Exceptional service in the national interest

Sandia National Laboratories

HIGH PENETRATION PV INTERCONNECTION MODELING AND REDUCTION OF DISTRIBUTION FEEDERS

Matthew J. Reno[1,2], Robert J. Broderick[1], Kyle Coogan[2], Jimmy Quiroz[1], and Santiago Grijalva[2]

[1] Sandia National Laboratories [2] 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.

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

SunShot U.S. Department of Energy

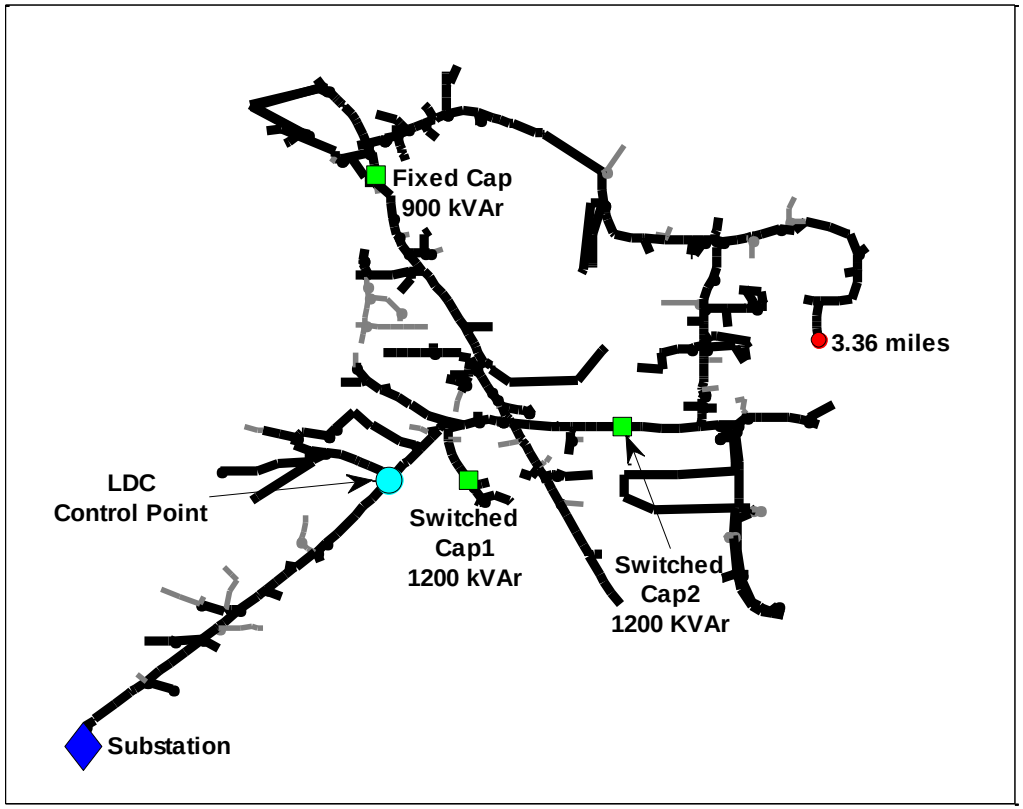
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

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

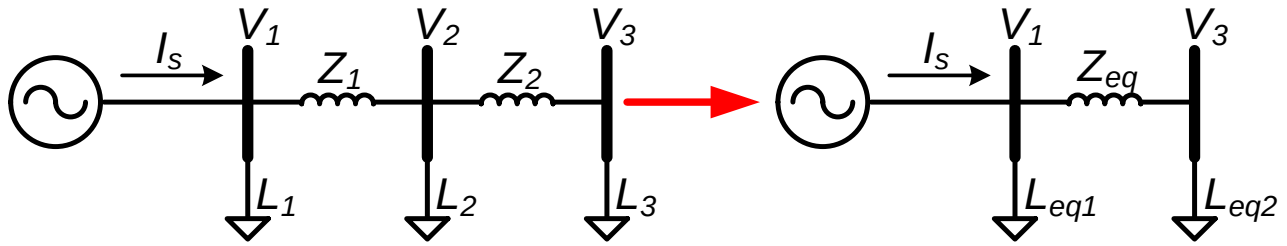


Circuit Reduction Motivation

- 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 propriety 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

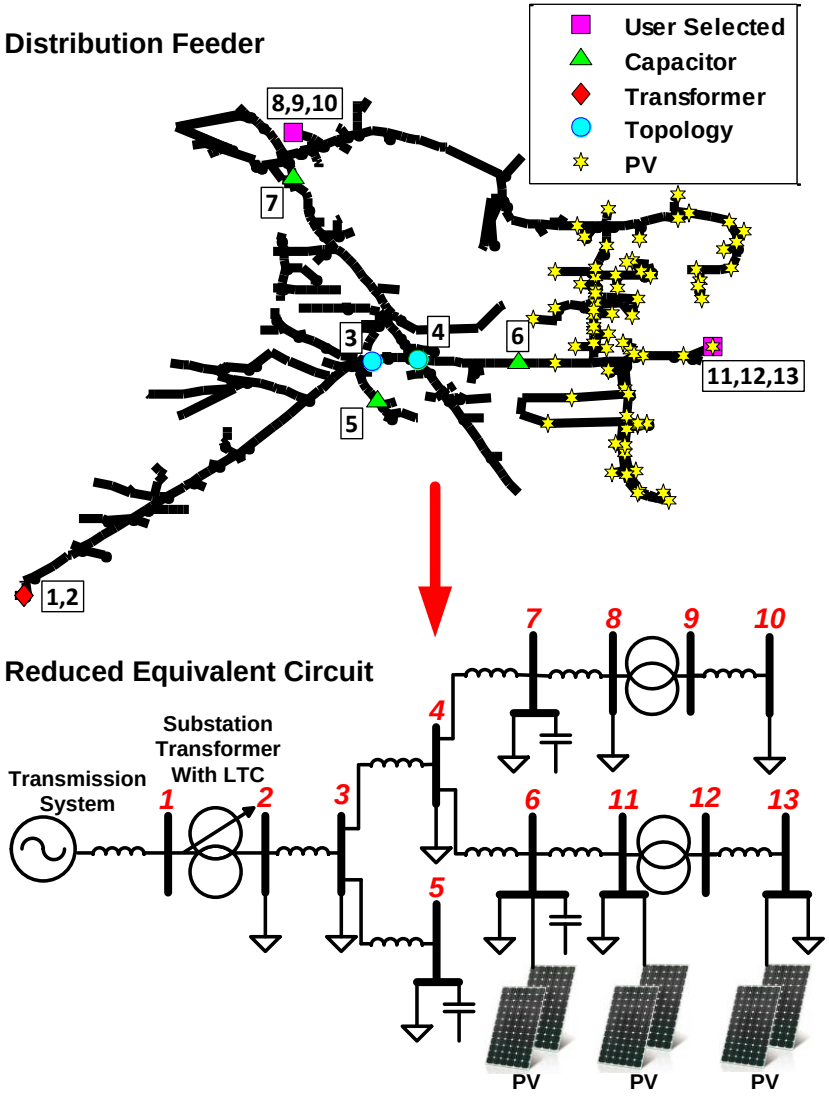
Load Bus Reduction Formulation

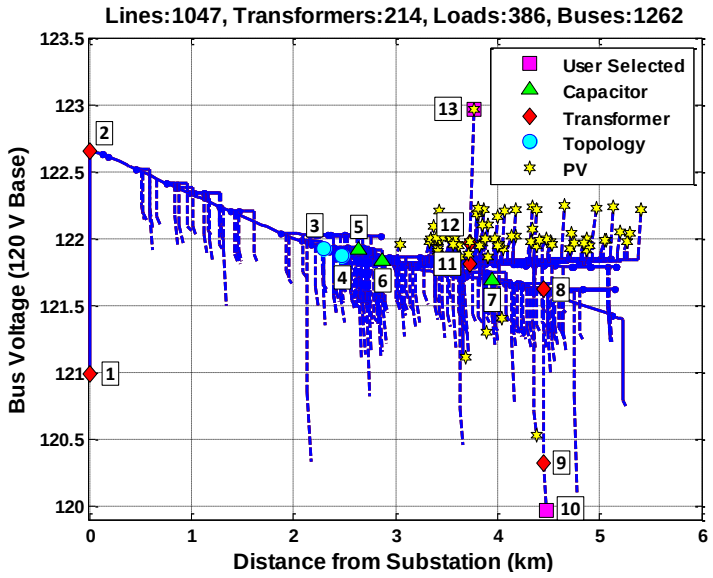
- Reduce a single load bus into adjacent buses
- Assumptions – fixed current loads, balanced system
- Ability to apply recursively and to branches
- Fully equivalent circuit – voltage, line losses, topology
- Complete proofs and methodology shown in SAND report
  - M. J. Reno, R. J. Broderick, and S.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

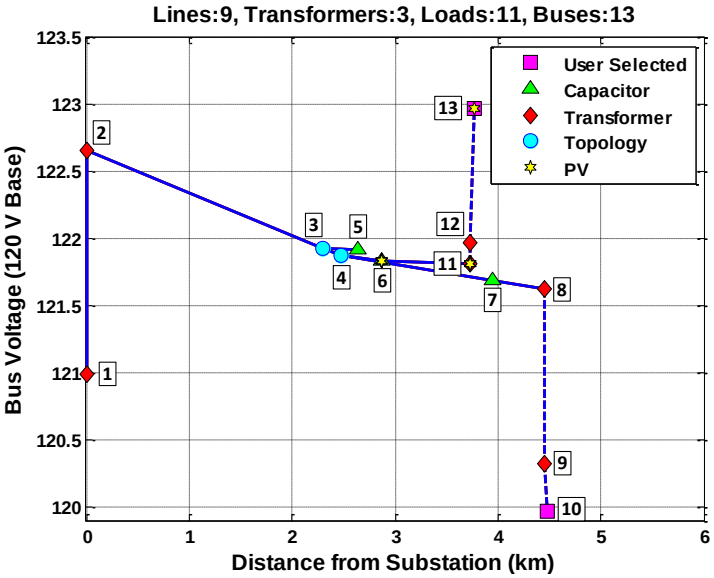


$$Z_{eq} = Z_1 + Z_2 \qquad L_{eq1} = L_1 + \frac{Z_2}{Z_1 + Z_2} L_2 \qquad L_{eq2} = L_3 + \frac{Z_1}{Z_1 + Z_2} L_2$$

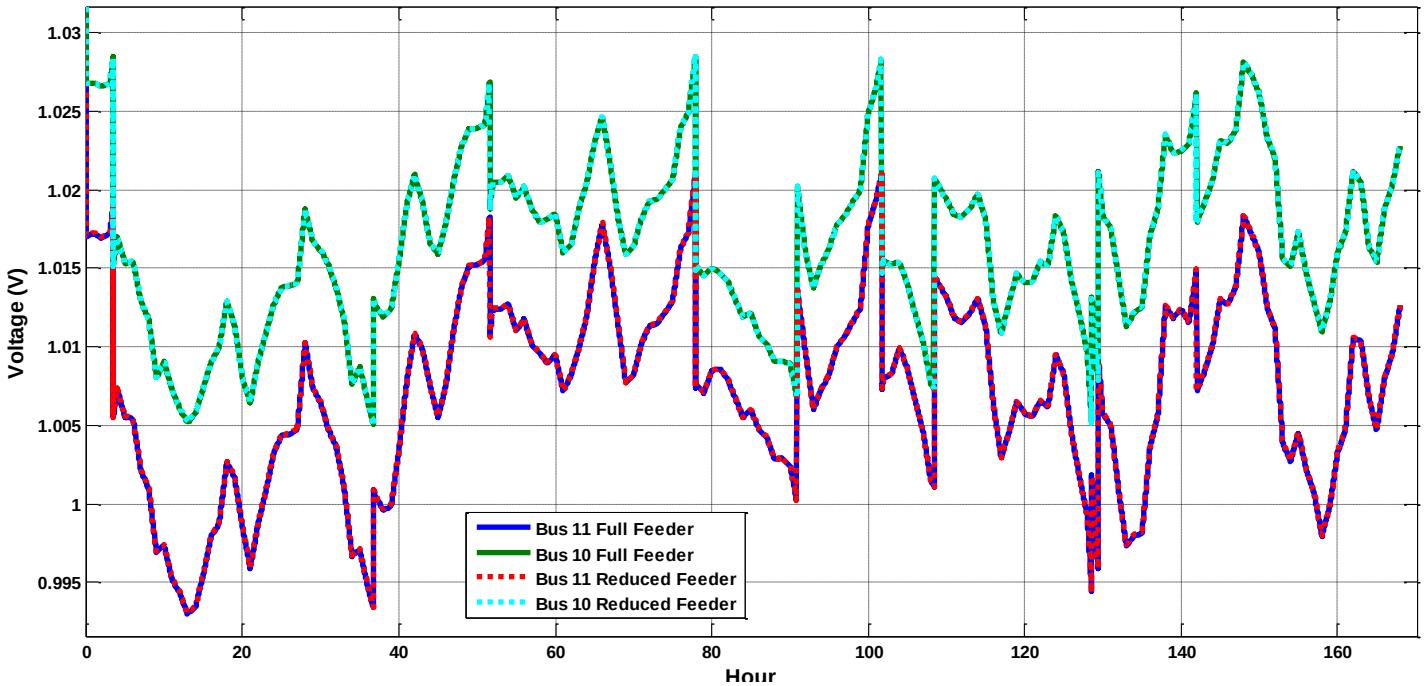
Complex Feeder Representation







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

Robert Broderick – rbroder@sandia.gov

www.sandia.gov/pv