SAND2019-7201PE

Energy Storage for Voltage Smoothing in Distribution System With High PV Penetration

PRESENTED BY

David Rosewater - 6 – 24 – 2019

P. Siratarnsophon, K. W. Lao, S. Santoso

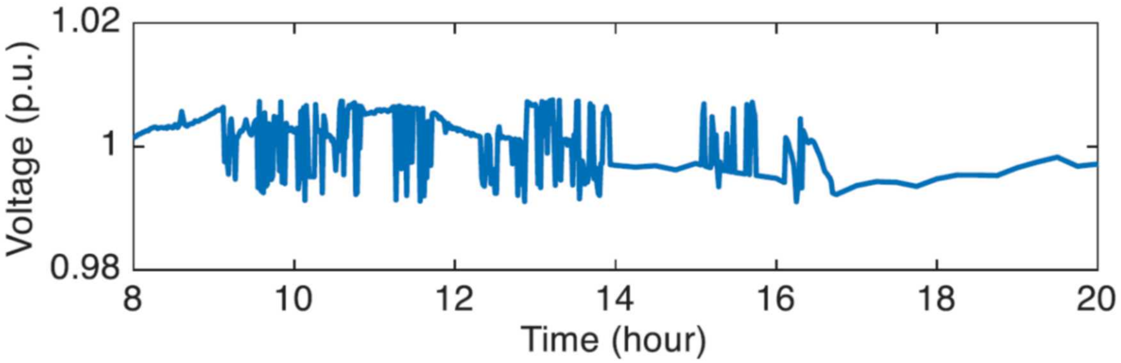
[1] P. Siratarnsophon, K. W. Lao, D. Rosewater, S. Santoso, “A Voltage Smoothing Algorithm using Energy Storage PQ Control in PV-integrated Power Grid” IEEE Power Systems Letters, 2018

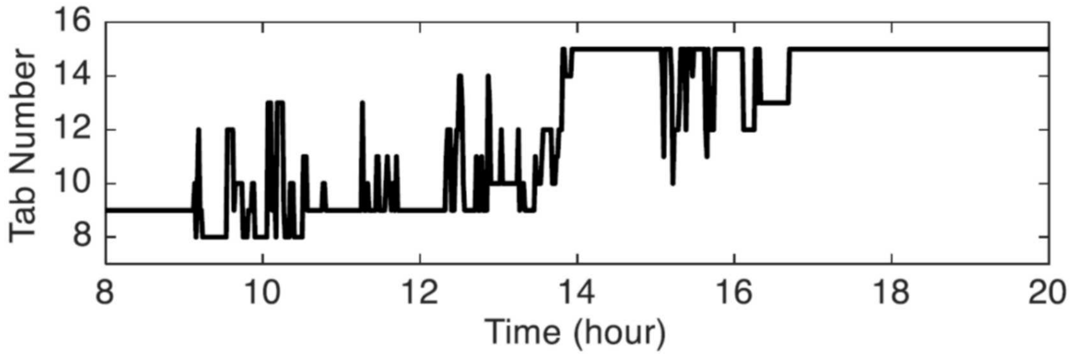
Outline

- Motivation
- Voltage Smoothing Techniques
  - Technique I: Active power ramp rate control by monitoring PV inverter power output
  - Technique II: Proposed algorithm of PQ power injection control by monitoring voltage
- System models for verification
  - Results on the IEEE 4-bus test system
  - Results on EPRI distribution test circuit 5

Motivation

- **Increasing photovoltaic (PV) integration** and weather conditions could vary PV active power injection and **cause voltage fluctuations**.
- Load tap changers (LTC) at transformer substations can mitigate voltage variations; however, LTC response is relatively slow and thus is not suitable for the ramp rate and frequency of fluctuations induced by PV.





[1] P. Siratarnsophon, K. W. Lao, D. Rosewater, S. Santoso, "A Voltage Smoothing Algorithm using Energy Storage PQ Control in PV-integrated Power Grid" IEEE Power Systems Letters, 2018

Motivation

- Battery Energy Storage (ES) can be controlled to dampen power fluctuations, prolonging LTC life, and preventing voltage violations.

Problem Statement: design a controller to reduce the impact of PV on distribution system voltage and LTC life

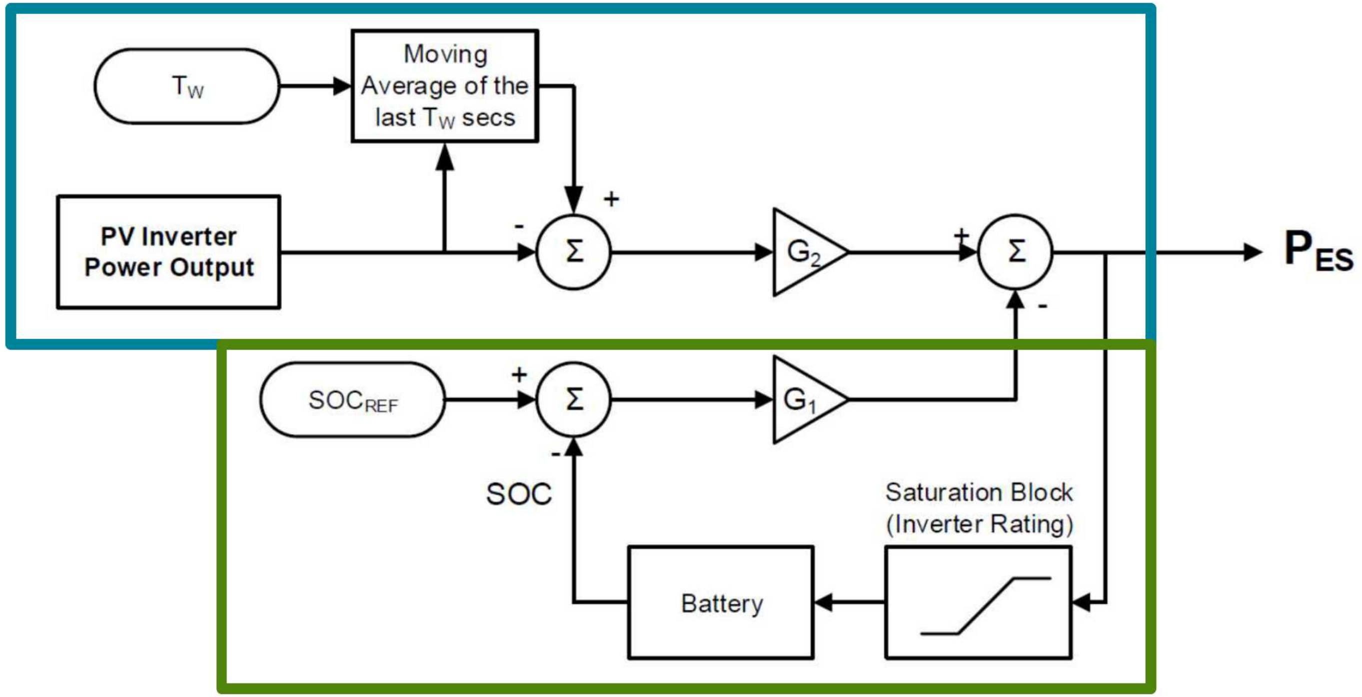
We will first evacuate the effectiveness of the controller on a simple IEEE 4 bus test system

Then we will evaluate them in a full EPRI distribution circuit model

[1] P. Siratarnsophon, K. W. Lao, D. Rosewater, S. Santoso, "A Voltage Smoothing Algorithm using Energy Storage PQ Control in PV-integrated Power Grid" IEEE Power Systems Letters, 2018

Voltage Smoothing Techniques

- Technique I monitors PV inverter active power output to control active power ramp rate [4].



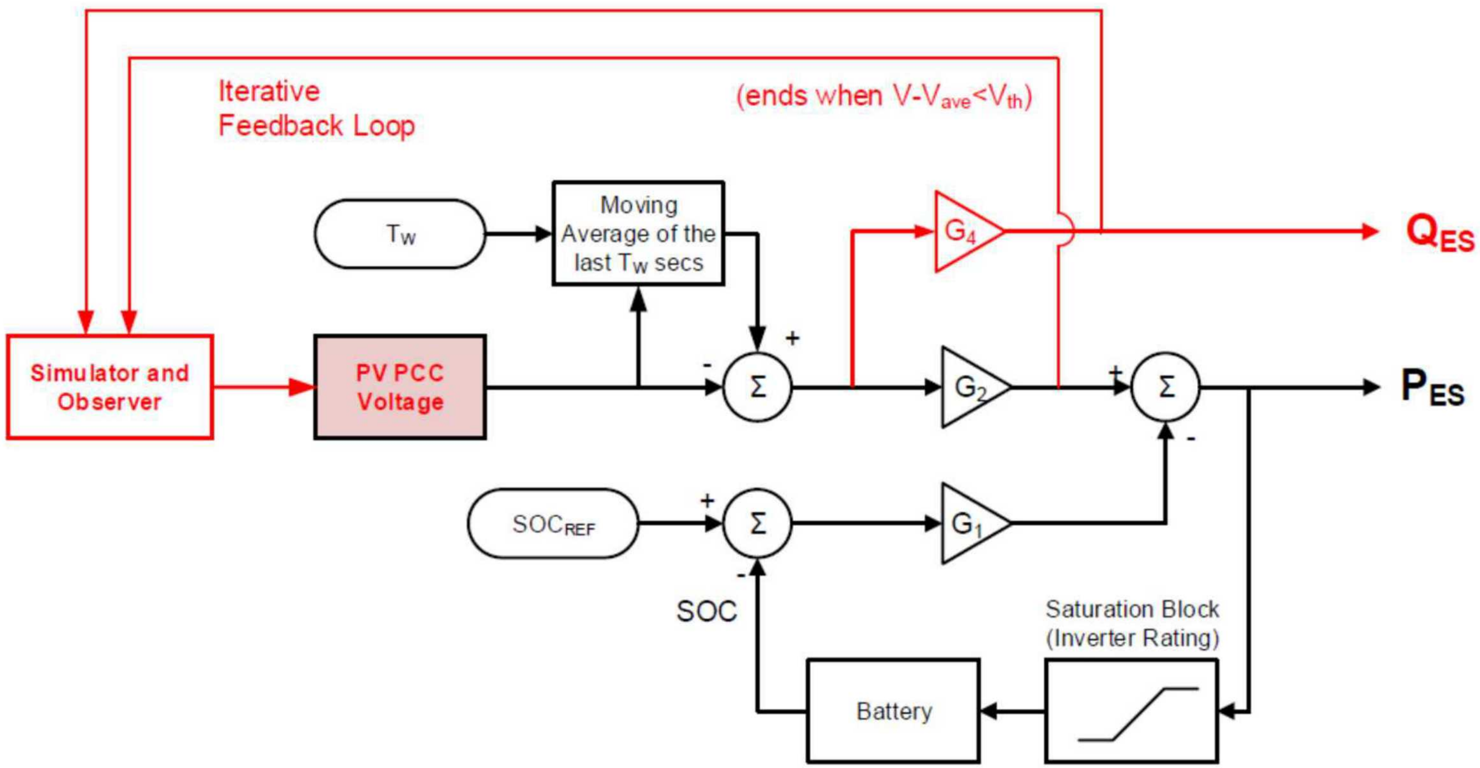
Control algorithm of voltage smoothing by limiting active power ramp rate in Technique I.

Upper block : Fluctuation mitigation
Lower block : State of charge (SOC) control

[4] M. J. Reno, M. Lave, J. E. Quiroz, and R. J. Broderick, "Pv ramp rate smoothing using energy storage to mitigate increased voltage regulator tapping," in 2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC), June 2016, pp. 2015–2020.

Voltage Smoothing Techniques

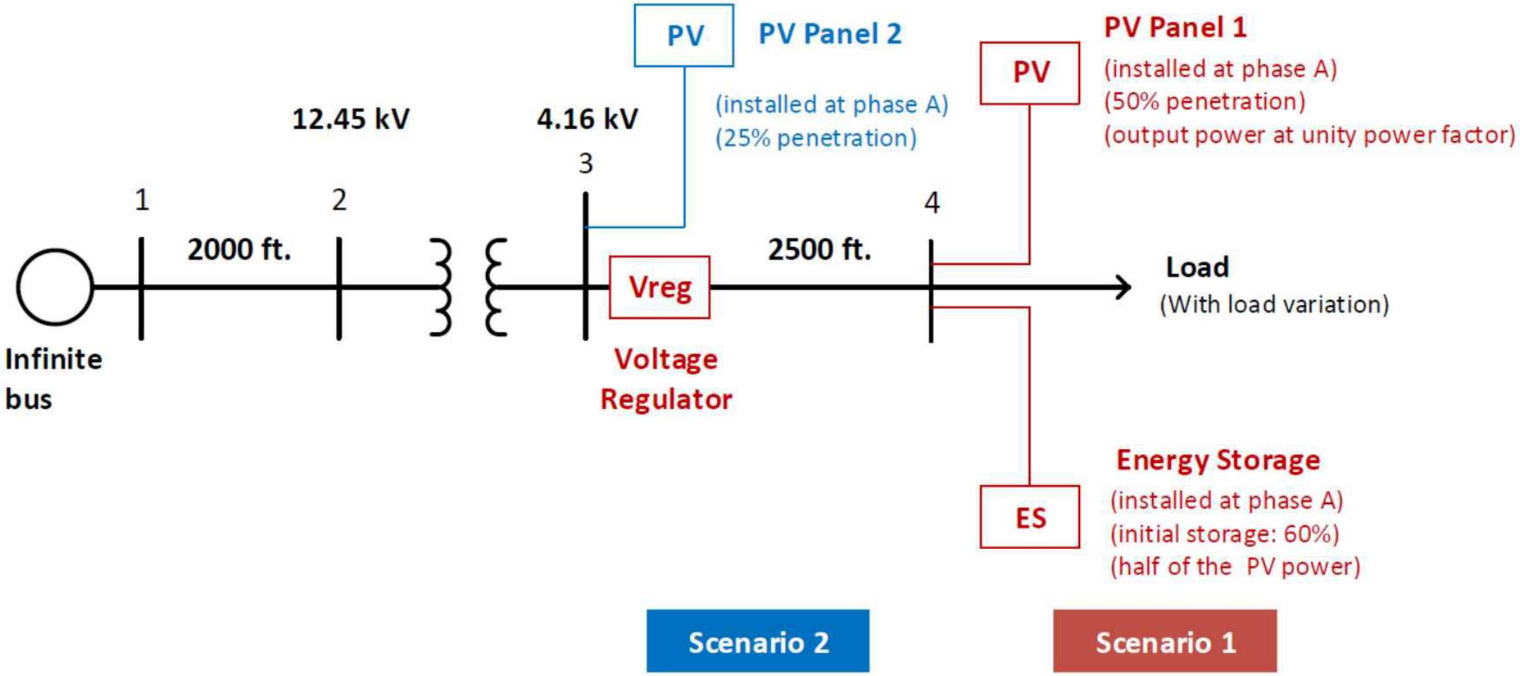
- Technique II is the proposed active and reactive power injection control that works by monitoring local bus voltage which the inverter is connected to. This effectively combines PV smoothing and volt-var.



Proposed control algorithm of ES PQ power injection by monitoring
local PV bus voltage in Technique II.

System models for verification

- IEEE 4-bus test system



We will first evacuate the effectiveness of the controller with **co-located** PV and second where the PV is **upstream** of the ES

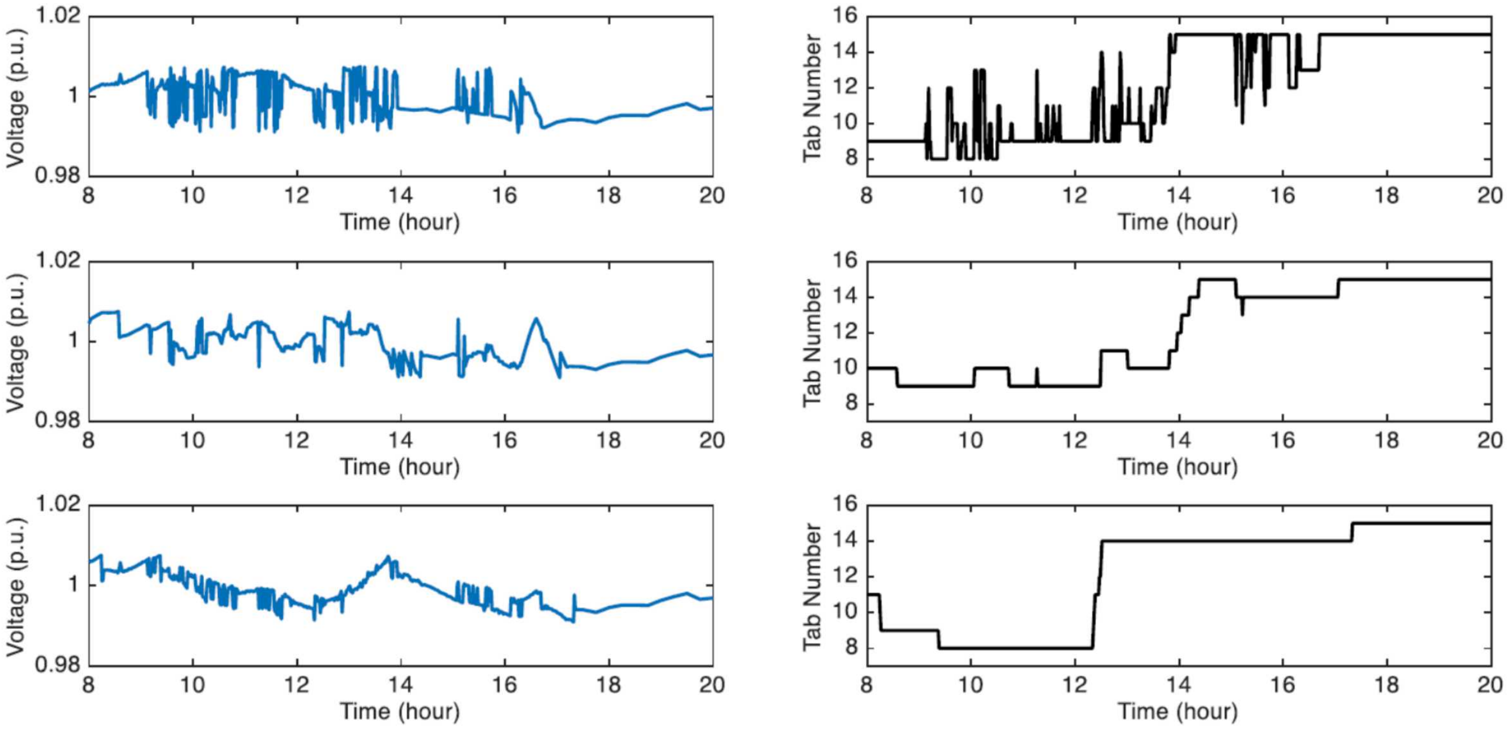
System models for verification

- **Results** on the IEEE 4-bus test system (Scenario 1)

Case without any voltage smoothing

Technique I

Technique II



(a)

(b)

(a) Line to neutral voltage at the load bus (bus 4 phase A)

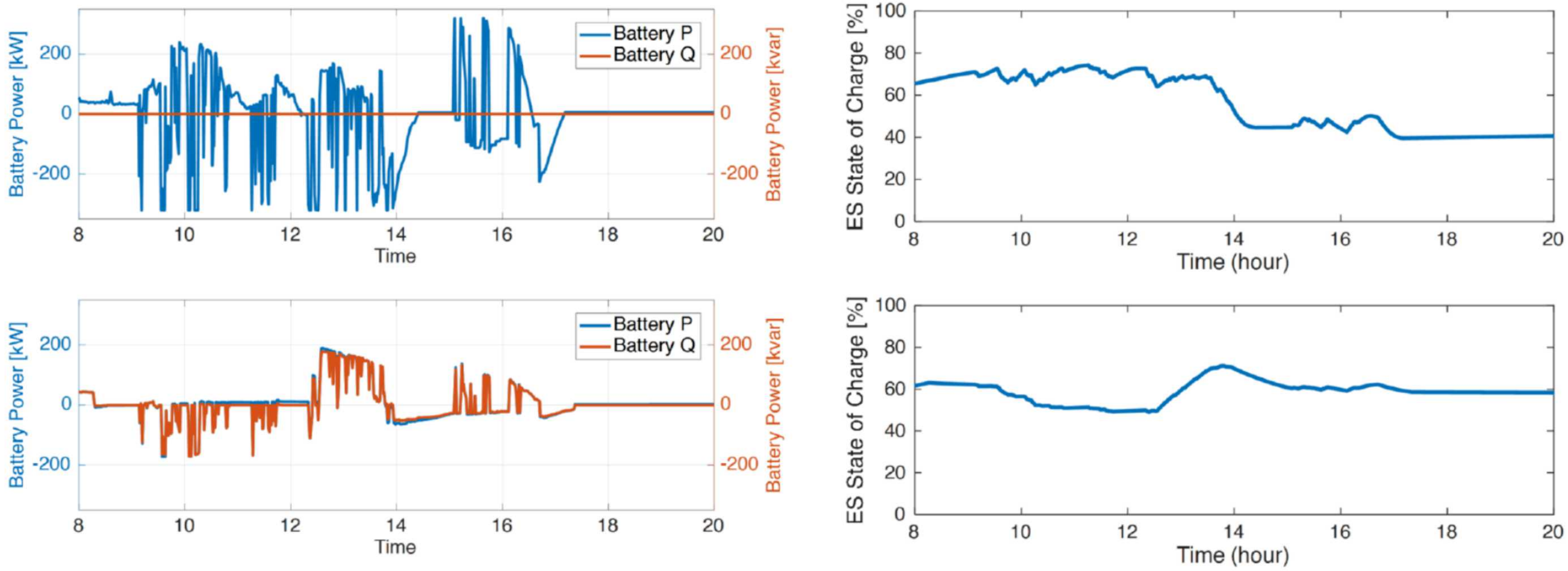
(b) Tap number at load tap changer

System models for verification

- **Results** on the IEEE 4-bus test system (Scenario 1)

Technique I

Technique II



(a) (b)

(a) Injection of active and reactive power from ES
(b) Battery SOC

System models for verification

- **Results** on the IEEE 4-bus test system

Summary of Verification Results

Scenario 1						
Control	**Tap changes**	P_{max}	Q_{max}	SOC_{max}	SOC_{min}	$RMSD$
No Control	201	0	0	60	60	0.101 kV
Tech. I	27	320	0	74.27	39.58	0.068 kV
Tech. II	13	197	193	72.19	44.68	0.029 kV
Scenario 2						
Control	**Tap changes**	P_{max}	Q_{max}	SOC_{max}	SOC_{min}	$RMSD$
No Control	245	0	0	60	60	0.121 kV
Tech. I	35	320	0	74.26	39.58	0.074 kV
Tech. II	13	231	219	72.92	43.69	0.031 kV

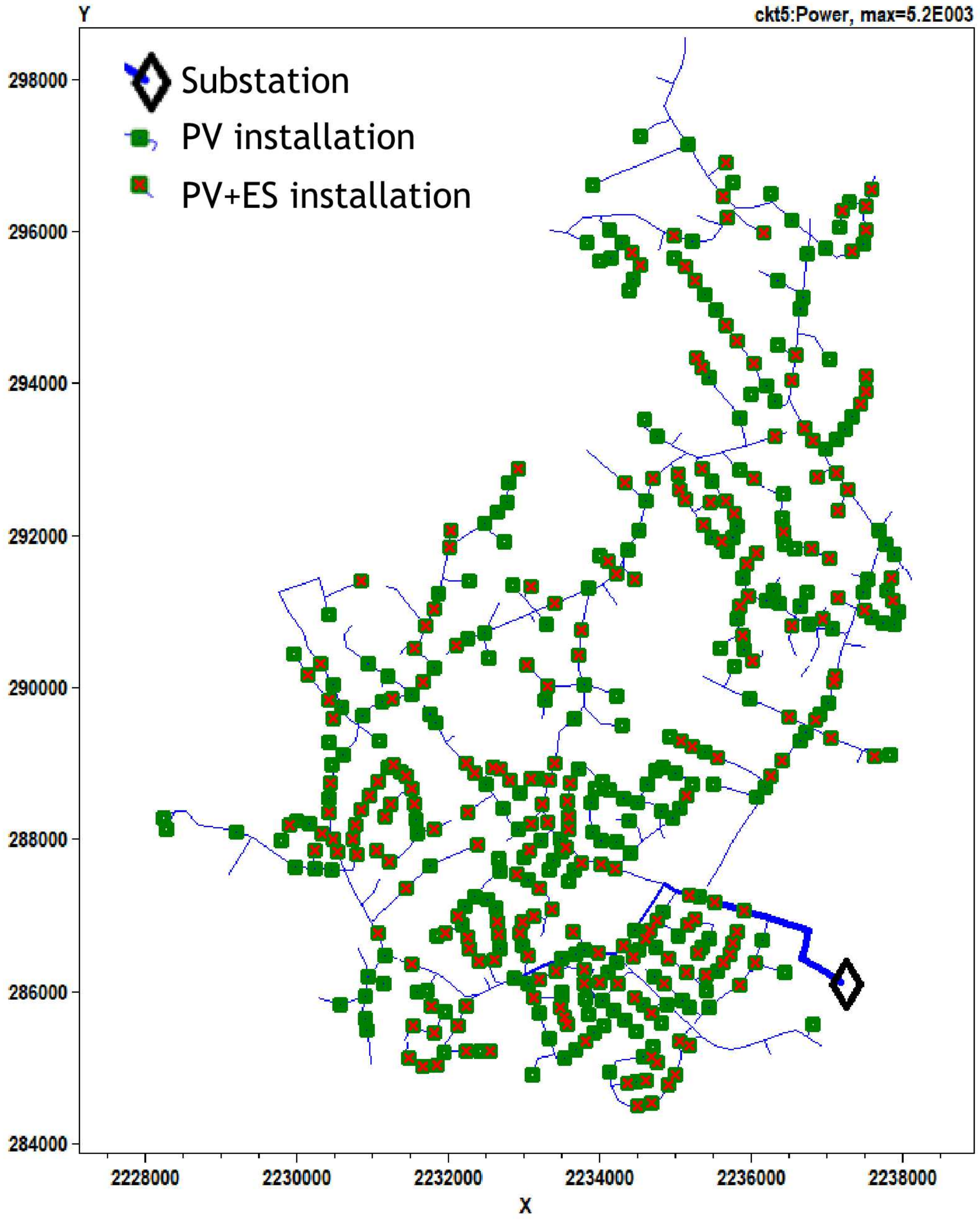
Results on EPRI distribution test circuit 5 (Preliminary results)

System models for verification

- **EPRI Test Circuit 5**

Modifications

- Added 688 (10kW) PV units on unique random busses (roughly 100% penetration)
- Added 344 (10kW, 10kWh) ES units on a subset of the PV busses
- Increased the resistance of the substation transformer 10x
- Added a LTC on the substation transformer regulating bus x_62302.2

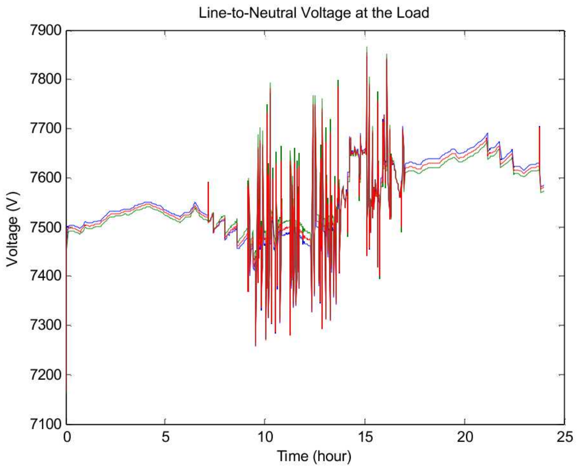


System models for verification

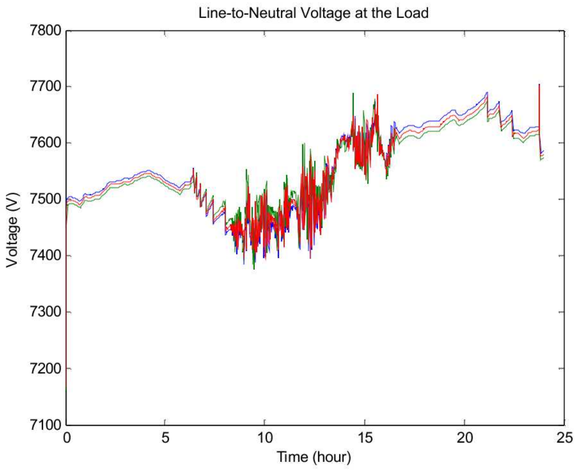
- **EPRI Test Circuit 5**

Modifications

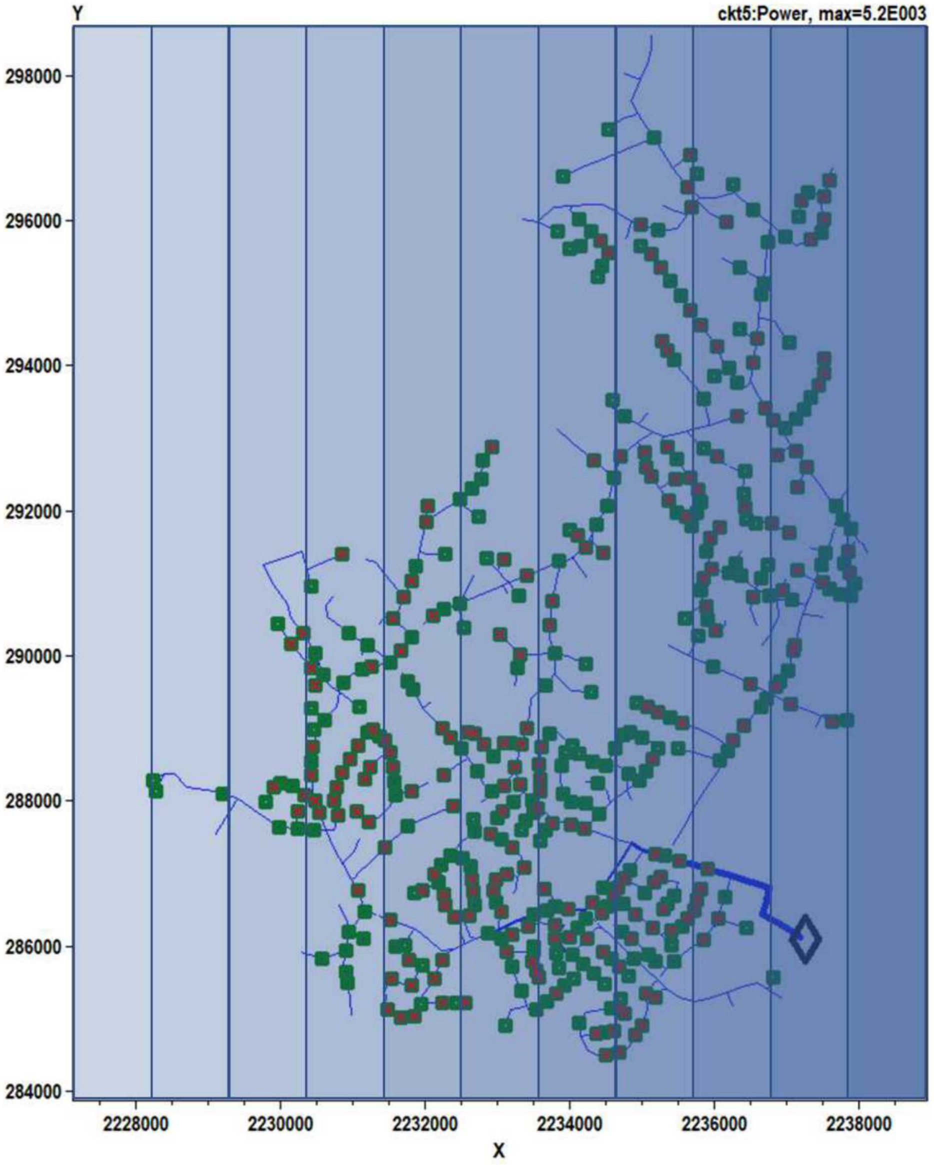
- Created 11 shifted irradiance profiles to model clouds moving at 10 miles per hour



Voltage with only one PV irradiance profile



Voltage with 11 PV irradiance profiles



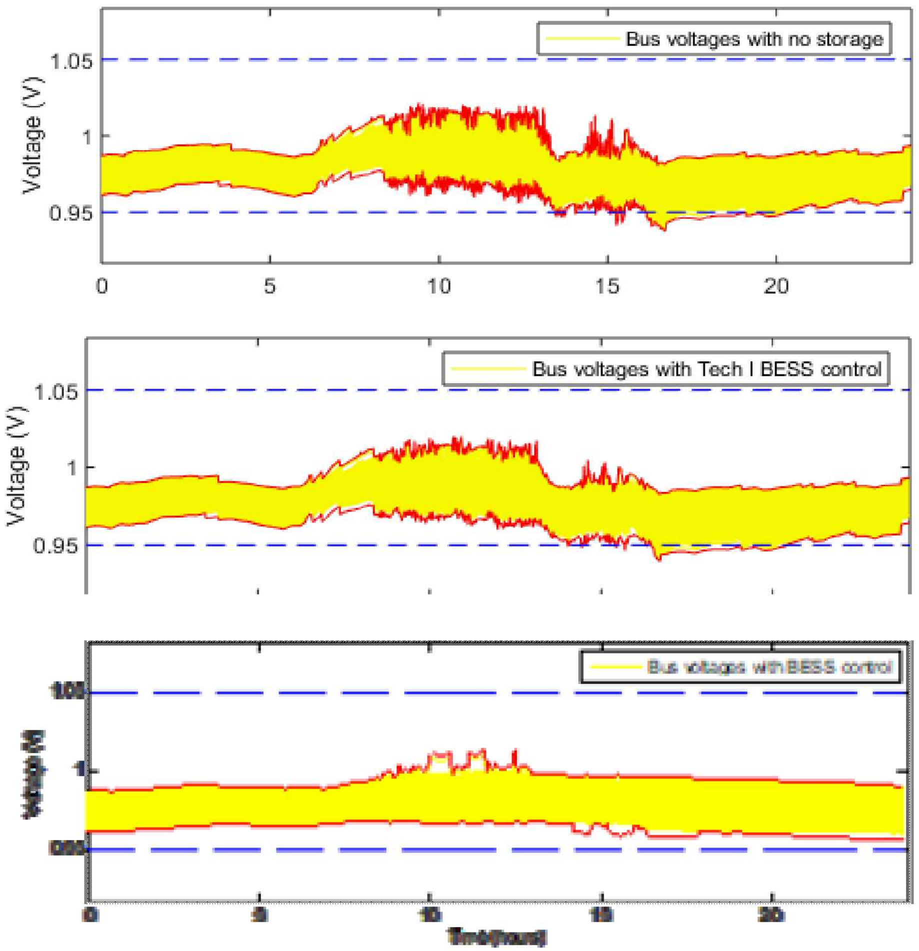
System models for verification

- **Results** on EPRI Test Circuit 5

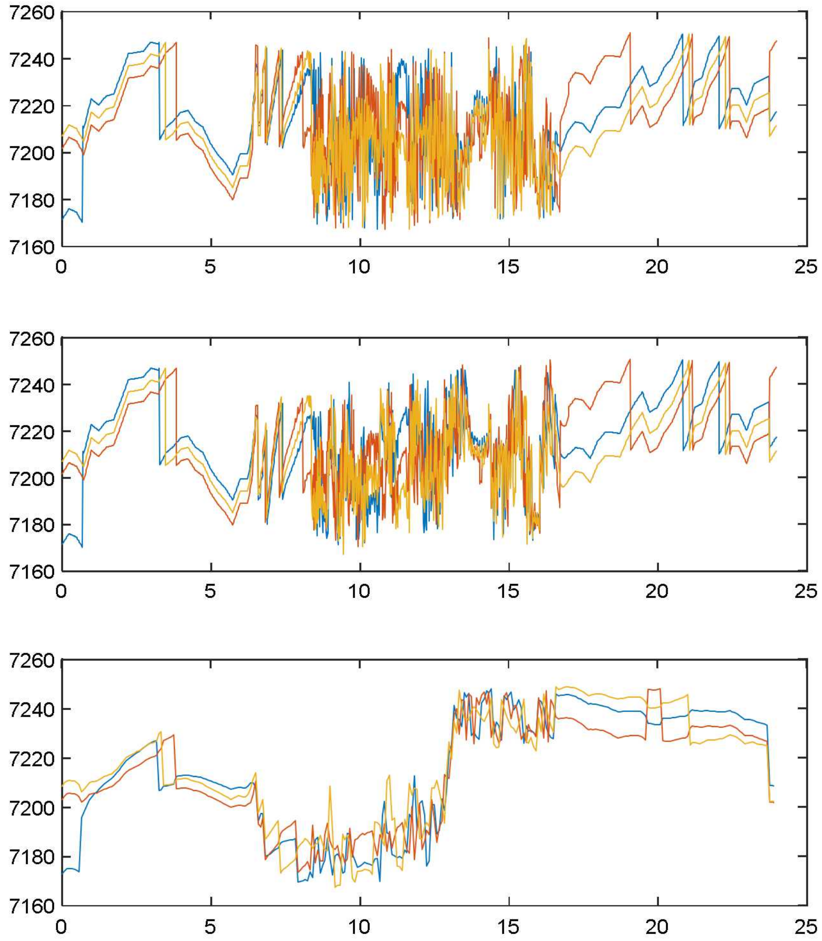
No Storage

Technique I

Technique II



Bus Voltages



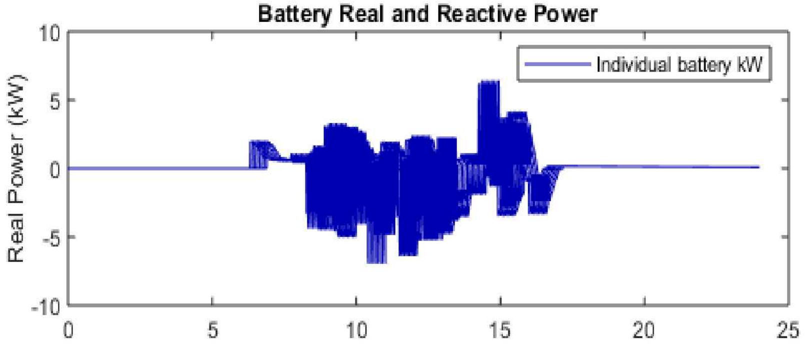
Substation Voltages

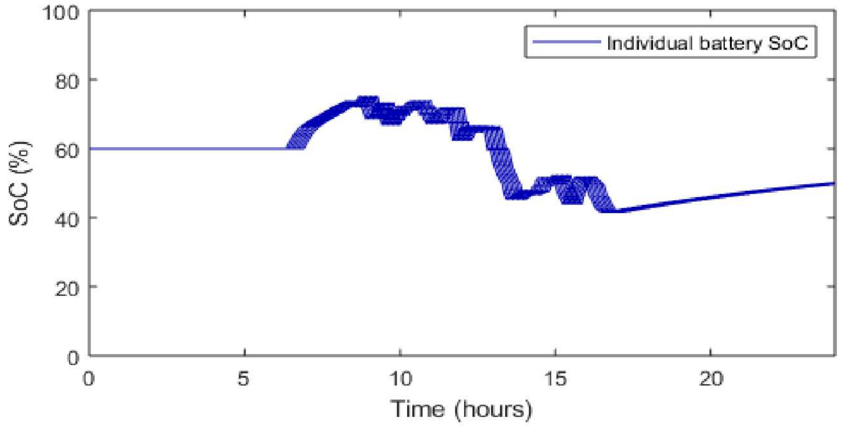
System models for verification

- **Results** on EPRI Test Circuit 5

Technique I

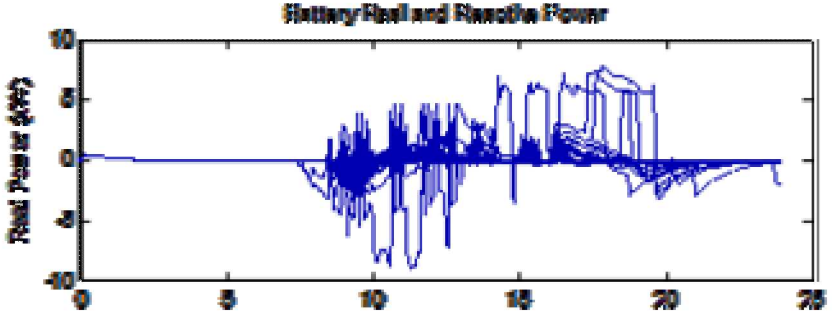
Real Power



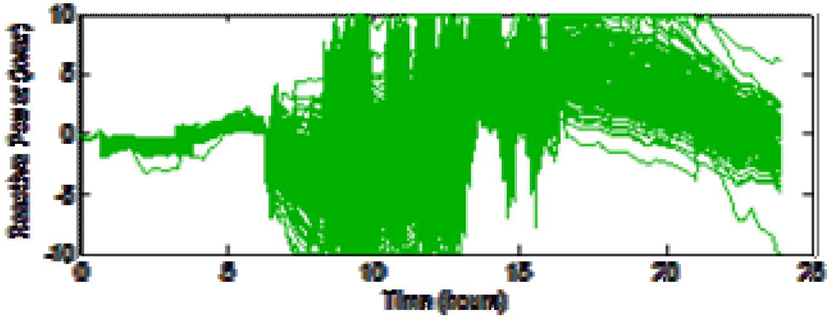


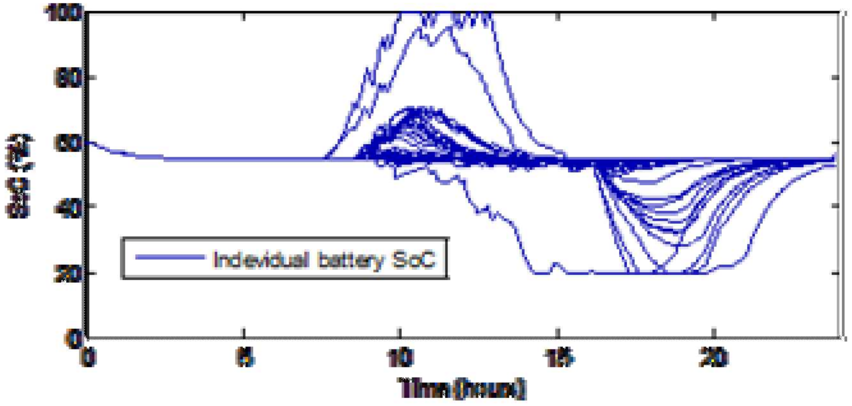
Technique II

Real Power



Reactive Power



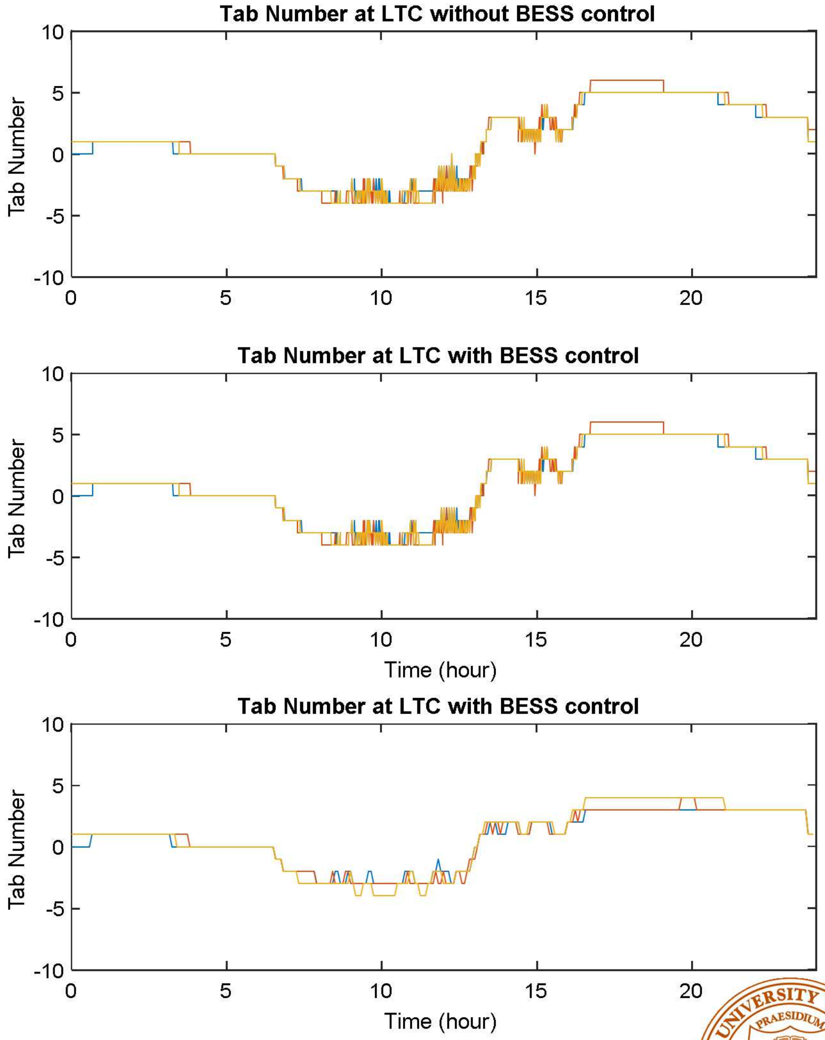


State-of-Charge

System models for verification

- **Results** on EPRI Test Circuit 5

Control	Tap Changes	% Reduction
No Control	ABC = 111 103 104	
Tech. I	ABC = 107 101 102	2.5%
Tech. II	ABC = 31 36 30	69.5%



3-Phase LTC Action

Conclusions

- Renewables do not (inherently) cause problems on the distribution system
- When they do cause problems, it often makes more sense to address the problems directly rather than focusing on the renewable generators
- Voltage power quality and the frequency of tap changes can be addressed more efficiently and effectively by a controller that focuses on smoothing voltage
- Storage can effectively improve power quality and LCT life in distribution systems

Thank You to the DOE OE for supporting research to integrate energy storage into distribution systems

Questions?

David Rosewater

dmrose@sandia.gov

(505) 844-3722