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Quasi-Static Time Series (QSTS) Simulations for Distribution System Analysis

Panel Session

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QSTS Panel

- Matthew Reno
  - *Sandia National Laboratories*
- Barry Mather
  - *National Renewable Energy Laboratory*
- Xiaochen Zhang
  - *Georgia Institute of Technology*
- Davis Montenegro
  - *Electric Power Research Institute*

Introduction

What is QSTS?

- Quasi-static time series (QSTS) analysis captures time-dependent aspects of power flow, including the interaction between the daily changes in load and PV output and control actions by feeder devices and advanced inverters.

Why do we need QSTS?

- PV output is highly variable and the potential interaction with control systems may not be adequately analyzed with traditional snapshot tools
- Many potential impacts, like the duration of time voltage violations and the increase in voltage regulator operations, cannot be accurately analyzed without it.

What is the problem with today's tools?

- Snapshot analyses that only investigate specific time periods can be overly pessimistic about PV impacts because it does not include the geographic and temporal diversity in PV production and load

Simple Comparison of PV Impact Study Methods

Steady-state (snapshot)

- Follow traditional planning practices
- Require relatively low-resolution input data (multiple time points)
- Are inherently conservative

Quasi-Static Time-Series

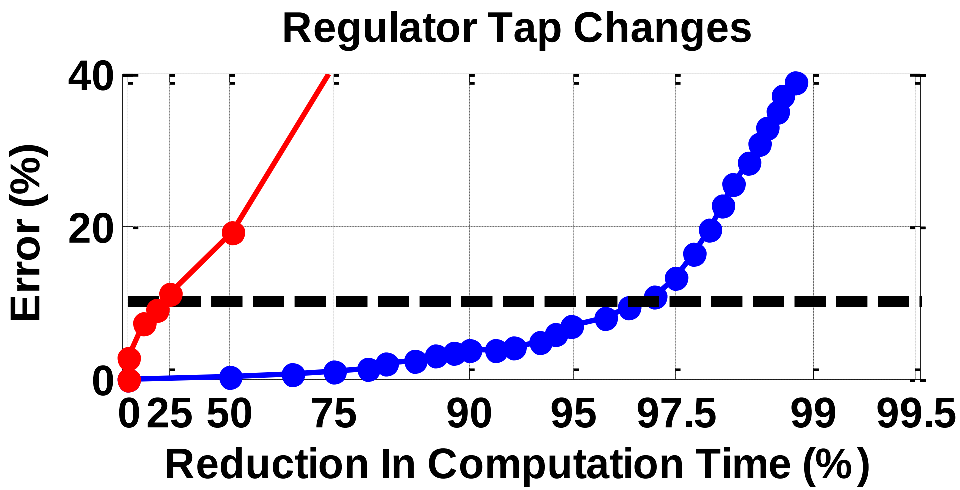
- Require new tools, new experience
- Require high-resolution input data (temporal and spatial)
- Are inherently realistic and more informative
  - Calculate automatic voltage regulation equipment operations, time durations of voltage excursions, etc.

In future hi-pen PV scenarios (1000s of PV systems on most circuits) conservative, worst-case analysis, will unnecessarily limit PV integration – thus we need to improve the PV impact study methods

Quasi-static Time Series (QSTS) Simulations

- QSTS Simulations need to be:
  - Extended-term simulations (year-long)
  - High resolution simulation to capture solar variability (time step less than 5 seconds)

Error Compared to Yearlong 1-second Resolution QSTS



A Closer Look at QSTS

- Require considerable time
  - QSTS with a resolution of 1-second requires 31M+ power flow solutions – it can take days to solve
- Require mountains of data/memory
  - Load/PV generation profiles need to be time synchronized and spatially correlated
- Currently QSTS analysis is not possible for utilities

Rapid QSTS Simulations for High-Resolution Comprehensive Assessment of Distributed PV

Funded by: U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

PIs: Sandia National Laboratories; NREL NATIONAL RENEWABLE ENERGY LABORATORY

Partners: EPRI ELECTRIC POWER RESEARCH INSTITUTE; Georgia Tech; CYME INTERNATIONAL T&D

Project Focus

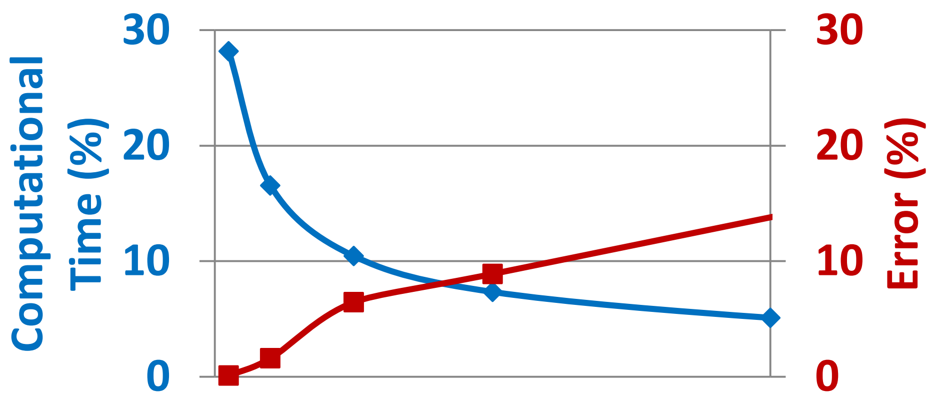
- Enable year-long QSTS distribution simulations by reducing analysis time from days to minutes
  - Time-series approximations
    - Reduce the number of individual solutions needed
  - Speed up power flow solutions
    - Circuit reduction
    - Power flow algorithm development
    - Computational parallelization of QSTS solution
- Develop load/PV models for QSTS
  - Accurate, location specific, models that reflect variability and diversity

Challenges to Increasing Speed of QSTS

- An individual power flow is often very fast, but QSTS is solving the power flow 31 million times
- Distribution systems are unbalanced nonlinear discontinuous system with thousands of buses
- Power flow solutions are dependent on the previous time-steps
- Nonlinear voltage controllers with hysteresis and deadbands
- Controllable element interactions and cascading errors
- Fast control elements that respond in seconds

Evaluating Speed and Accuracy

- Speed improvements can come at the expense of accuracy



- All new algorithms are tested extensively and validated against yearlong 1-second resolution QSTS results
  - Regulator tap changes, capacitor switching operations
  - Bus voltages, hours per year with ANSI violations
  - Thermal loading (worst overloads and time overloaded)
  - Yearly line losses

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Panel Outline

- Matthew Reno
  - Overview of QSTS
  - Circuit Reduction
- Barry Mather
  - High-Resolution Data for Accurate QSTS Simulations
  - Variable Time-Step Methods
- Xiaochen Zhang
  - Vector Quantization
  - Event-based Simulation
  - Sampling Partial Year
- Davis Montenegro
  - Temporal Decomposition for Time-Series Analysis
  - Parallelization using Diakoptics
- Matthew Reno
  - Implementation of Algorithms
- Questions

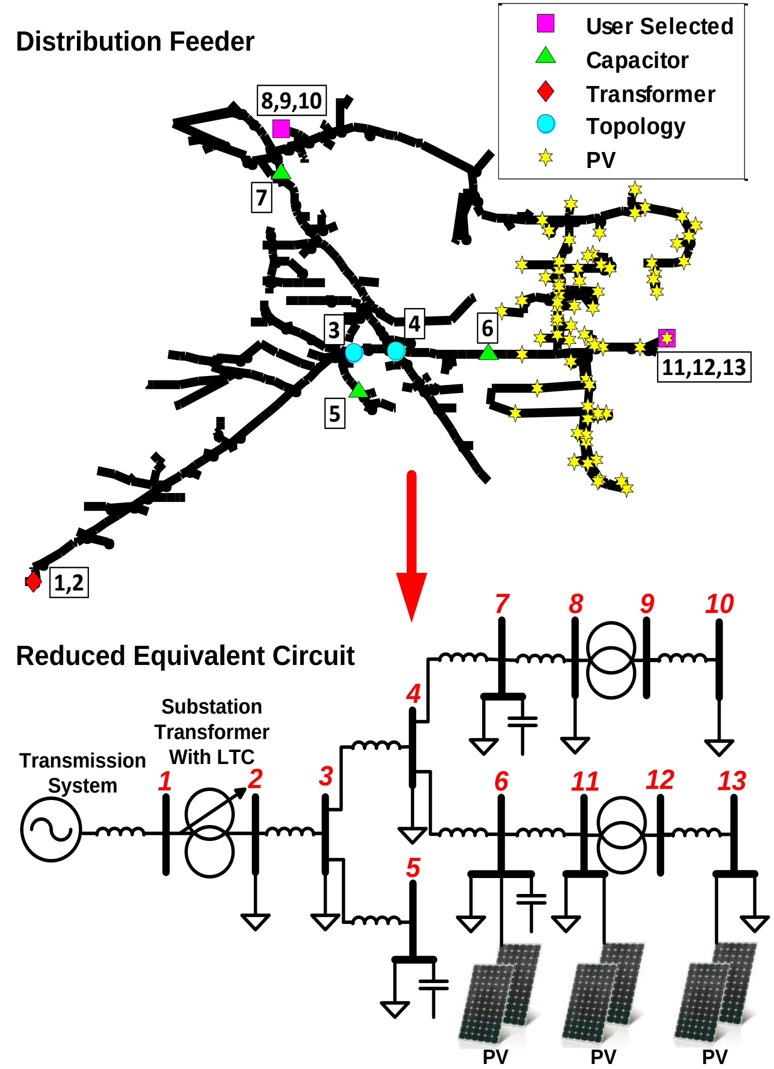
Circuit Reduction

Objective:

– Use an equivalent reduced circuit with fewer buses to decrease the power flow simulation time

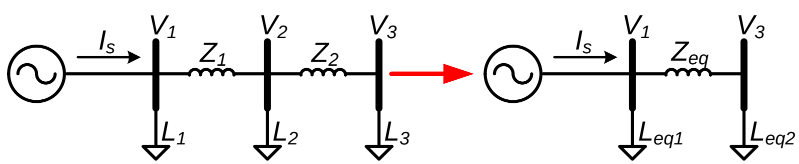
Solution:

– Many buses can be removed or aggregated into nearby buses, while keeping the results for the remaining buses equivalent



Circuit Reduction

- Reduction algorithms can handle unbalanced loads and PV, unbalanced and unsymmetrical wire impedance, mutual coupling, shunt capacitance, transformer magnetizing currents, and multiple different load profiles and PV power profiles.
- With certain assumptions, the results are exactly equivalent for the reduced circuit
- Steps:
  1) Select buses to keep
  2) Remove buses without objects (Kron reduction)
  3) Remove unnecessary laterals (Norton equivalents)
  4) Load Bus Reduction



Circuit Reduction Results

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<tr><th></th><th>Feeder UT11
96% Reduction
<0.01% Error</th><th>Feeder Ckt 7
98% Reduction
<0.02% Error</th><th>Feeder UQ11
97% Reduction
<0.02% Error</th></tr>
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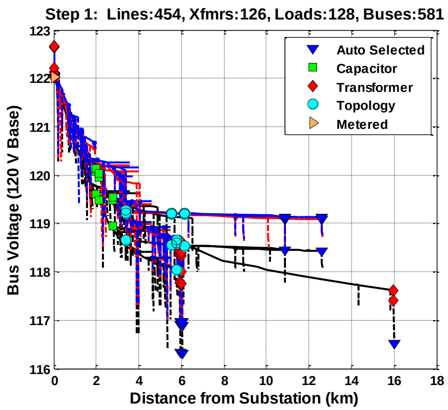
<td>
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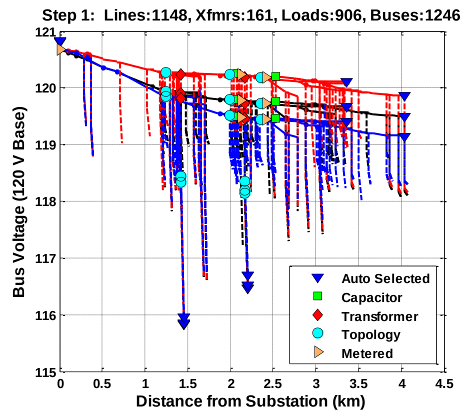
<td>
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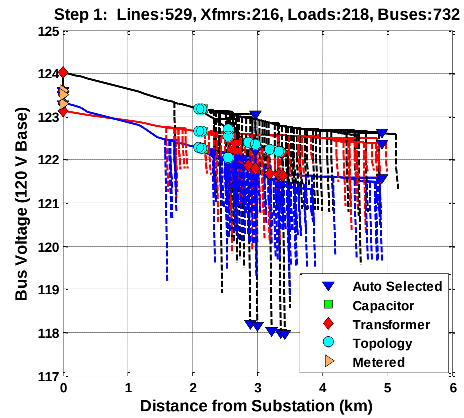
<td>
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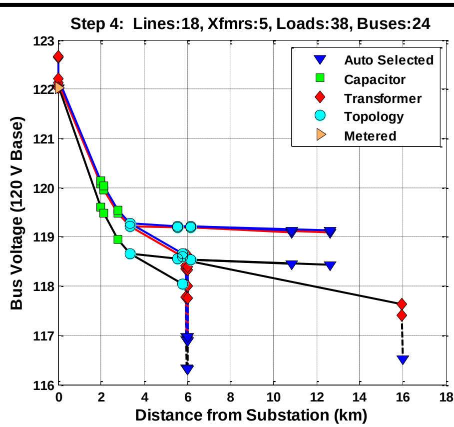
<tr><td>Reduced</td>
<td>
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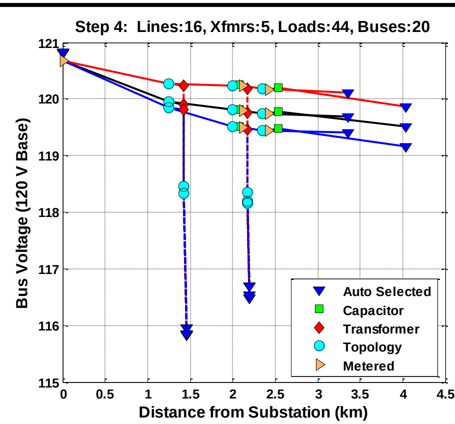
<td>
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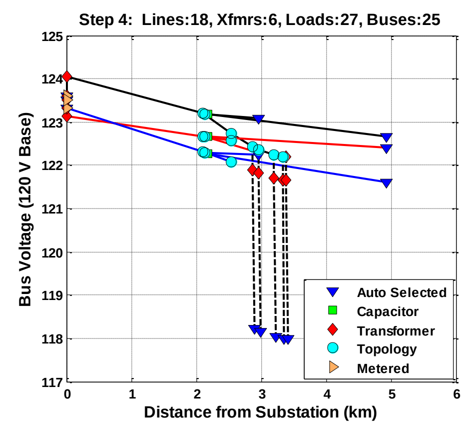
<td>
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