

*Exceptional service in the national interest*



# HIGH PENETRATION PV INTERCONNECTION MODELING AND REDUCTION OF DISTRIBUTION FEEDERS

Matthew J. Reno<sup>1,2</sup>, Robert J. Broderick<sup>1</sup>, Kyle Coogan<sup>2</sup>,  
Jimmy Quiroz<sup>1</sup>, and Santiago Grijalva<sup>2</sup>

<sup>1</sup> Sandia National Laboratories

<sup>2</sup> Georgia Institute of Technology



Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



High Penetration PV Deployment Webinar Series  
Distribution Modeling and Model Reduction

29 August 2013

# Distribution System Modeling - OpenDSS

- OpenDSS solves the power flow
  - Open source three-phase distribution system simulation software from EPRI
- OpenDSS is controlled from MATLAB through COM server
  - Integrates solar data, perform post-simulation analysis, and loop through scenarios
- Sandia toolbox GridPV to interface between OpenDSS and MATLAB

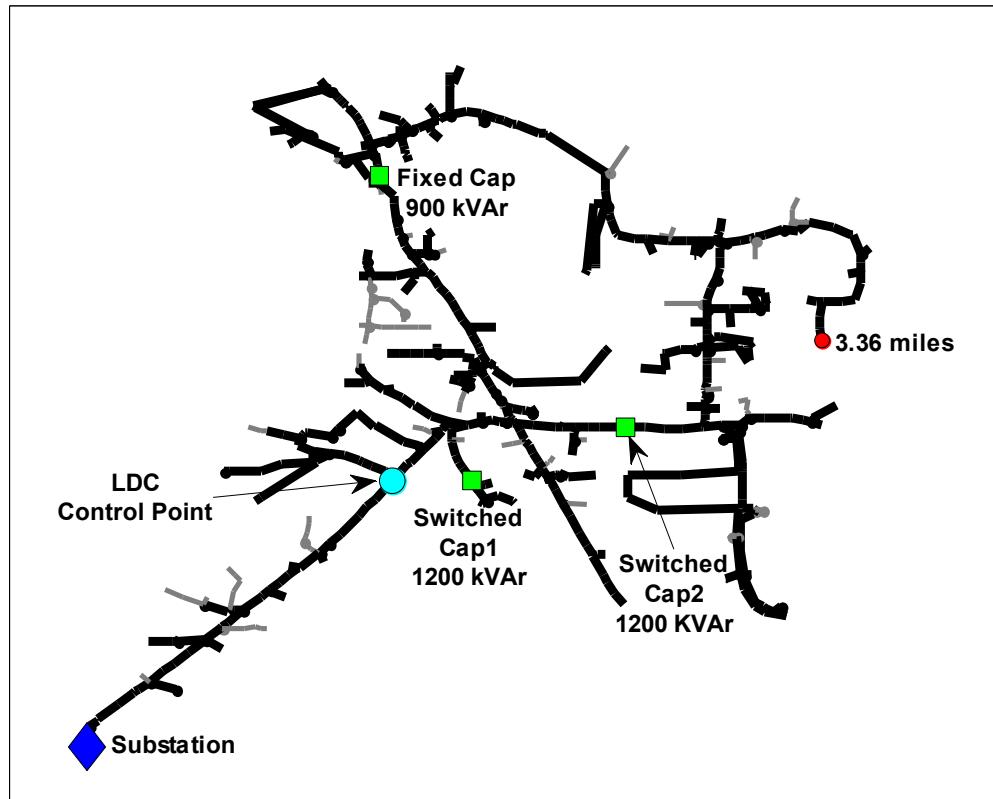


High Penetration PV Deployment Webinar Series  
Distribution Modeling and Model Reduction

29 August 2013

# Distribution Feeder Modeling

- 19.8 kV distribution system, LTC with LDC, five feeders
- Feeder - 7.5 MVA peak load, two switched capacitors
- PV scenarios at 100% of feeder peak load

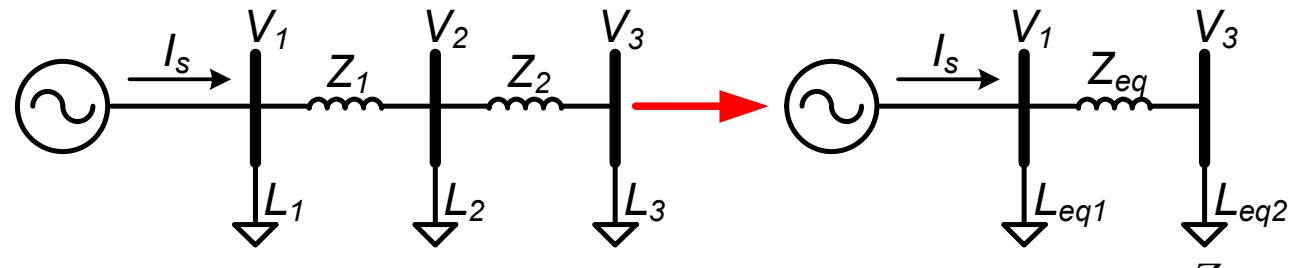


# Circuit Reduction Motivation

- A full detailed model of the distribution system can be time consuming to produce and to enter into simulation software. A reduced circuit also improves the ease of converting from one software package to another with few line segments and no proprietary full feeder models
- Time-series simulation of a large distribution system at a high time-resolution requires significant computational processing. Stochastic simulations or multiple study scenarios also involve large amounts of computation for full circuit models
- Circuit reduction provides faster and more accurate interconnection screening criteria by reducing the circuit to a simpler equivalent representation with only the key circuit parameters

# Load Bus Reduction Formulation

- Reduce a single load bus into adjacent buses
- Assumptions – fixed current loads, balanced system
- Ability to apply recursively and to branches
- Fully equivalent circuit – voltage, line losses, topology
- Complete proofs and methodology shown in SAND report
  - M. J. Reno, R. J. Broderick, and S. Grijalva, "Formulating a Simplified Equivalent Representation of Distribution Circuits for PV Impact Studies," Sandia National Laboratories, 2013.

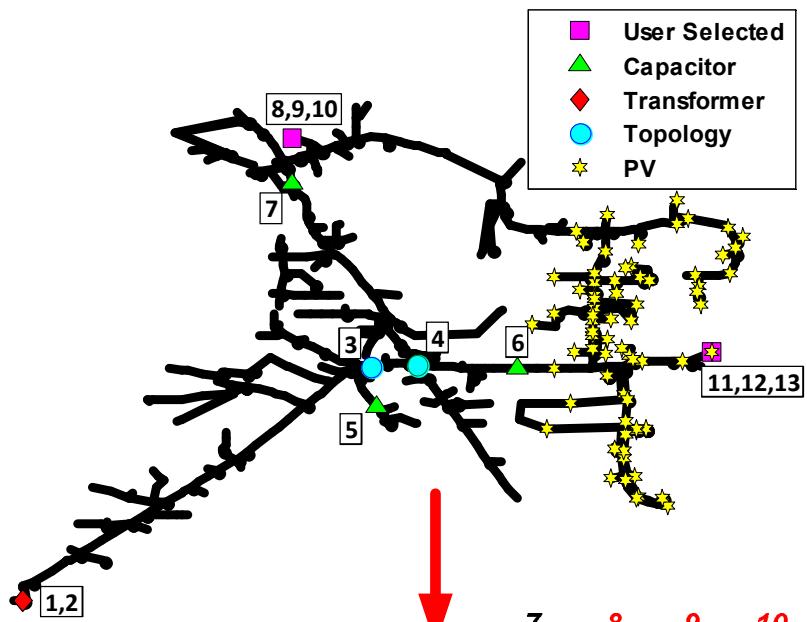


$$Z_{eq} = Z_1 + Z_2$$

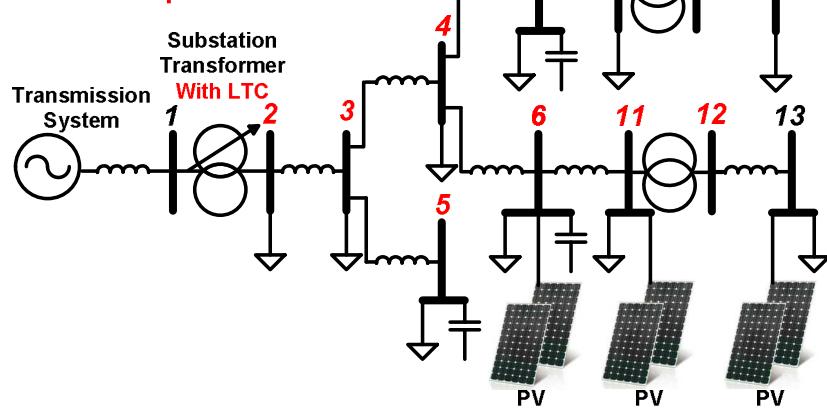
$$L_{eq1} = L_1 + \frac{Z_2}{Z_1 + Z_2} L_2$$

$$L_{eq2} = L_3 + \frac{Z_1}{Z_1 + Z_2} L_2$$

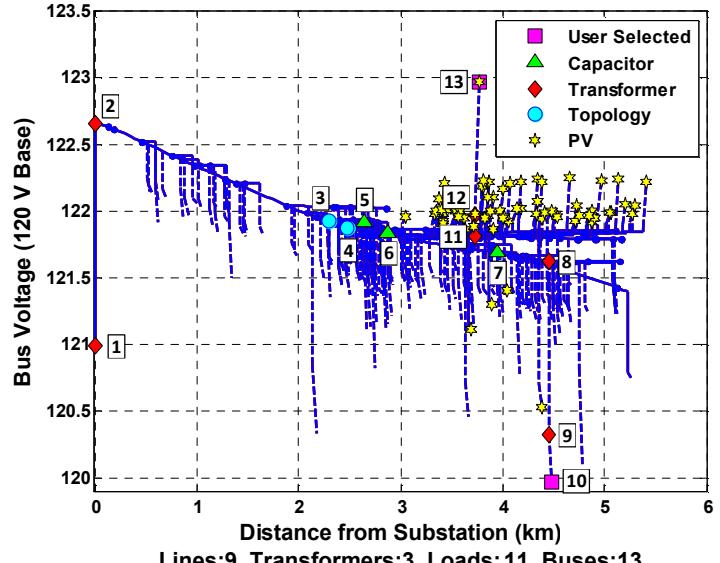
# Complex Feeder Representation



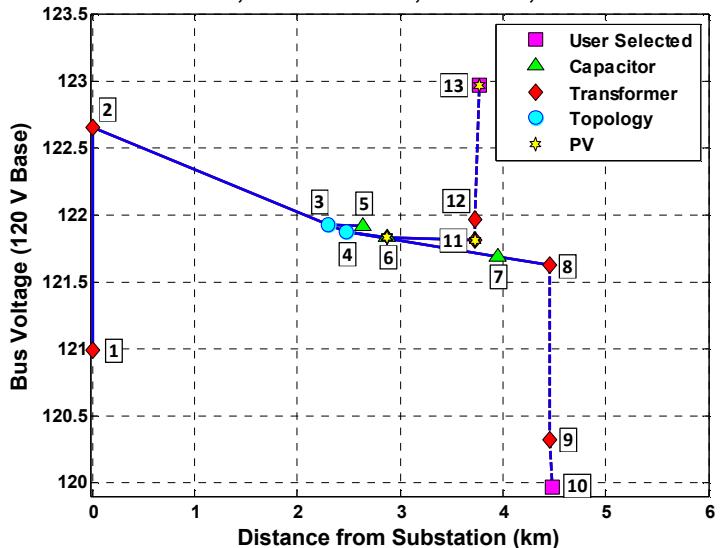
Reduced Equivalent Circuit



Lines:1047, Transformers:214, Loads:386, Buses:1262



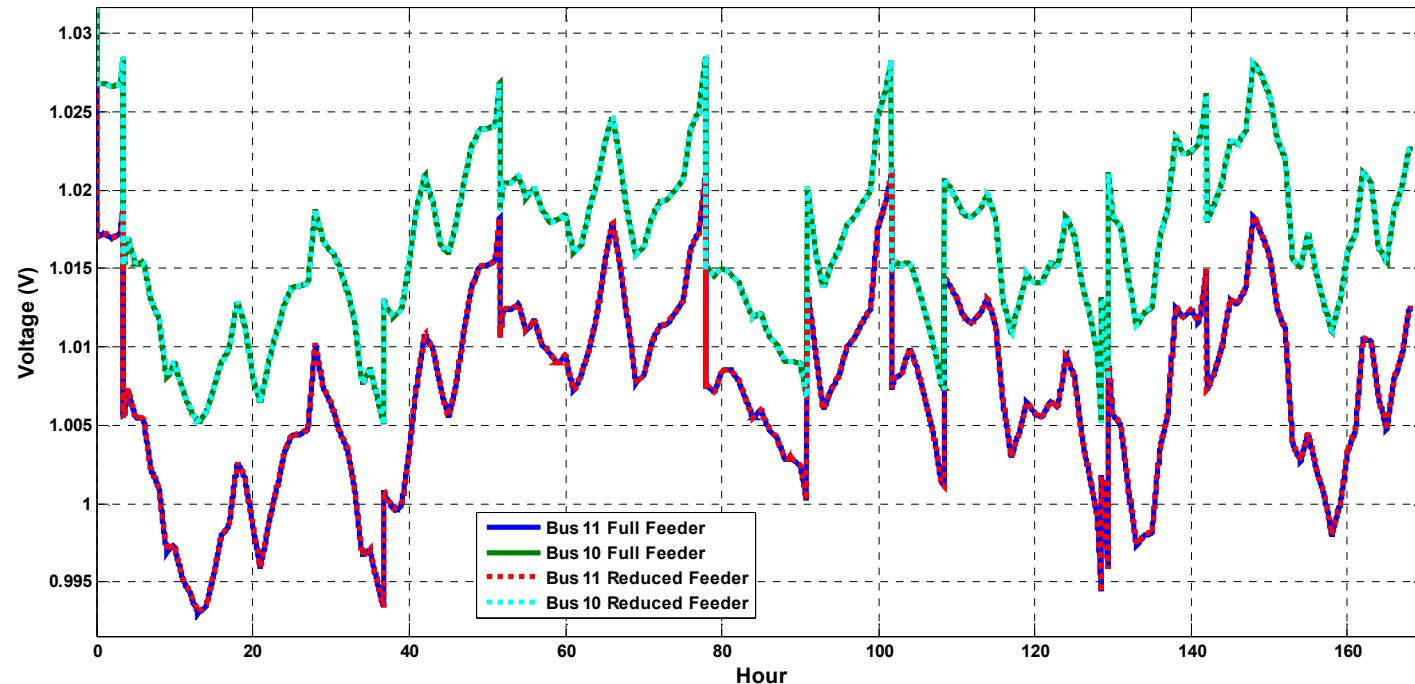
Lines:9, Transformers:3, Loads: 11, Buses:13



High Penetration PV Deployment Webinar Series  
Distribution Modeling and Model Reduction

29 August 2013

# Validation and Percent Reduction



	Full Circuit	Reduced Circuit	% of Original
Time (seconds) to perform a week simulation at 1-second resolution	837.94	15.48	1.85%
Circuit – Number of Lines	1047	8	0.76%
Circuit – Number of Transformers	214	2	0.93%
Circuit – Number of Loads	386	10	2.59%
Circuit – Number of Buses	1262	11	0.87%

# Conclusions

- Circuit reduction allows high-resolution detailed models to be run efficiently and accurately
- A method was developed for simplifying the complex system to an equivalent representation of the feeder with fewer buses while maintaining an electrically equivalent feeder and topology
- Circuit reduction was validated to be equivalent for time-series simulations with time-varying load and variable solar generation

# References

1. M. J. Reno, K. Coogan, R. J. Broderick, and S. Grijalva, "Reduction of Distribution Feeders for Simplified PV Impact Studies," in IEEE Photovoltaic Specialists Conference, Tampa, FL, 2013.
2. M. J. Reno, R. J. Broderick, and S. Grijalva, "Formulating a Simplified Equivalent Representation of Distribution Circuits for PV Impact Studies," Sandia National Laboratories SAND2013-2831, 2013.
3. R. J. Broderick, J. E. Quiroz, M. J. Reno, A. Ellis, J. Smith, and R. Dugan, "Time Series Power Flow Analysis for Distributed Connected PV Generation," Sandia National Laboratories SAND2013-0537, 2013.

## Q & A AND DISCUSSION

---

Matthew Reno – [mjreno@sandia.gov](mailto:mjreno@sandia.gov)

Robert Broderick – [rbroder@sandia.gov](mailto:rbroder@sandia.gov)

[www.sandia.gov/pv](http://www.sandia.gov/pv)