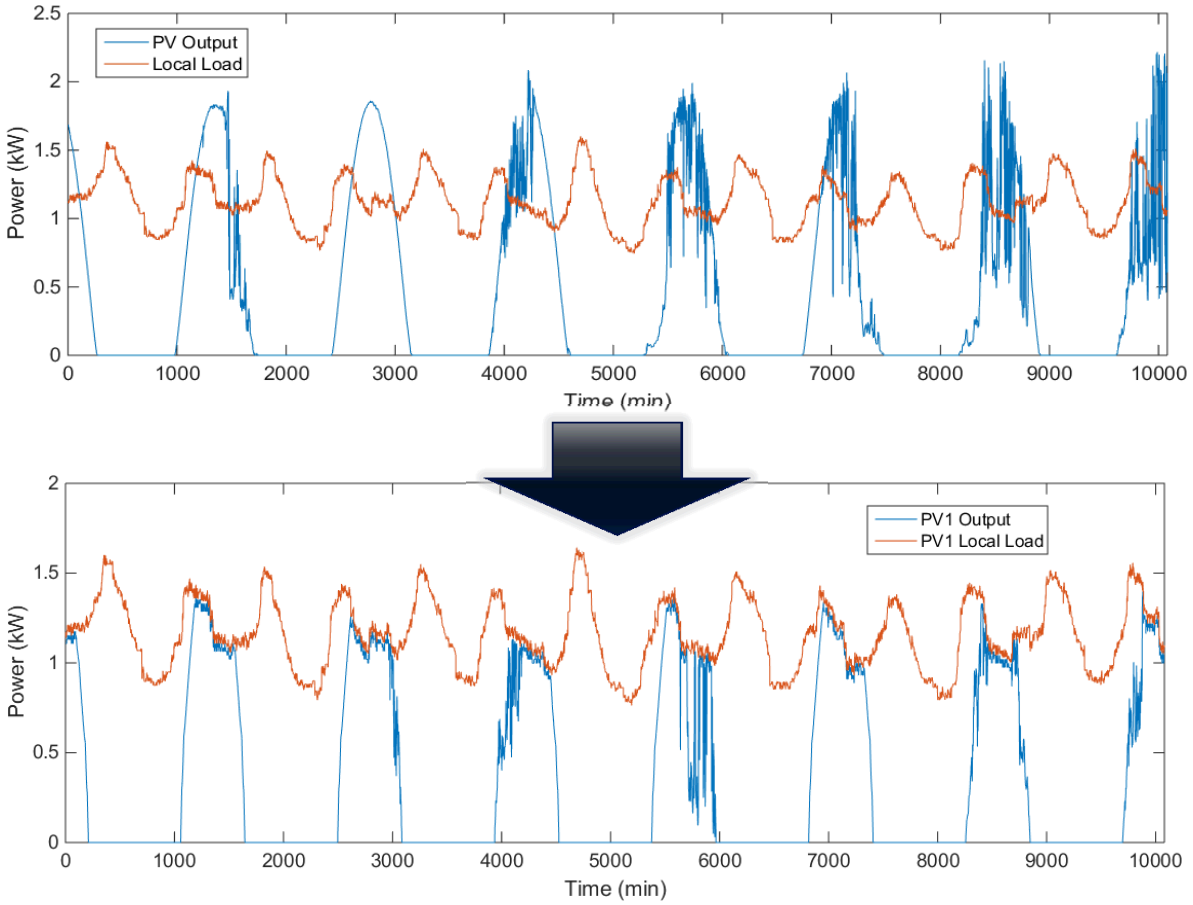
- PV systems regularly back-feed feeder substation
- Large portions of the feeder are in over-voltage violation for much of the year

Goal: Reduce over-voltage violations to zero with advanced inverter controls

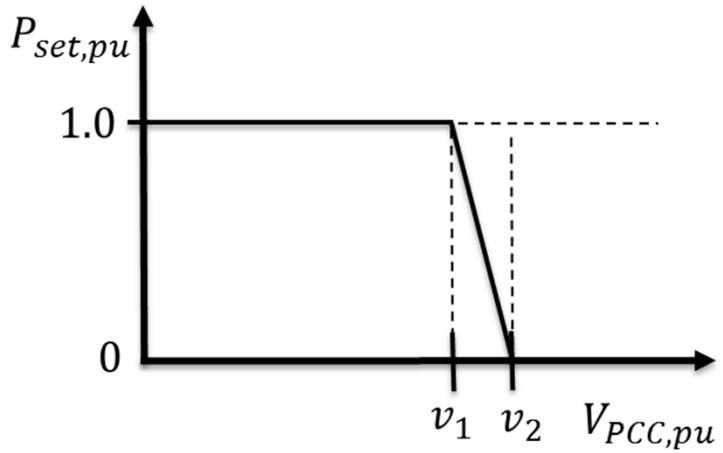
Advanced Inverter Controls

Local Controls

Zero Current Injection



Local Voltage-Based Curtailment



Volt/Watt droop curve

Centralized Controls

Sensitivity-Based Centralized Dispatch

See paper for details!

- Dispatches unique power setpoint to each inverter
- Inverters with biggest impact on voltage prioritized

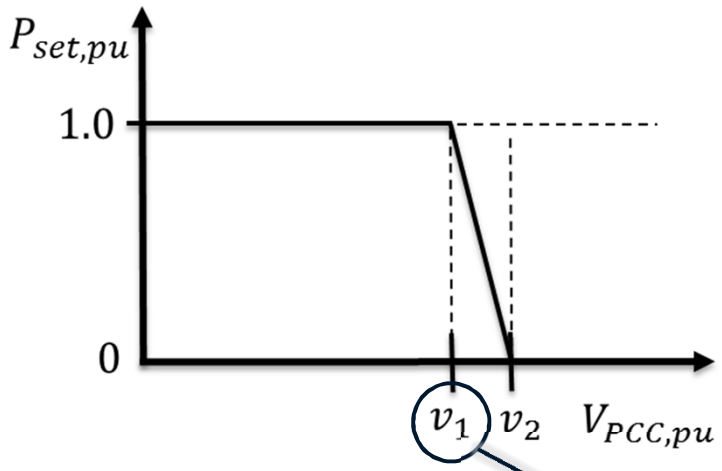
Fair Centralized Dispatch

See paper for details!

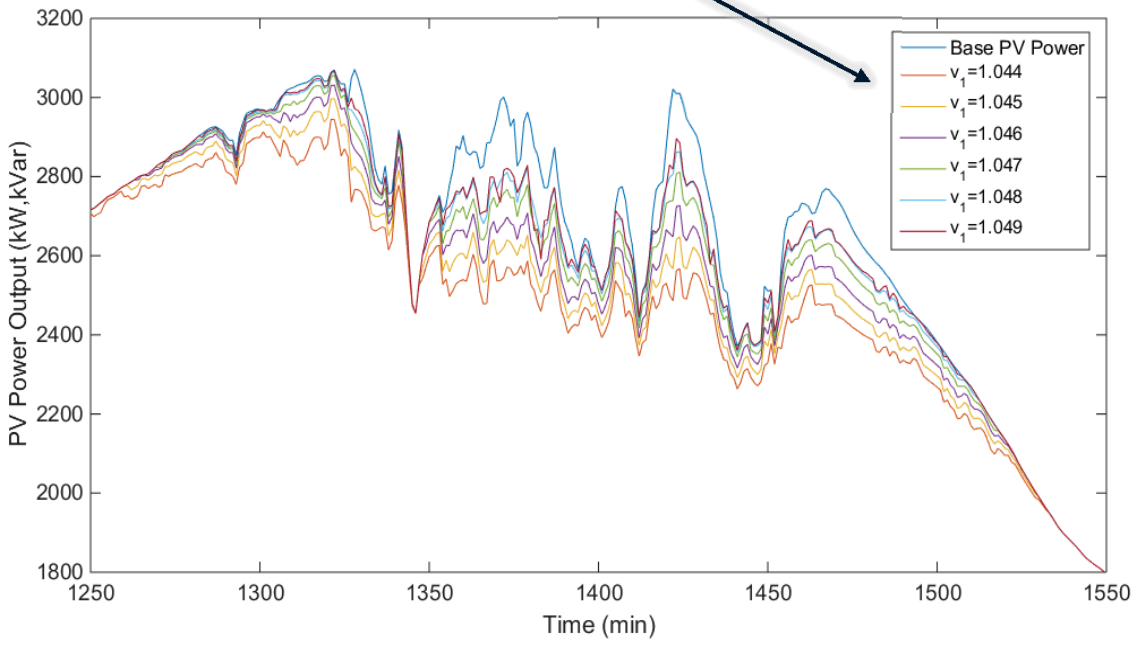
- Dispatches same power ratio setpoint to all inverters
- Drives max network voltage to within nominal range

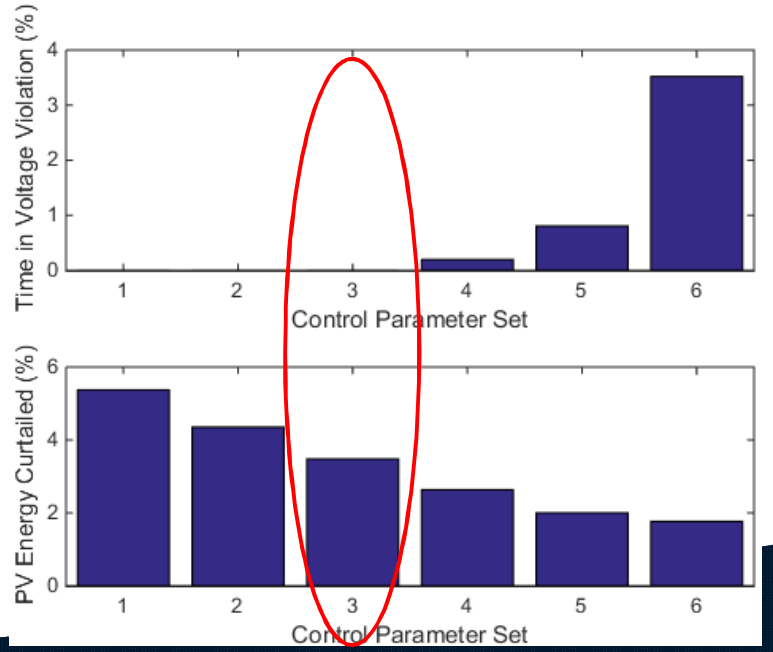
Control Tuning

Control Tuning



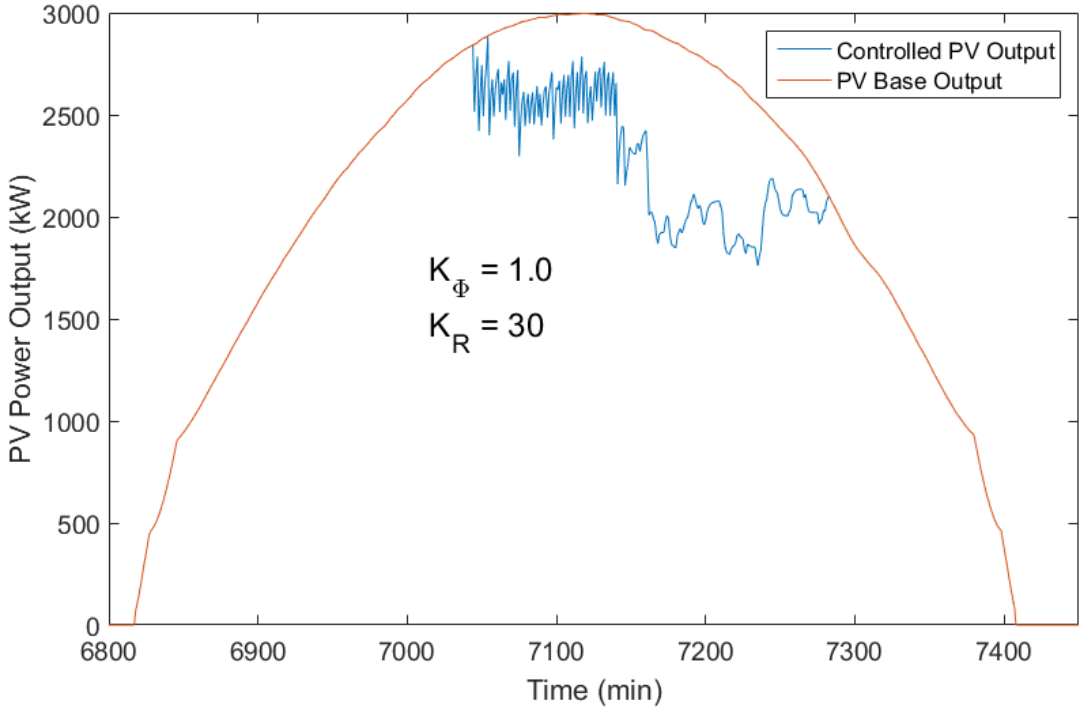
- Control parameters tuned on one-week period representing highest number of over-voltage violations
- E.g. v_1 setting of Volt/Watt droop slope
- Parameters chosen that best mitigate over-voltages at lowest curtailment levels and few power oscillations



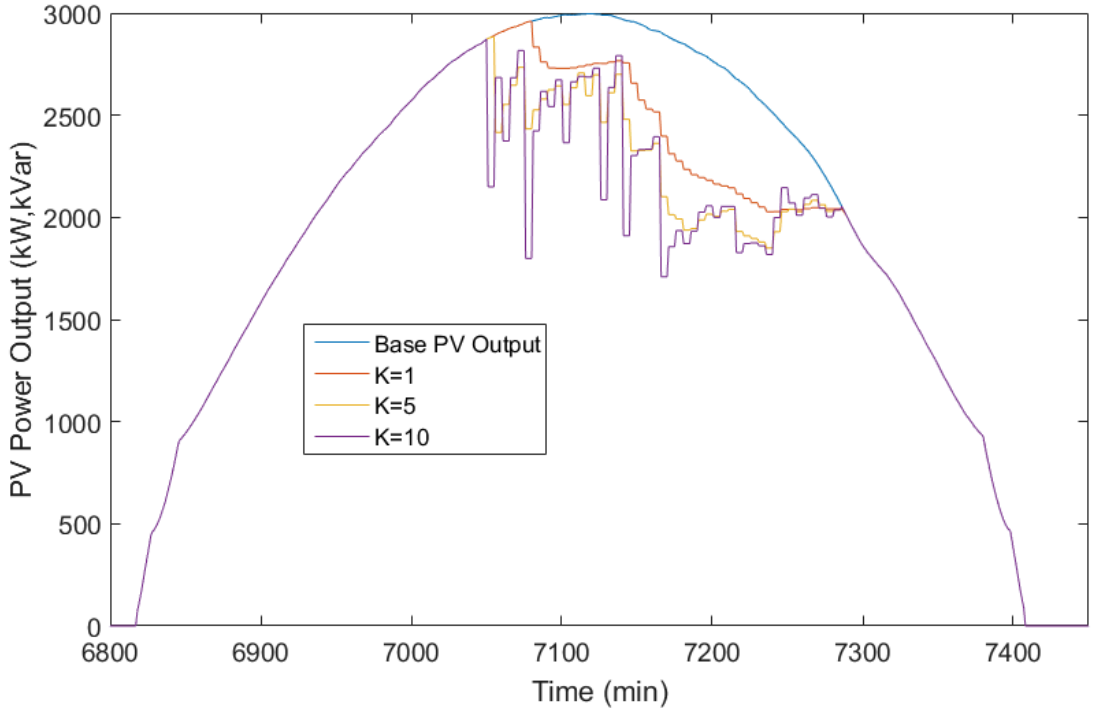


Control Tuning

- Central controls also have a time to dispatch window
- Larger dispatch windows cannot handle high control gains



1-minute dispatch

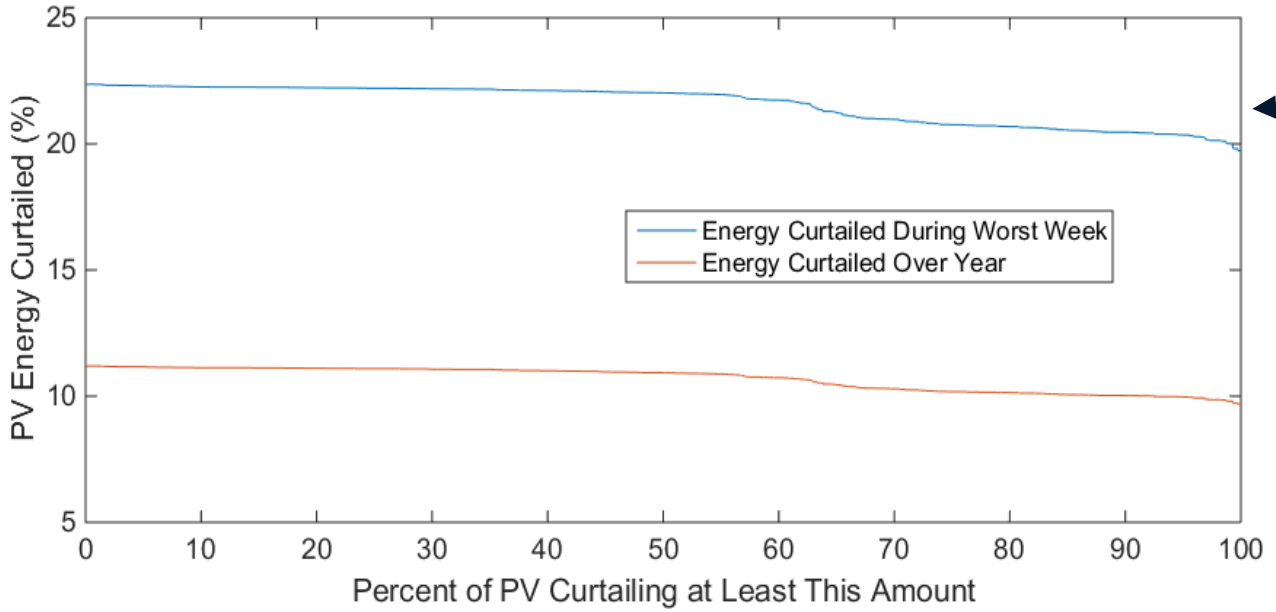


5-minute dispatch

Simulation Results

Simulation Results

Zero Current Injection

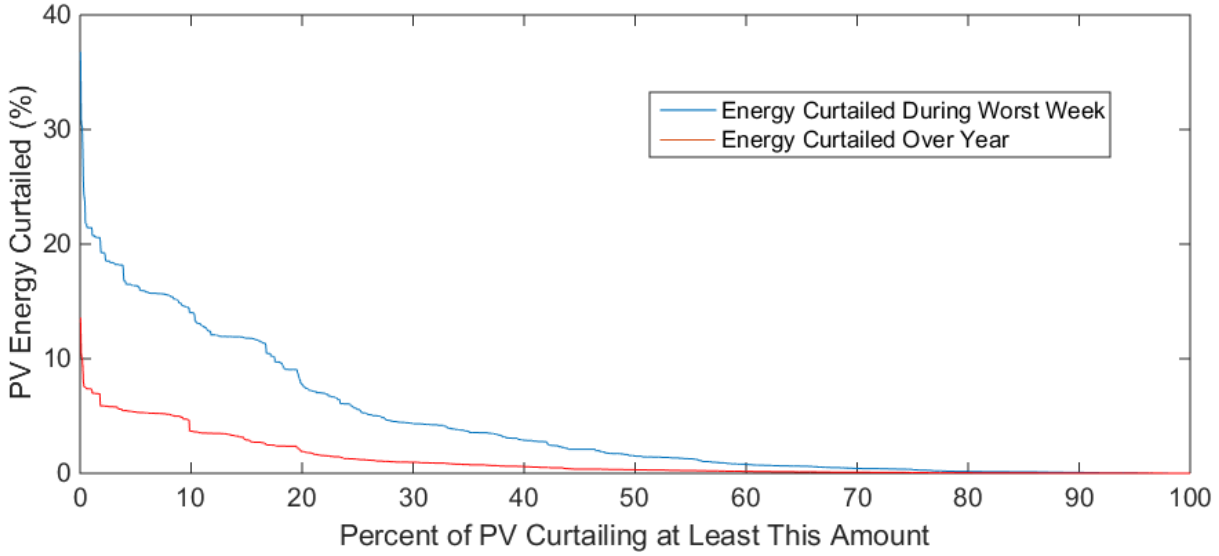


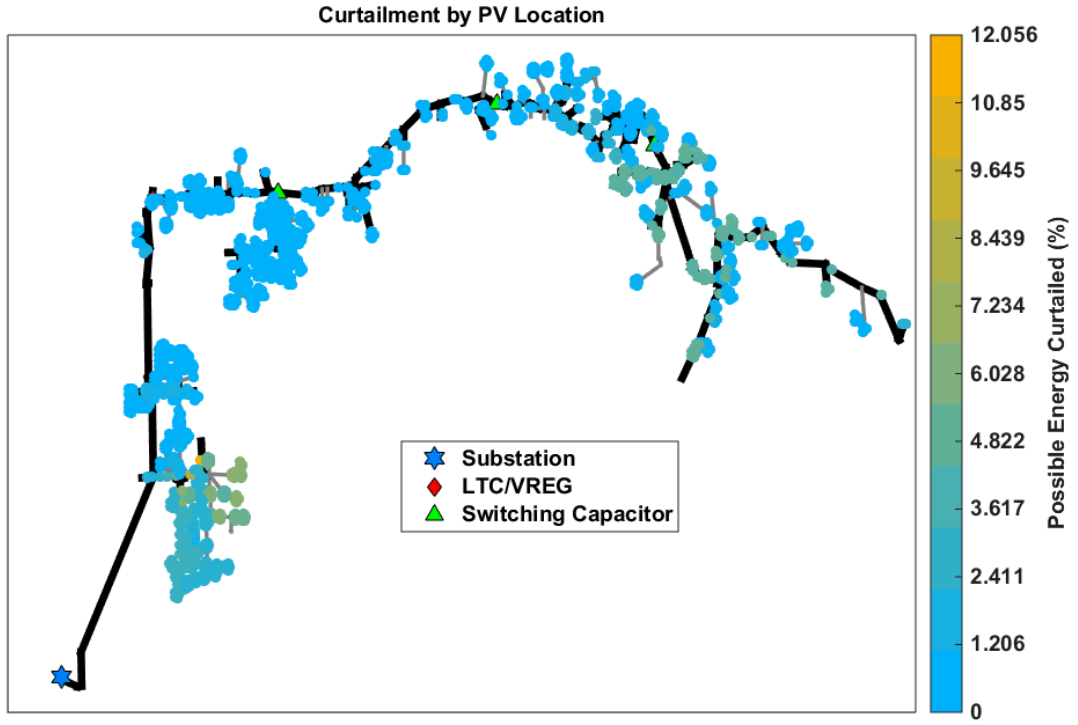
A flatter distribution means a fairer control

- 100% over-voltage times mitigated
- 21.6% PV generation curtailed
- 0.75% deviation in curtailments

Simulation Results

Local Voltage-Based Curtailment





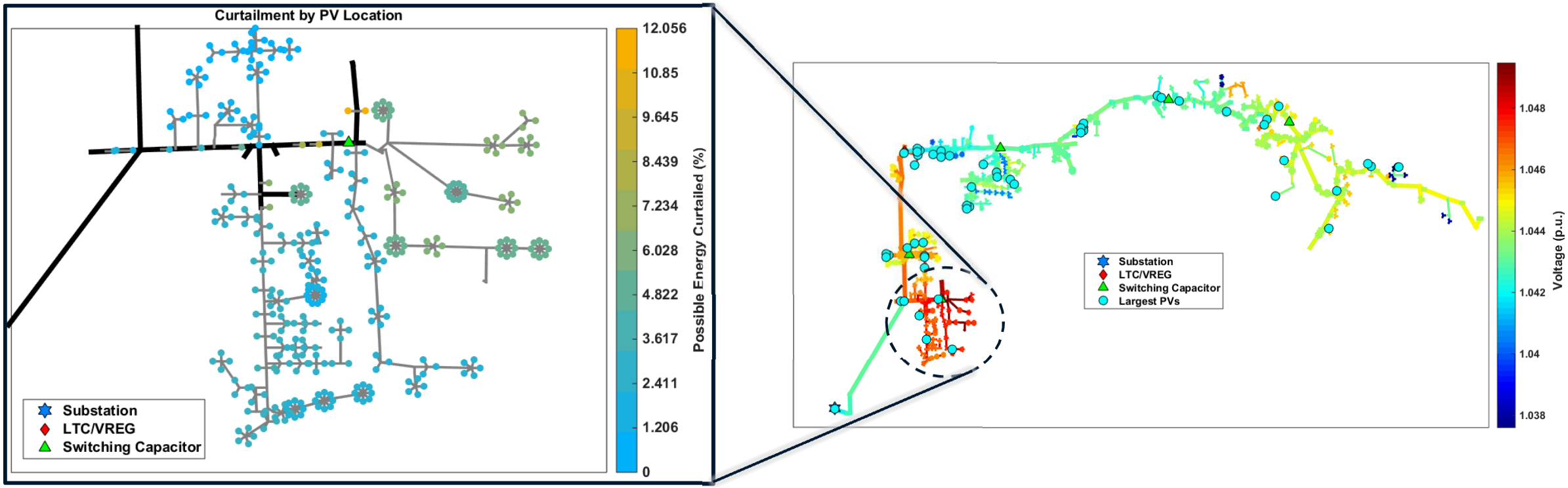
- 100% over-voltage times mitigated
- 4.35% PV generation curtailed
- 5.69% deviation in curtailments

One fifth energy curtailed!

Large disparity in fairness…

Simulation Results

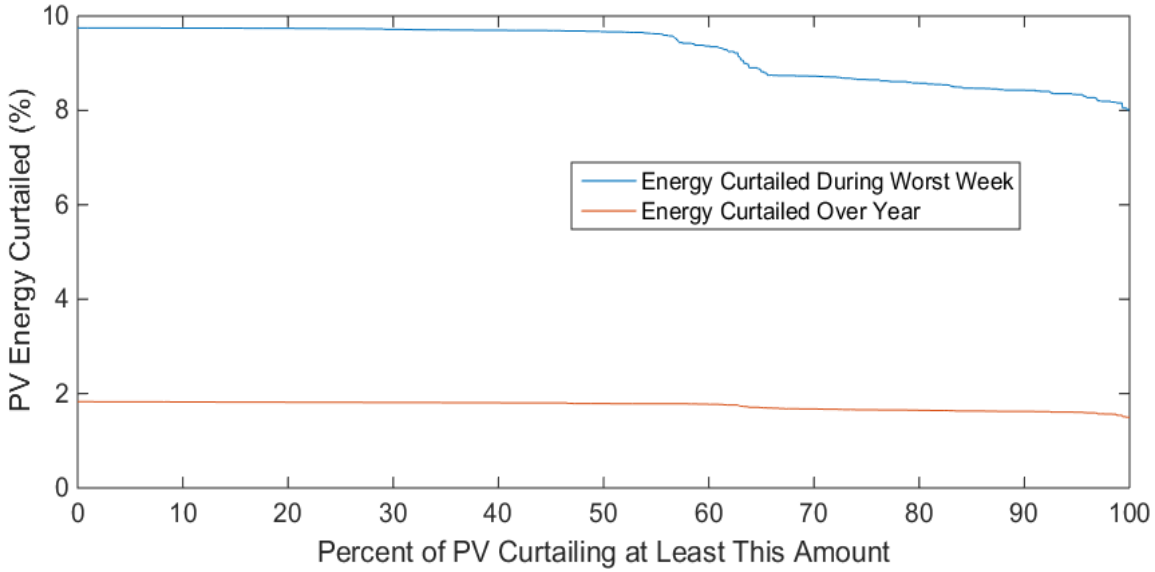
Local Voltage-Based Curtailment

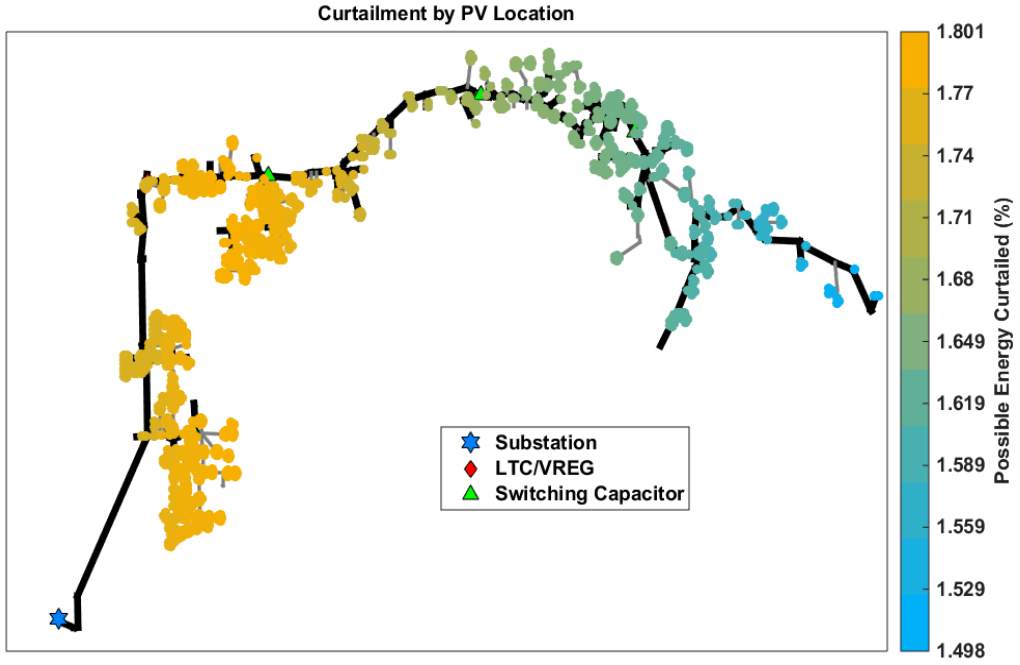


Highest curtailments occur for PV systems in areas of high base voltage

Simulation Results

Fair Centralized Dispatch





1-minute dispatch

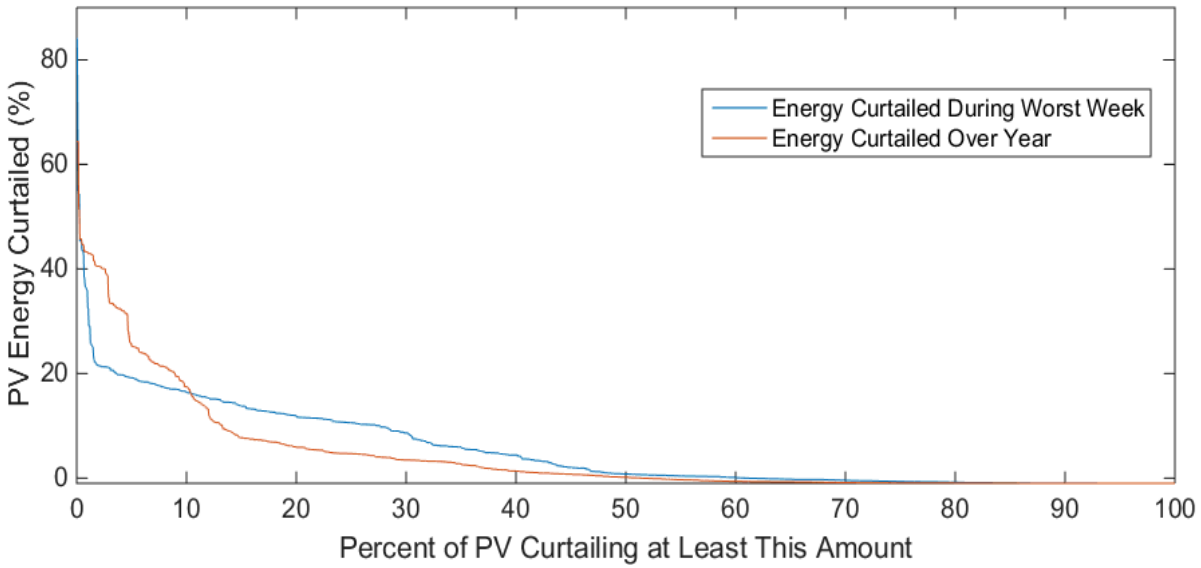
- 99.2% over-voltage times mitigated
- 9.3% PV generation curtailed
- 0.57% deviation in curtailments

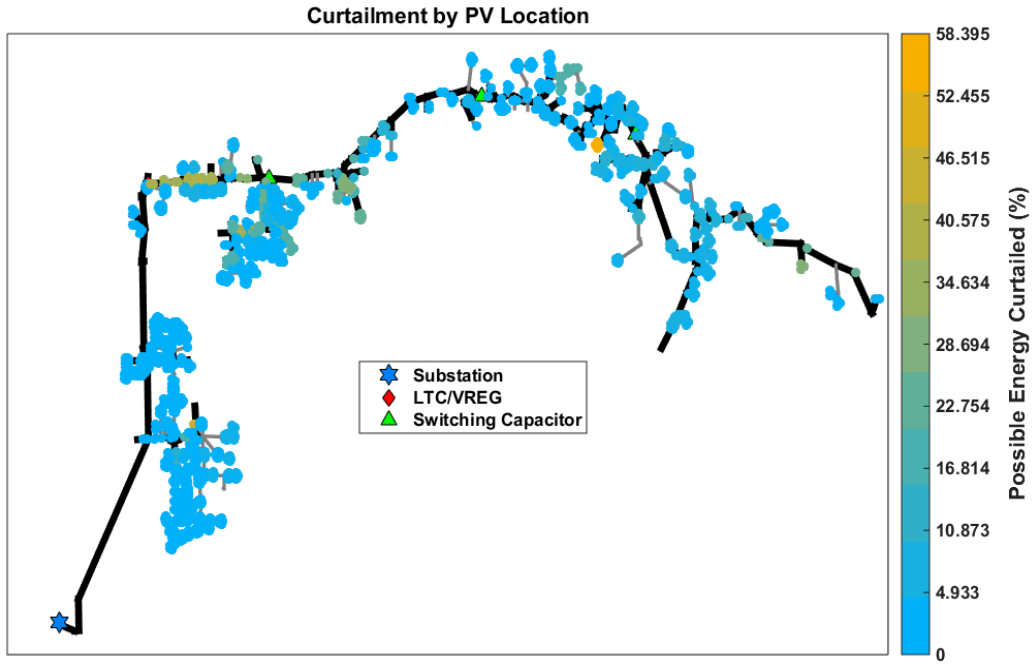
5-minute dispatch

- 41.9% over-voltage times mitigated
- 5.89% PV generation curtailed
- 0.16% deviation in curtailments

Simulation Results

Sensitivity-Based Centralized Dispatch





1-minute dispatch

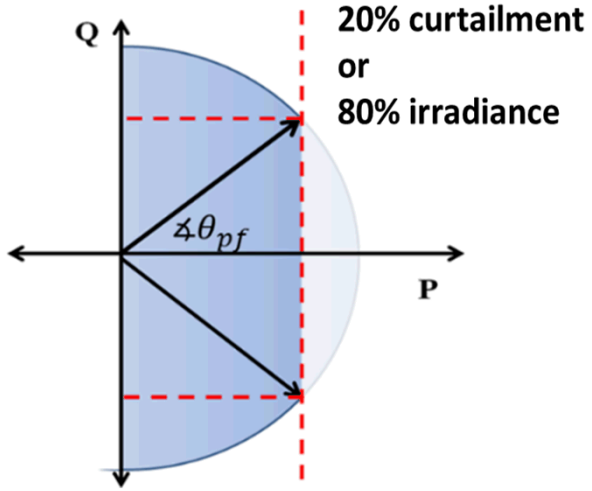
- 99.6% over-voltage times mitigated
- 3.99% PV generation curtailed
- 8.21% deviation in curtailments

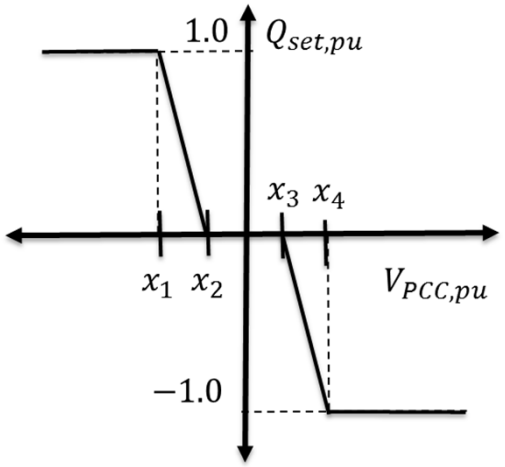
5-minute dispatch

- 98.9% over-voltage times mitigated
- 4.58% PV generation curtailed
- 8.23% deviation in curtailments

Reactive Power Support

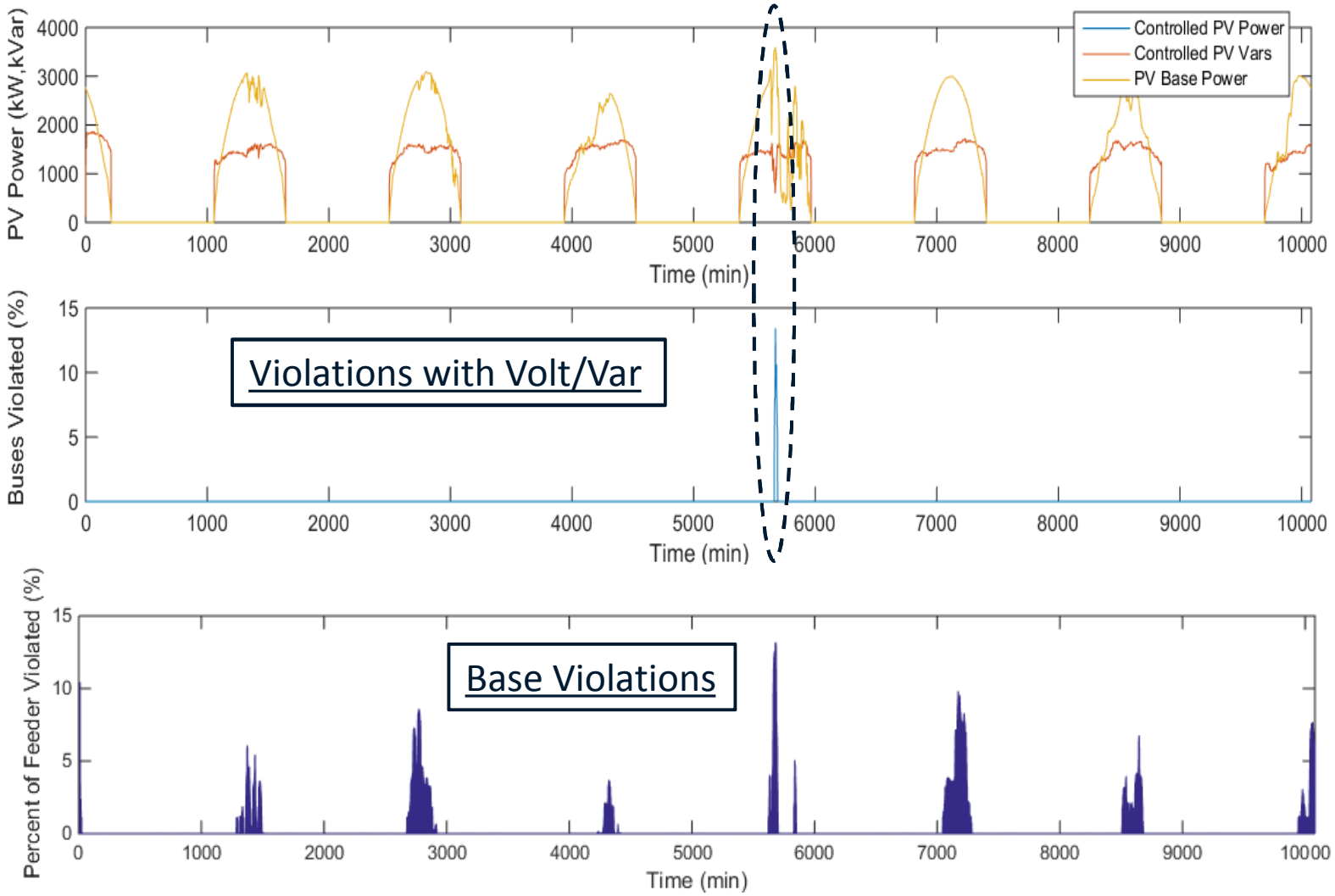
Reactive Power Support





- Reactive power available to PV inverter is limited by inverter rating and prioritized real power output
- A Volt/Var droop curve is applied to the available reactive power to drive voltages towards nominal
- In practice, a significant amount of reactive power is available even without over-sizing the PV inverter

Reactive Power Support



- During week of most over-voltage violations, only once did reactive power support lose capability to mitigate voltage
- Over the year, with Volt/Var control the feeder is in voltage violation only 624 minutes
- 96.7% reduction in over-voltage violations
- Takeaway: with reactive power support, curtailment should only be necessary ~0.1% of the time

Summary of Findings

Summary of Findings

Comparison of Controls Over One Week

Control Type	ZCI	Volt/ Watt	Volt/ Var	Central Fair (1m)	Central Fair (5m)	Sensitivity-based (1m)	Sensitivity-based (5m)
Overall Voltage Issues Mitigated (%)	100.0	100.0	98.7	100.0	91.7	100.0	99.7
Time with Violations Mitigated (%)	100.0	100.0	97.9	99.2	41.9	99.6	98.9
Power Curtailed (%)	21.6	4.35	0	9.3	5.89	3.99	4.58
Curtailment Deviation (%)	0.75	5.69	0	0.57	0.16	8.21	8.23

Summary of Findings

Key Takeaways

- All PV-induced voltage violations were mitigated by curtailing less than 1% of PV generation over the year
- Adding reactive power support to curtailment should reduce the amount of time curtailment is necessary significantly
- Centralized PV curtailment can be used to fairly distribute control signals with little drop in performance
- Some control parameters are highly dependent on the data used to tune them
- Faster centralized dispatch signals yield better results

Thank you!

Questions?

Backup Slides

Summary of Findings

Comparison of Controls Over Year

Control Type	ZCI	Volt/ Watt	Volt/ Var	Central Fair (1m)	Central Fair (5m)	Sensitivity-based (1m)	Sensitivity-based (5m)
Overall Voltage Issues Mitigated (%)	100.0	100.0	98.2	100.0	97.6	100.0	99.8
Time with Violations Mitigated (%)	100.0	100.0	96.7	99.3	88.4	99.4	99.2
Power Curtailed (%)	10.7	0.85	0	1.75	2.00	2.46	2.82
Curtailment Deviation (%)	0.46	1.81	0	0.09	0.05	9.78	9.89