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PV Grid Integration Using Time-Series Analysis

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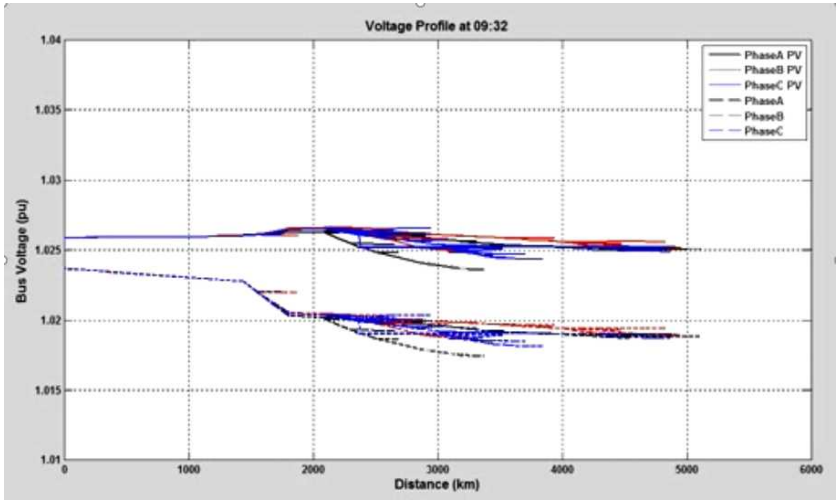
PV Grid Integration

- High penetrations of PV can affect the distribution feeder equipment and the operation of the system
  1. Designed for radial flow in one direction from the substation
  2. Designed for aggregated loads with little short-term variability

- Distribution system impacts
  - Voltage Regulation Device Operations
  - Steady State Voltage
  - Voltage Flicker
  - Protection Coordination



Time Series Simulations

- PV output is highly variable and the potential interaction with control systems may not be adequately analyzed with traditional snapshot tools and methods
- 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
- Requires more data to represent the time-varying PV output coincident with time-varying load

QSTS Simulations

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?

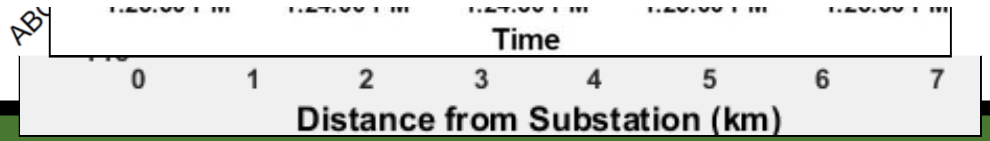
- PV output is highly variable and the potential interaction with control systems may not be adequately analyzed with traditional snapshot tools
- Many potential impacts, like the duration of time voltage violations and the increase in voltage regulator operations, cannot be accurately analyzed without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

Time-series Analysis of Distributed PV

- Impact of seasonal correlation of load and PV production
- Smart inverters analysis in time-series simulation
- PV variability profile (location) impact on tap changes
- Impact of voltage regulator control modes
- Low voltages caused by PV



Simple Comparison of Distribution Simulation Methods

Steady-state (snapshot)

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

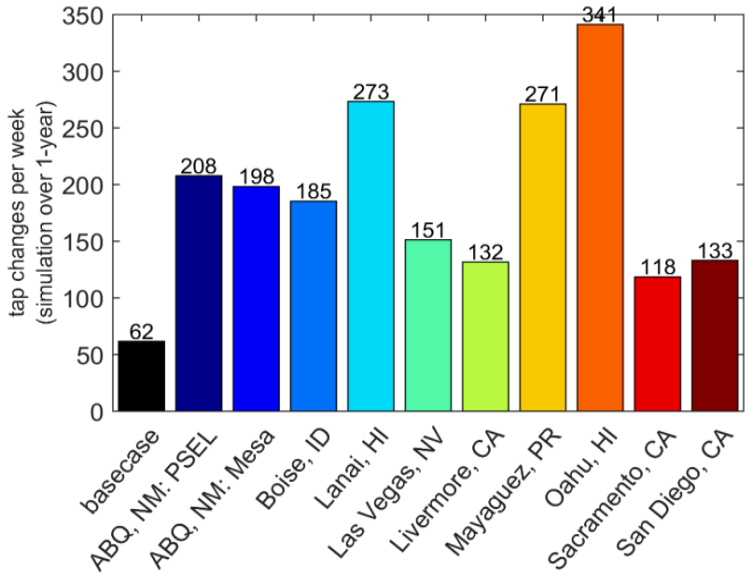
In future hi-pen PV scenarios (or other types of DER) conservative, worst-case analysis, will unnecessarily limit PV integration – thus we need to improve the PV impact study methods

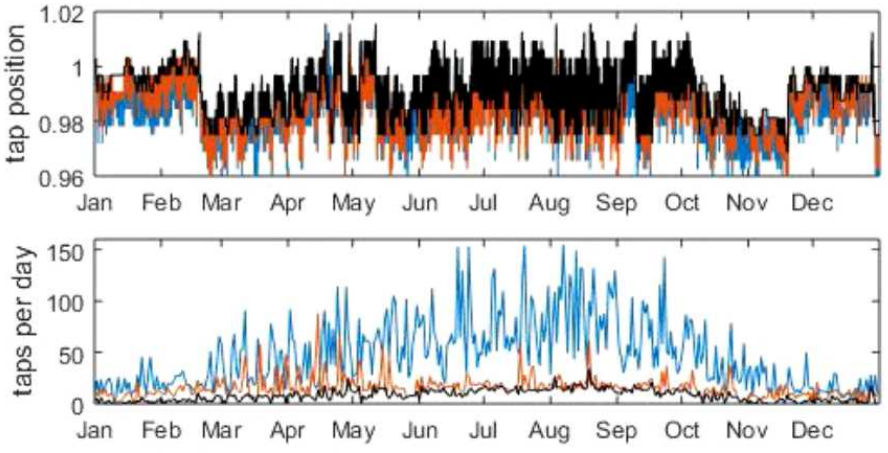
Quasi-Static Time-Series

- 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.

Quasi-Static Time-Series (QSTS) Simulations

- Analyze potential interactions between PV variability and distribution system controls. Also captures time-dependent aspects of power flow for daily changes in load and PV output
- QSTS simulates the number of tap changes on voltage regulators
- QSTS simulations present a significant computational burden





date: 31-Dec-2013
simulation time: 175.89 hours
taps basecase: 2974
taps Sacramento: 5784
taps Oahu: 17324

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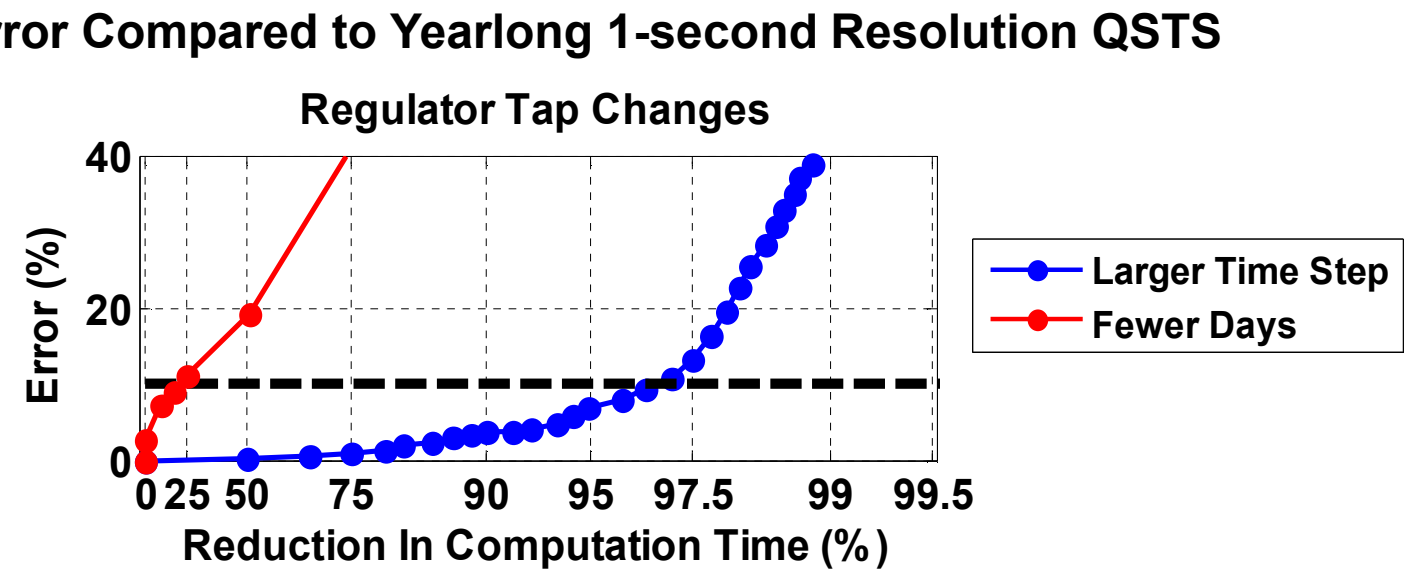
Quasi-Static Time Series (QSTS) Requirements

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



A Closer Look at QSTS

- Require considerable time
  - Yearlong QSTS with a resolution of 1-second requires 31 million 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 cumbersome for utilities

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

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PIs: Sandia National Laboratories; NREL NATIONAL RENEWABLE ENERGY LABORATORY

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

Rapid QSTS Project Focus

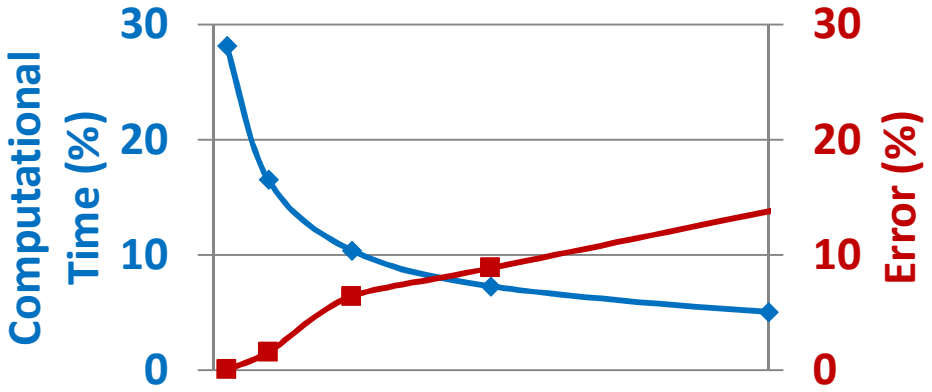
- Enable year-long QSTS distribution simulations by reducing analysis time from days to minutes
  - Speed up power flow solutions
    - Circuit reduction
    - Power flow algorithm development
    - Computational parallelization of QSTS solution
  - Time-series approximations
    - Reduce the number of individual solutions needed
- 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

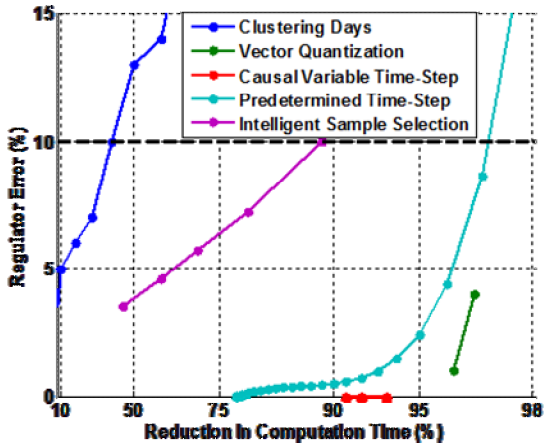
- Speed improvements can come at the expense of accuracy



- 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

Novel Approaches to QSTS

- Investigating several algorithms for improving the speed
  - Variable time-step
  - Event-based simulations
  - Vector quantization
  - Circuit reduction
  - Parallel processing



- Working on implementing rapid QSTS algorithms into OpenDSS and CYME
- Panel Session “Advances in Accelerated Distribution System Time-Series Analysis” on Tuesday at 10am

QUESTIONS?

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