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Quasi-Static Time Series (QSTS) Simulations for High-Resolution Comprehensive Assessment of Distributed PV (SI- 30691)

Robert Broderick
rbroder@sandia.gov
Sandia National Laboratories
Sunlamp
30691

SYSTEMS INTEGRATION

PROBLEM STATEMENT

The rapid increase in penetration of distributed energy resources on the electric power distribution system has created a need for more comprehensive interconnection modeling and impact analysis. Unlike conventional scenario-based studies, quasi-static time-series (QSTS) simulations can realistically model time-dependent voltage controllers and the diversity of potential impacts that can occur at different times of year. However, to accurately model a distribution system with all its controllable devices, a yearlong simulation at 1-second resolution is often required, which could take conventional computers a computational time of 10 to 120 hours when an actual unbalanced distribution feeder is modeled.

PROJECT OVERVIEW

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. QSTS is not directly a PV screening or hosting capacity calculation, but a detailed method and tool to directly simulate potential grid impacts for a variety of future scenarios.

This project is accelerating QSTS simulation capabilities through use of new and innovative methods for advanced time-series analysis. This concept will seamlessly integrate equivalent reduced-order feeder models to precisely simulate grid impacts while dramatically reducing the computational time required to solve the power flow time-series – making QSTS analysis the industry preferred PV impact assessment method.

VALUE PROPOSITION

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

TECHNOLOGY OVERVIEW

This computational burden is a clear limitation to the adoption of QSTS simulations in interconnection studies and for determining optimal control solutions for utility operations. Our ongoing research to improve the speed of QSTS simulation has revealed many unique aspects of distribution system modelling and sequential power flow analysis that make fast QSTS a very difficult problem to solve. In this project, the most relevant challenges in reducing the computational time of QSTS simulations are: number of power flows to solve, circuit complexity, time dependence between time steps, multiple valid power flow solutions, controllable element interactions, and extensive accurate simulation analysis

PROJECT OBJECTIVE

Computation times for 1-second resolution QSTS

	Simulation Duration		
	1 Day	1 Month	1 Year
Existing Methods	1.6 – 20 minutes	0.8 - 10 hours	10 - 120 hours
Proposed Algorithm Target	3 minutes	4 minutes	5 minutes

MILESTONES

By the end of the first year:

- ✓ At least one time-series approximation method will be shown to have a significant (at least 90%) reduction in processing time, and all other proposed methods have been developed to show at least 50% reduction in time for simple distribution systems. Mean Absolute error (MAE) is less than 10% for tap operations.
- ✓ The circuit reduction method includes high penetrations of distributed PV with smart inverter functionality. The algorithm will have at least 90% reduction and a voltage error less than 0.2%.

By the end of Second year:

- ✓ At least one time-series approximation method will be able to run in 10% of the time and accurately approximate the QSTS results for an extremely complex distribution system.
- ✓ 3 new algorithms incorporated into OpenDSS and provided as open source code.
- ✓ The temporal and Diakoptic parallelization methods for QSTS analysis have been developed and demonstrate less than 2% error for fast simulations.

By the end of Third year:

- ❑ Implement accelerated QSTS analysis into CYME Long-Term Dynamics commercial distribution system analysis software package and OpenDSS and demonstrate solution times of 5 minutes or less for year-long simulations using at least three complex feeder types.

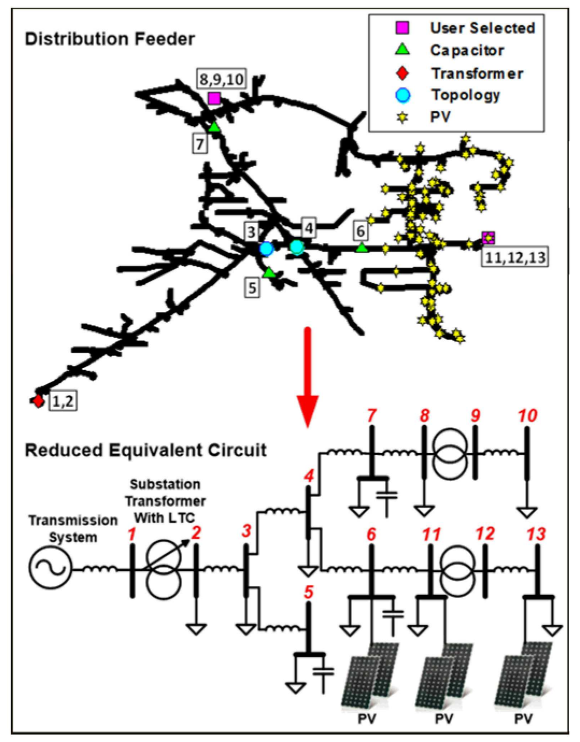
RESULTS

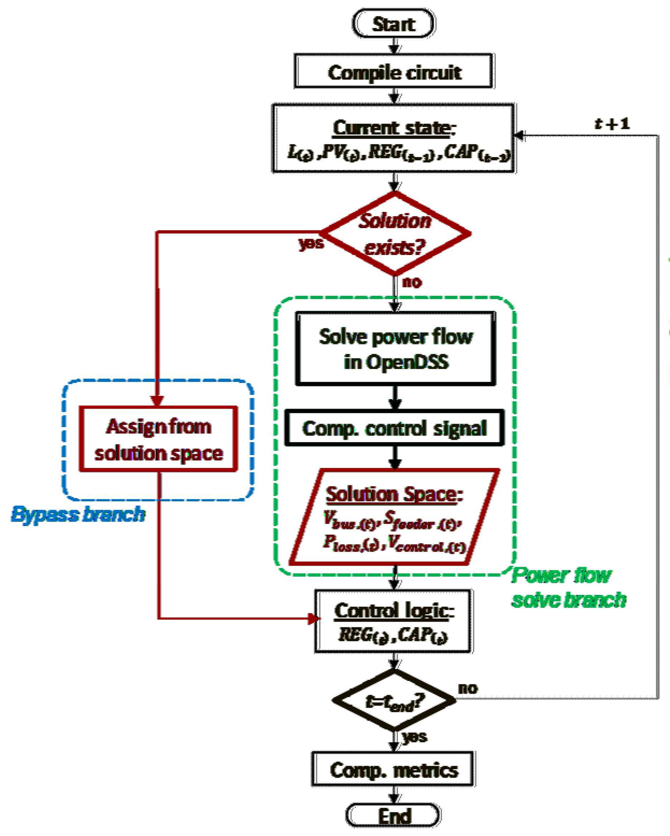
Desired Outcome	Project Output to Date
Develop QSTS algorithms that show speed improvements of 90% or more.	5 rapid time series approximation algorithms have been successfully developed and show speed improvements of 90% or more
Develop Power Flow solution algorithms that speed improvements	Both CYME and EPRI have shown speed improvements of 50% or more
Implement accelerated QSTS analysis into CYME & Open DSS software packages	Combination of the best methods ongoing to verify scalability and accuracy for very complex feeders.
Share data and results	3 journal articles, 13 published papers, 8+ presentations, 1 SAND report and 2 conference panel sessions

Key Results → Design → Open-DSS → CYME

"Article Title"	Journal Name	Significance
Fast Quasi-Static Time-Series (QSTS) for Yearlong PV Impact Studies using Vector Quantization	Solar Energy	Demonstrates time reductions of the vector quantization method to achieve 99+% reductions in QSTS analysis time.
Challenges in reducing the computational time of QSTS simulations for distribution system analysis	Sandia National Laboratories	Provides a detailed review of the key challenges and potential solutions for speeding up QSTS simulations based on the first 1.5 years of the project.
An Iterative method for detecting and localizing islands within sparse matrixes using DSSim-RT	IEEE Transactions on Industry Applications	Describes an innovative method to use Diakoptics- a spatial tearing method to assign parts of a feeder to different processors in a parallelization scheme.
A Fast-Scalable Quasi-Static Time Series Analysis Method for PV Impact Studies using Linear Sensitivity Model	IEEE Transactions on Sustainable Energy	Demonstrates time reductions of the event based method to achieve 99+% reductions in QSTS analysis time.

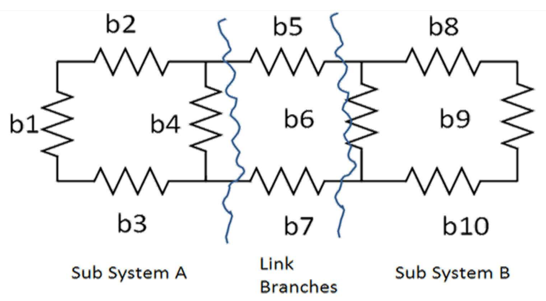
Circuit Reduction



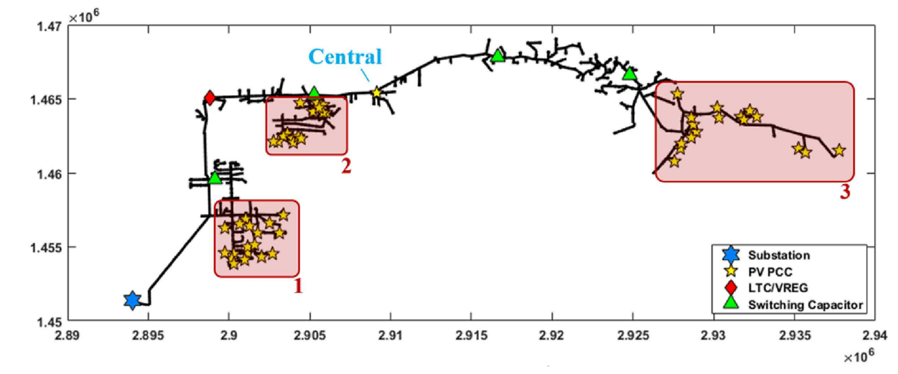


Time series approximation using quantization

Diakoptics- Spatial parallization



Analysis using complex, full fidelity feeder models



INDUSTRY IMPACT

The overall impact of this work is that it will allow precise simulation of grid impacts while dramatically reducing (potentially 1000-fold) the computational time required to solve the power flow time-series – this will make QSTS analysis the industry preferred PV impact assessment method.

Make possible **100s GW** Solar Penetration in 2020 and beyond by:

- ➢ Allow **PV Generation capacity>100% peak load** by accurately determining the expected impact of PV interconnections
- ➢ Integrate QSTS capability into utility distribution planning and operations with a **<5 second time step**
- ➢ Interconnection **approval time < 5 days** for large scale installations, <1 hour for residential.

SOLAR ENERGY TECHNOLOGIES OFFICE
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