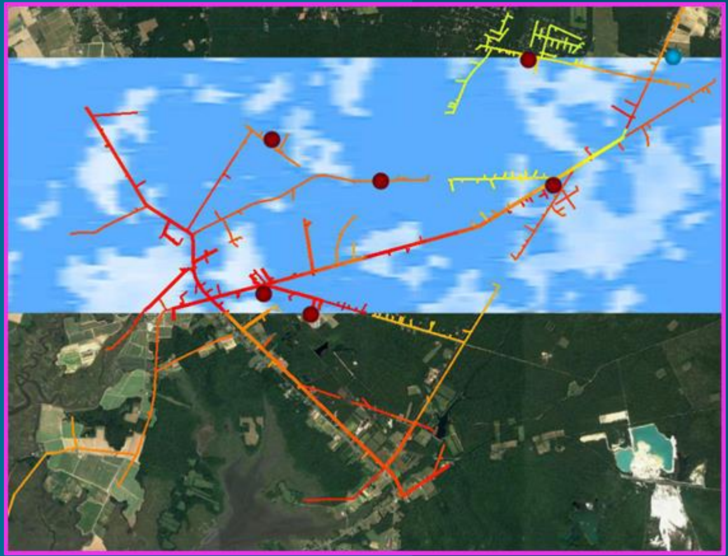
Towards High Fidelity Modeling of DER Integration to Distribution Grids



PRESENTED BY

Matthew Lave

Smart Grid Edge Analytics Workshop
Atlanta, GA
June 5, 2019
SAND2019-6176 C

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

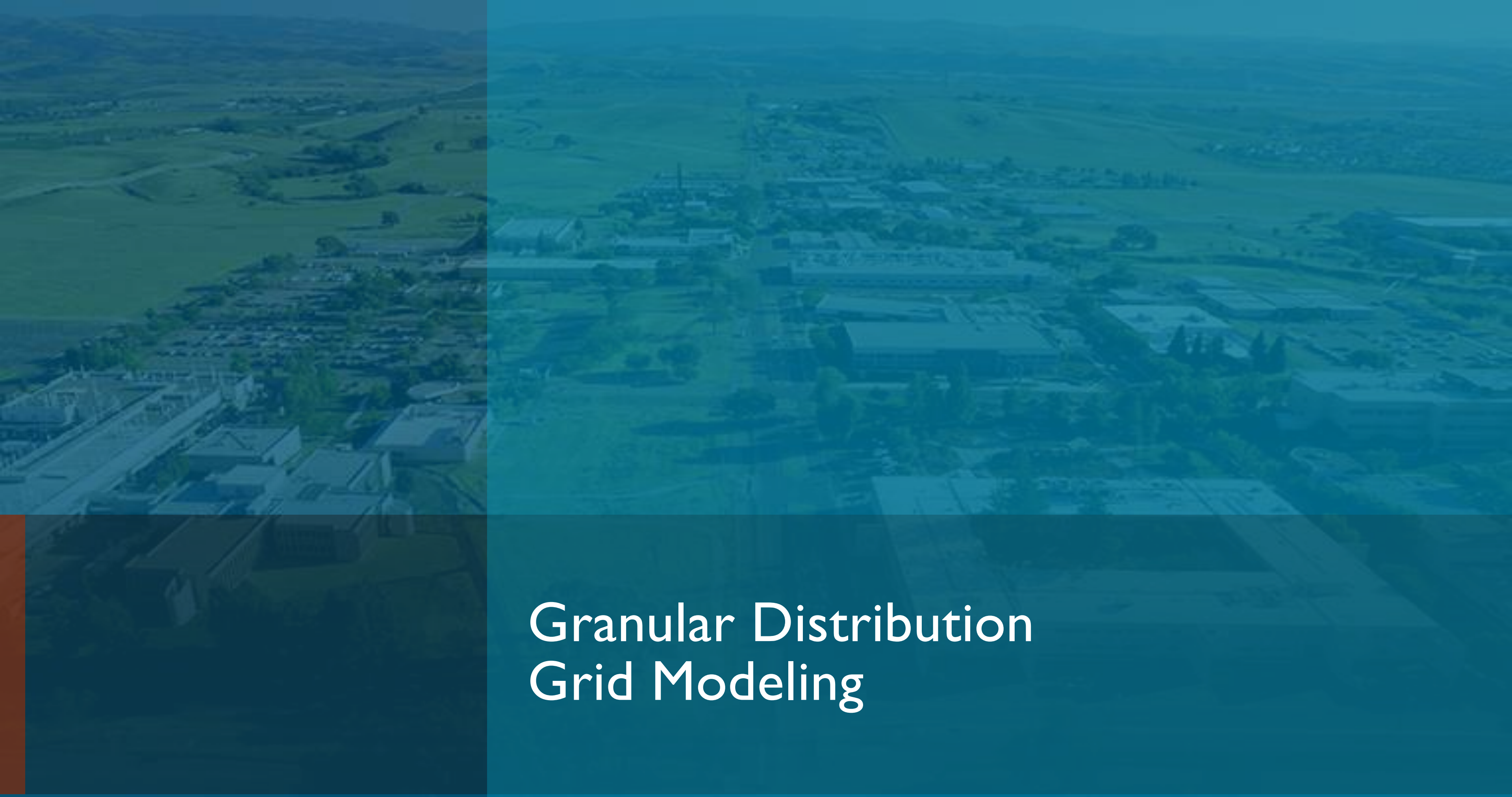
High-fidelity – a reproduction faithful to the original

For DER integration, we mean "accurately modeled," including:

1) Granular Distribution Grid Modeling
   - Phase identification
   - Topology identification and parameter estimation

2) Detailed Locational Impact Analysis
   - Locational hosting capacity
   - Synthetic Cloud Fields

3) Long-term Timeseries Analysis
   - Daily/seasonal variability in generation and impact to grid operations
   - Rapid QSTS



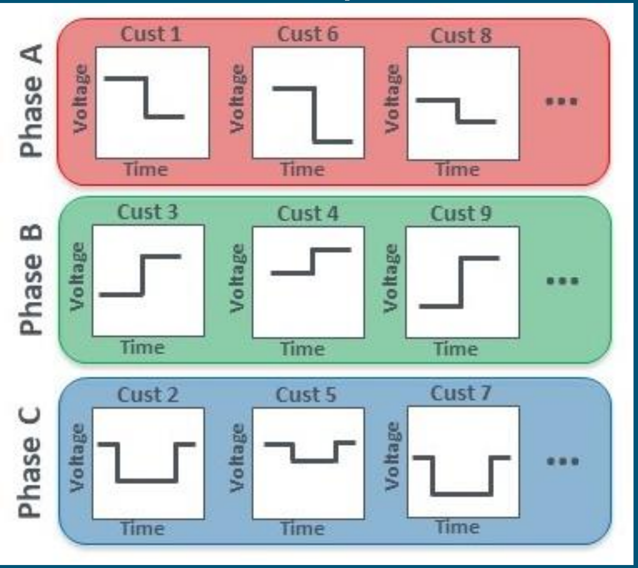
Granular Distribution Grid Modeling

- Phase identification
- Topology identification and parameter estimation

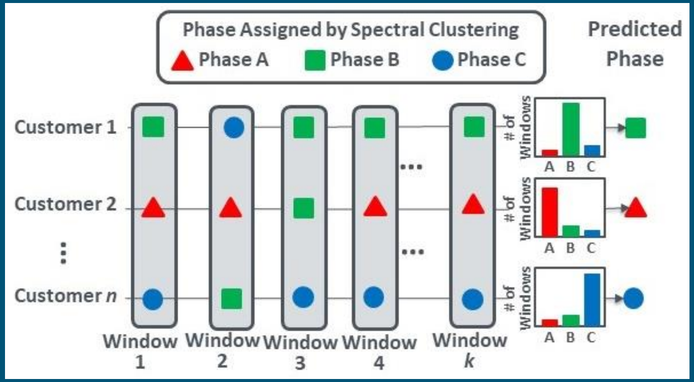
Phase Identification

Use Machine Learning on voltage profiles from AMI meters to cluster by phase.

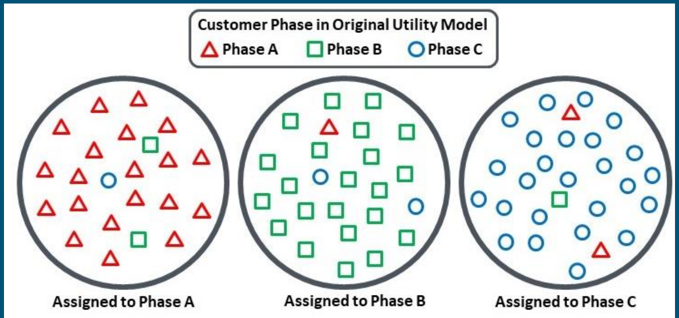
Concept



Method



Result

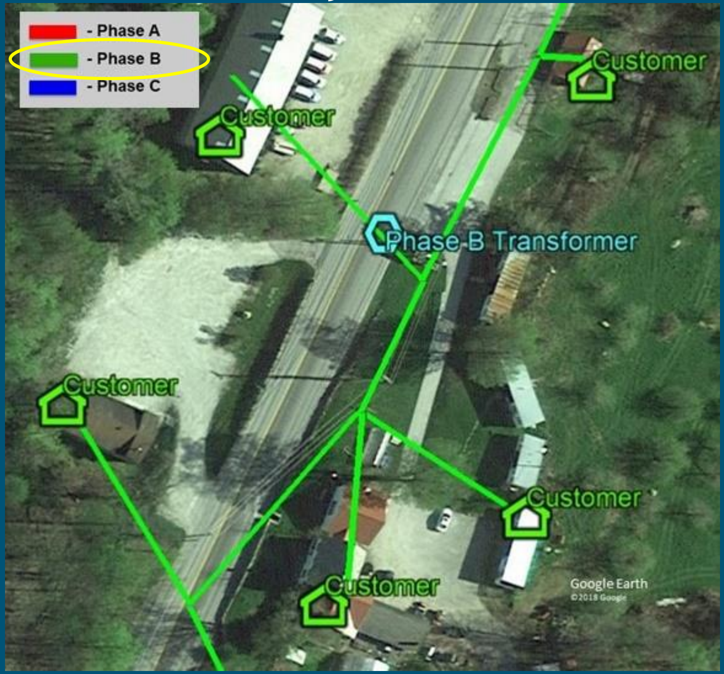


L. Blakely, M. J. Reno and W. Feng, "**Spectral Clustering for Customer Phase Identification Using AMI Voltage Timeseries**," 2019 IEEE Power and Energy Conference at Illinois (PECI), Champaign, IL, USA, 2019, pp. 1-7.
doi: 10.1109/PECI.2019.8698780
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8698780&isnumber=8698776

Phase Identification

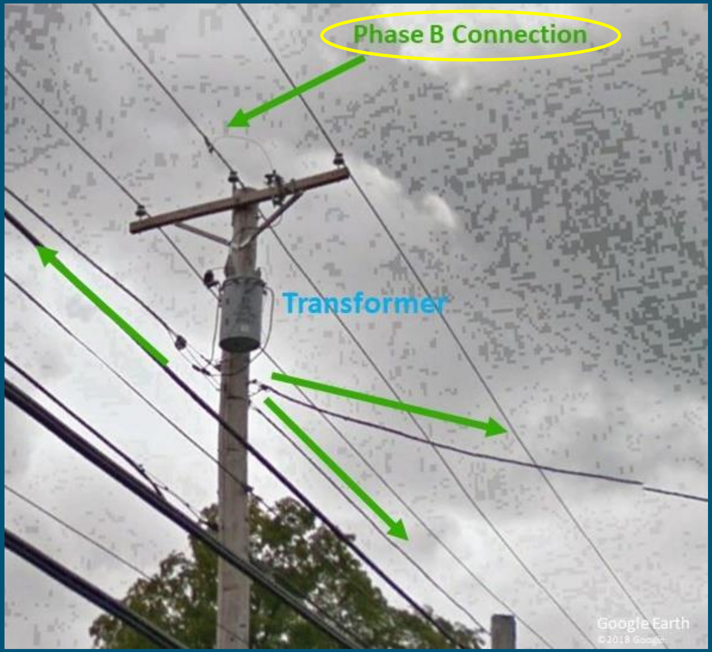
May confirm utility model:

Utility Model



Phase Identification: Phase B

Street View



Utility Model	Phase Identification	Street View
Phase B ✓	Phase B ✓	Phase B ✓

Phase Identification

Or may correct model:

Utility Model

Phase Identification: Phase B

Utility Model

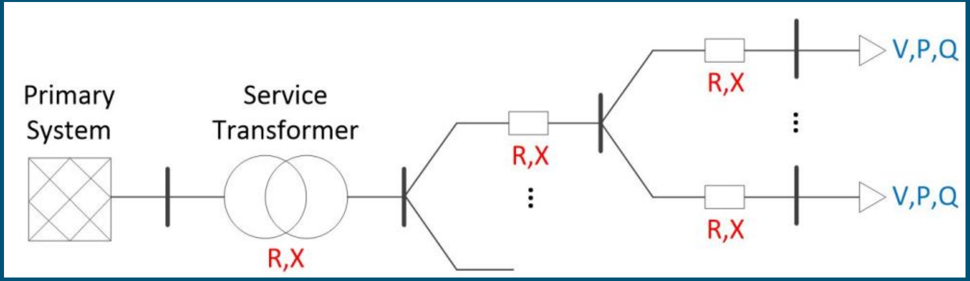
Utility Model	Phase Identification	Street View
Phase C ×	Phase B ✓	Phase B ✓

Topology and Parameter Estimation

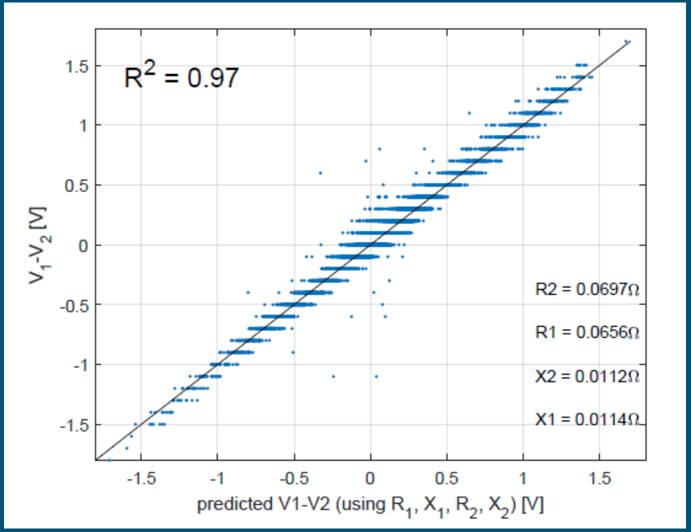
Use AMI voltage and power measurements to derive secondary system topology and impedances.

$$V_1 - V_2 = I_{R1}R_1 + I_{X1}X_1 + I_{R2}R_2 + I_{X2}X_2 + \epsilon$$

Known Unknown



Linear regression to find R1, R2, X1, X2 values which best fit the V1-V2 fluctuations

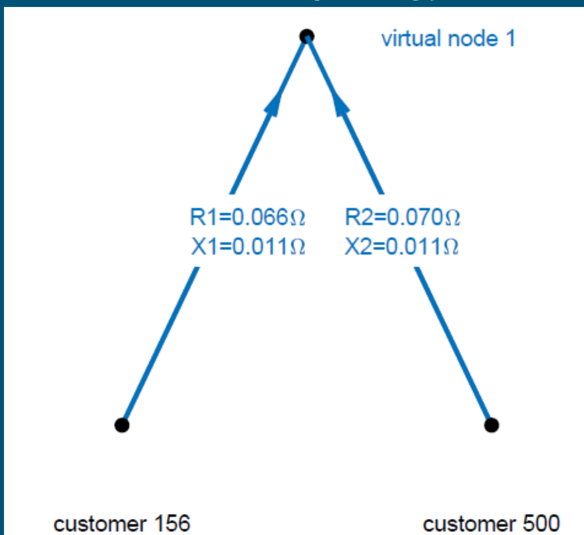


M. Lave, M. J. Reno and J. Peppanen, "**Distribution System Parameter and Topology Estimation Applied to Resolve Low-Voltage Circuits on Three Real Distribution Feeders,**" in *IEEE Transactions on Sustainable Energy*.
doi: 10.1109/TSTE.2019.2917679
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8718261&isnumber=5433168

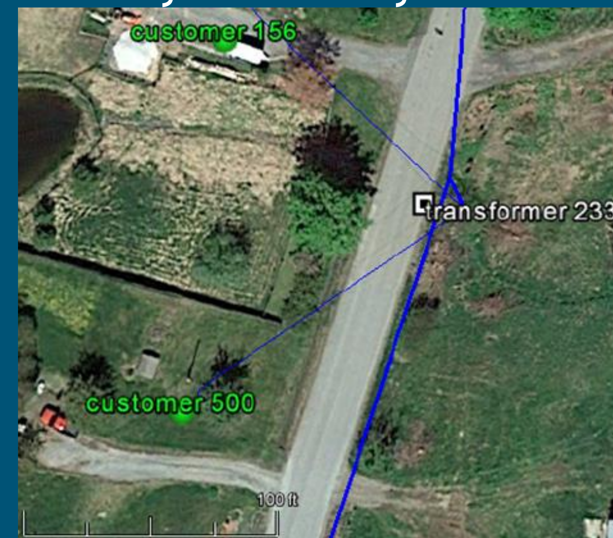
Topology and Parameter Estimation

Topology and parameter estimation (DSPE) matched well with the (good) utility secondary model.

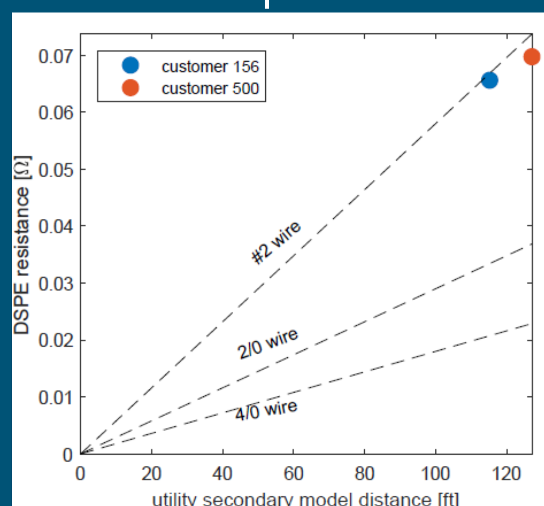
Parameter/Topology Est.



Utility Secondary Model



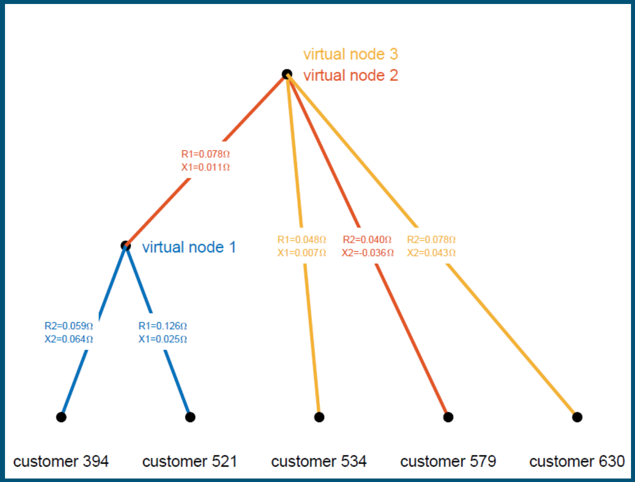
Comparison



Topology and Parameter Estimation

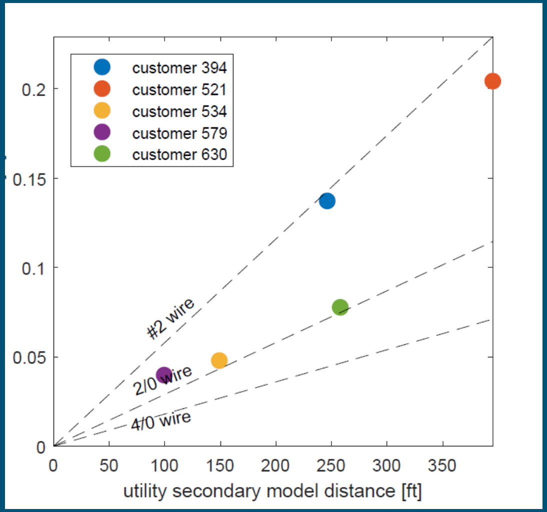
Topology and parameter estimation (DSPE) matched well with the (good) utility secondary model, even for complicated topologies.

Parameter/Topology Est.



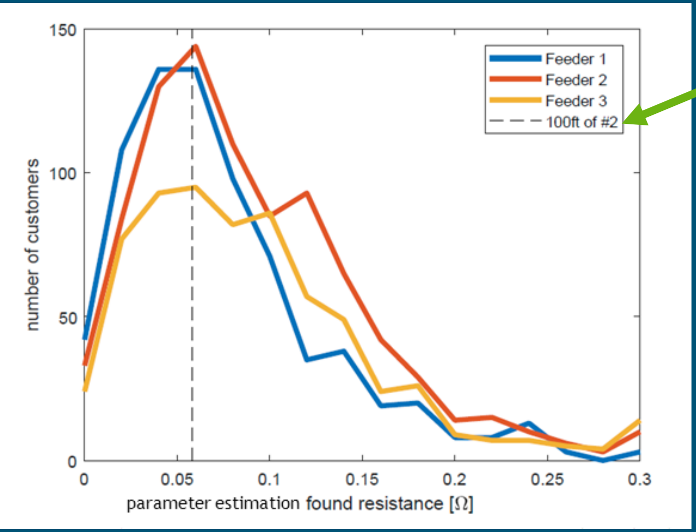
Utility Secondary Model

Comparison

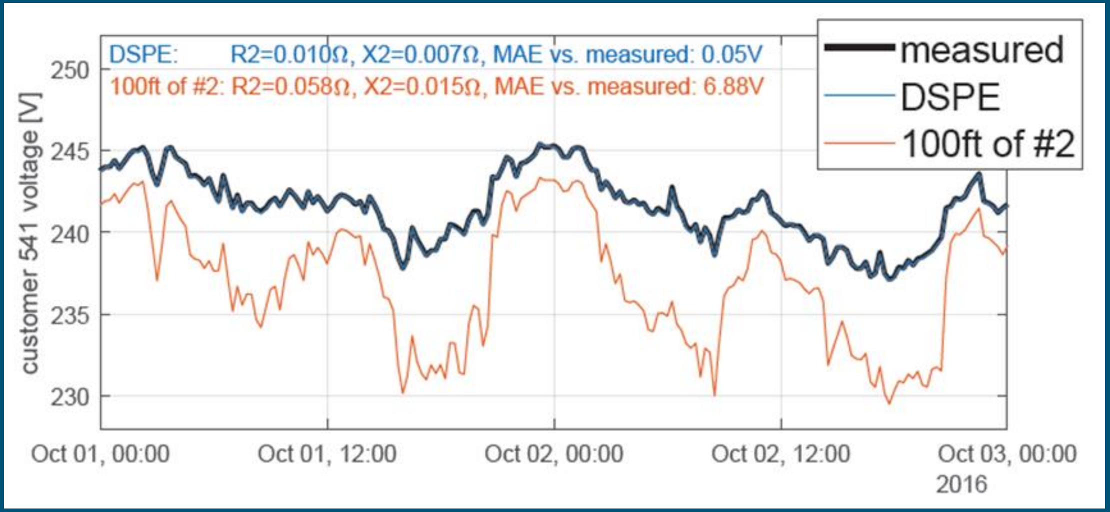


Topology and Parameter Estimation

For bad or nonexistent utility secondary models (common), topology and parameter estimation can be used to develop a high-fidelity secondary model.

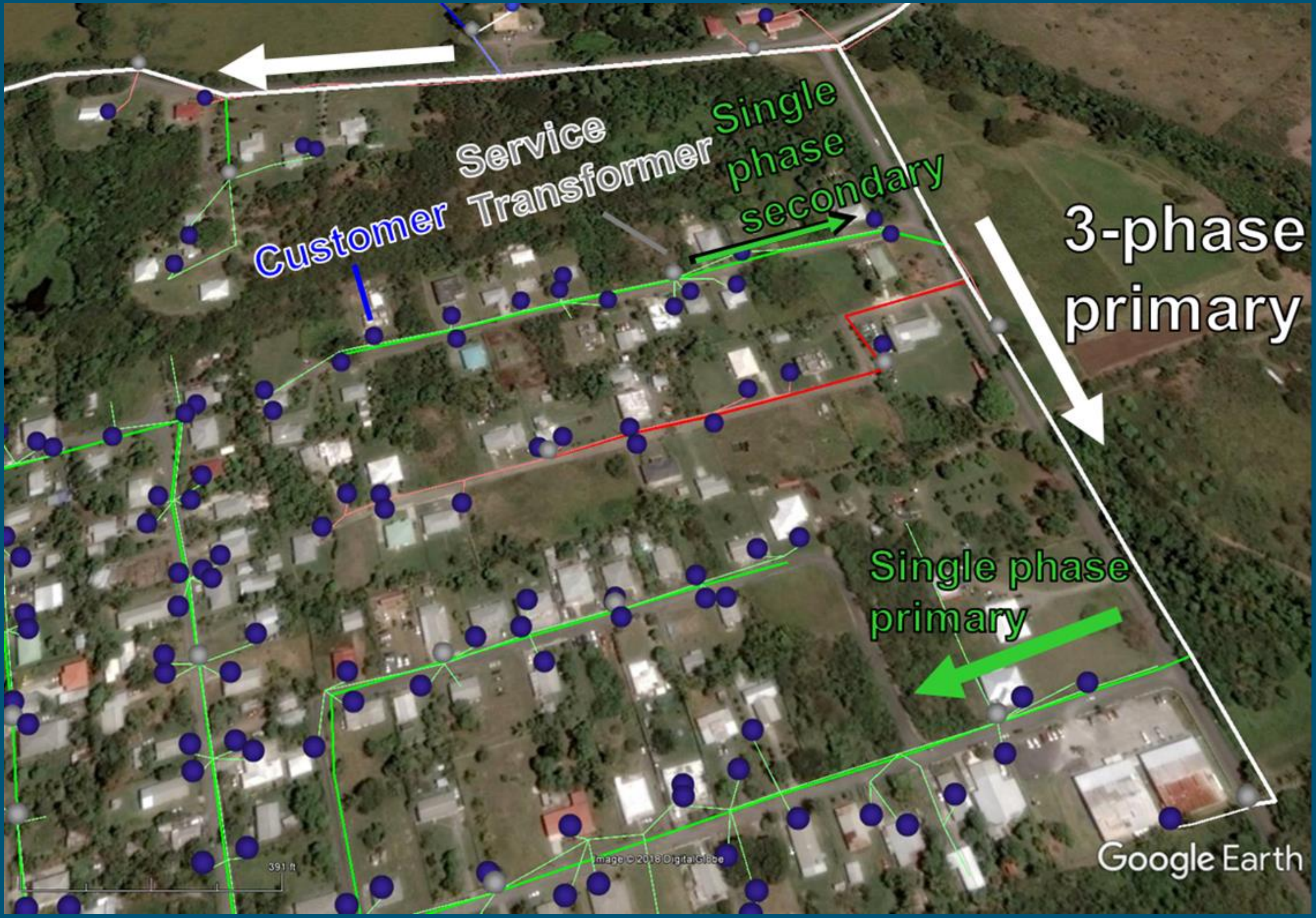


Common assumption when no secondary model



Result of Granular Modeling

Detailed and verified utility secondary model.

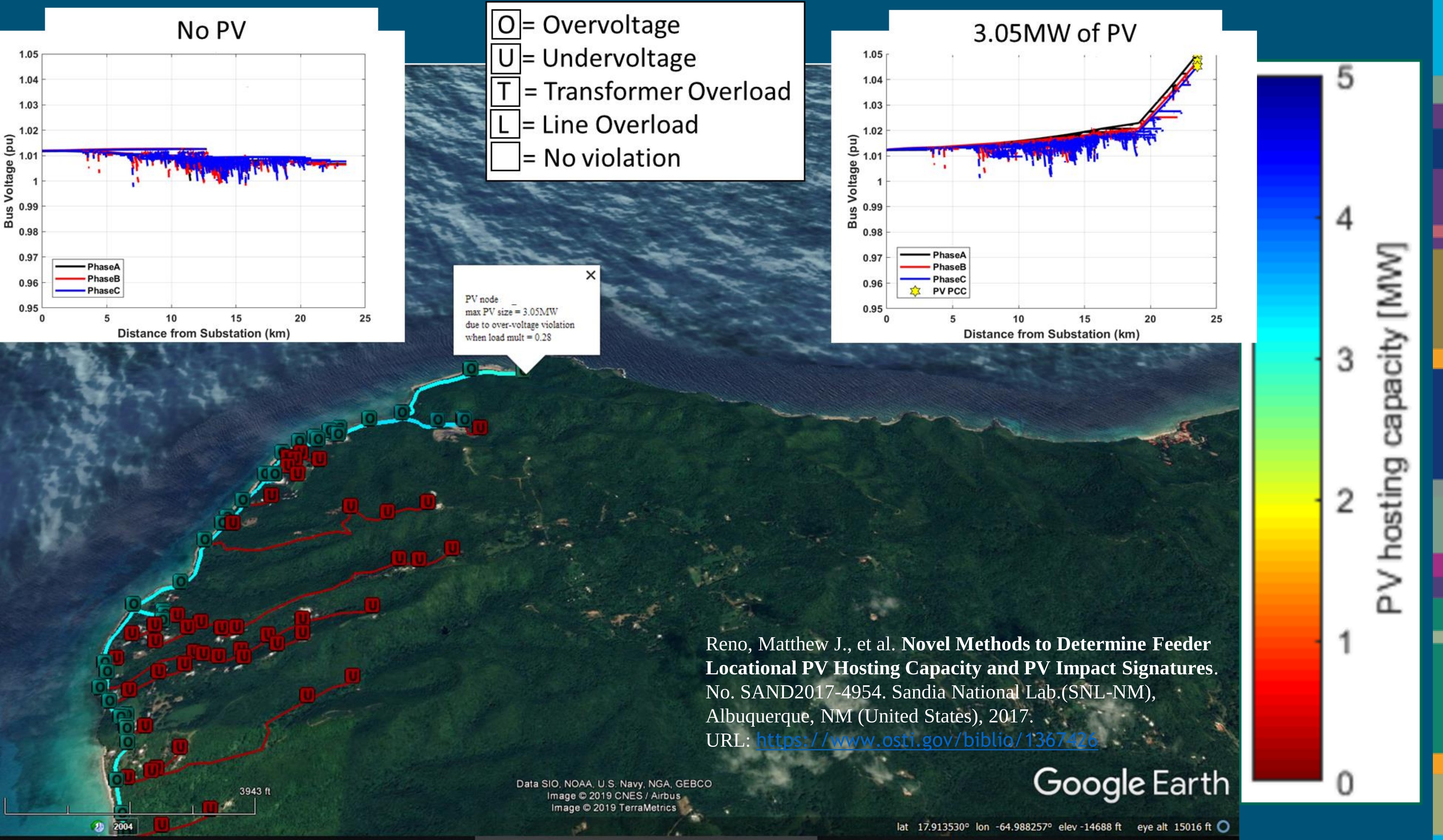


Detailed Locational Impact Analysis

- Locational hosting capacity
- Synthetic Cloud Fields

Locational Hosting Capacity

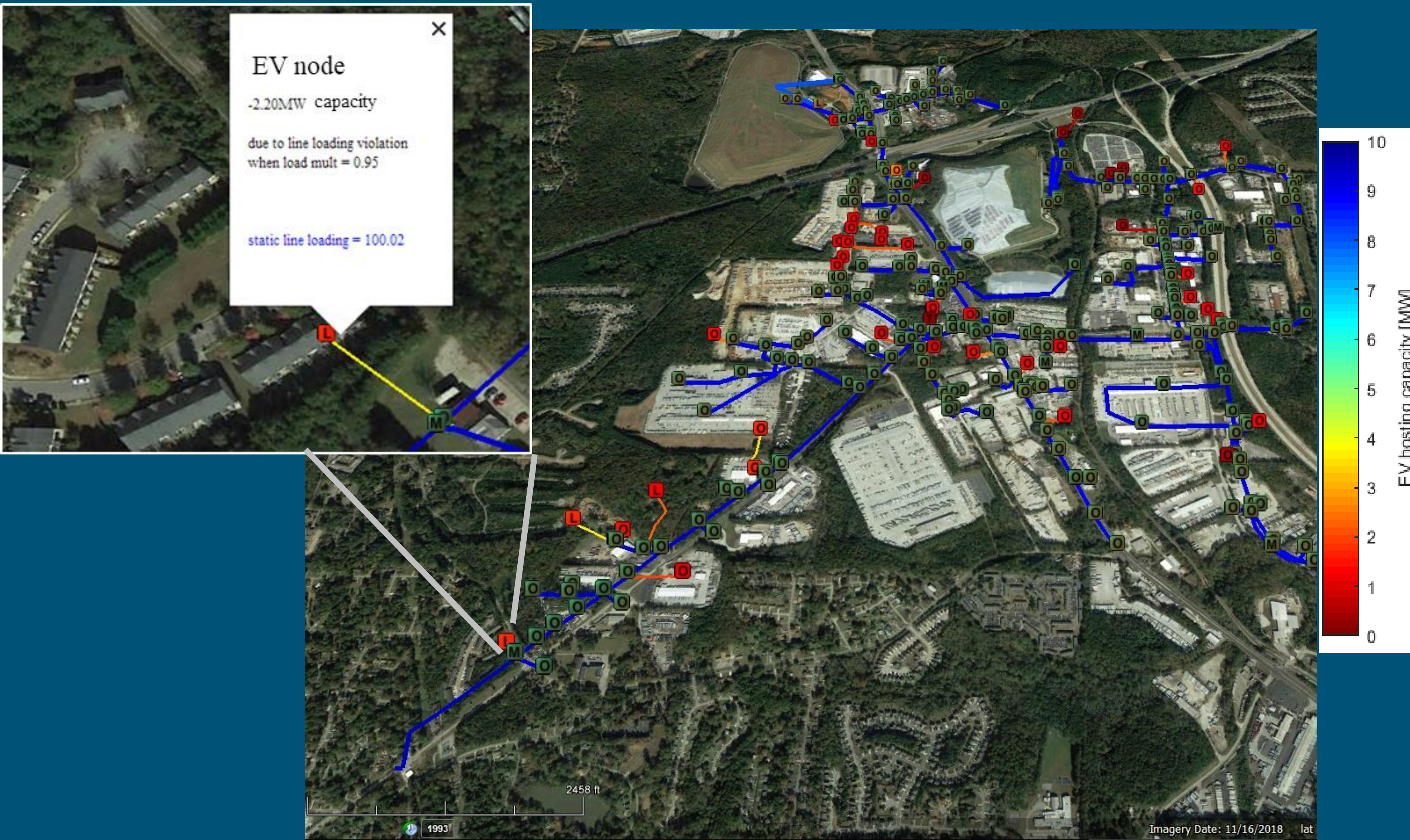
Concept –add more and more PV at a single node until it causes a problem – voltage, line loading, or transformer loading. The largest amount of PV that does not cause a problem is the locational hosting capacity.



Reno, Matthew J., et al. **Novel Methods to Determine Feeder Locational PV Hosting Capacity and PV Impact Signatures**. No. SAND2017-4954. Sandia National Lab.(SNL-NM), Albuquerque, NM (United States), 2017.
URL: https://www.osti.gov/biblio/1367426

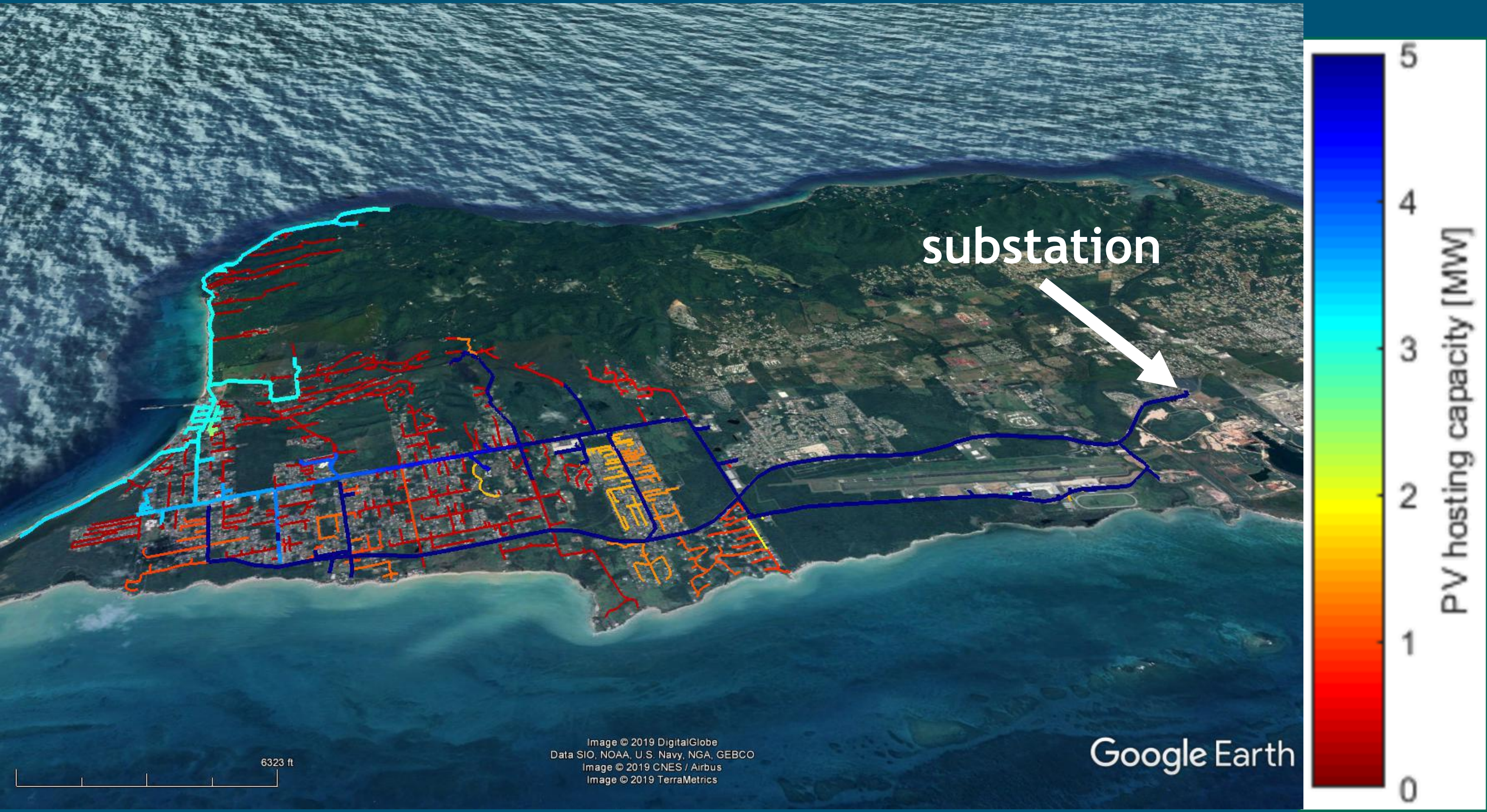
Locational Hosting Capacity

Can also apply to electric vehicles – for EVs, line loading, transformer loading, or under voltage may be more common (EVs are essentially additional loads).



Locational Hosting Capacity

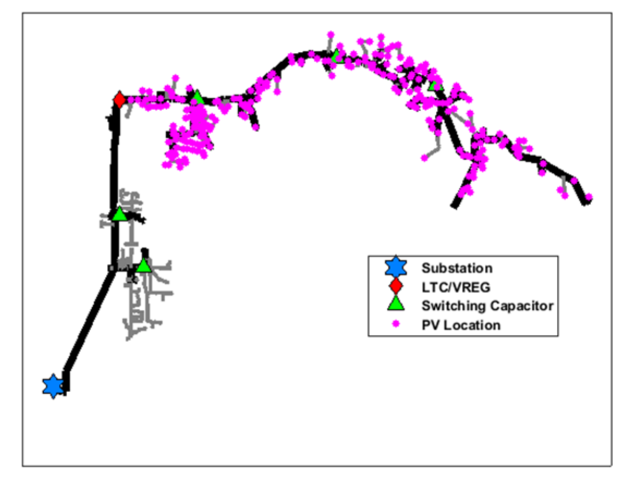
Can be applied to facilitate interconnection requests across a feeder.



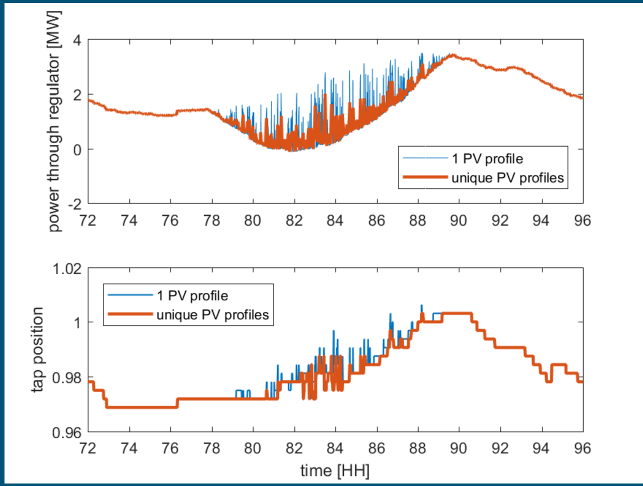
Synthetic Cloud Fields

Modeling many PV interconnections on a feeder is difficult: usually only 1 (or no) solar irradiance measurement available near a feeder.

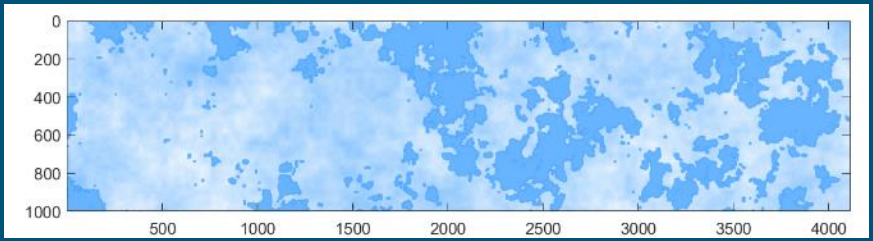
Challenge

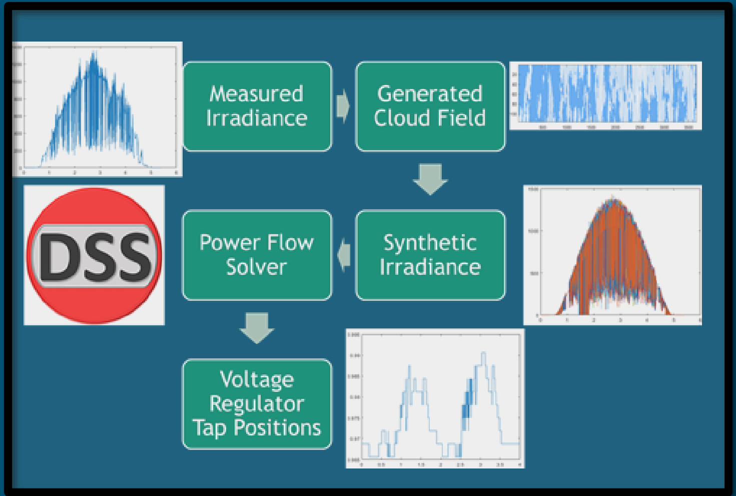


Impact



Solution: synthetic cloud fields

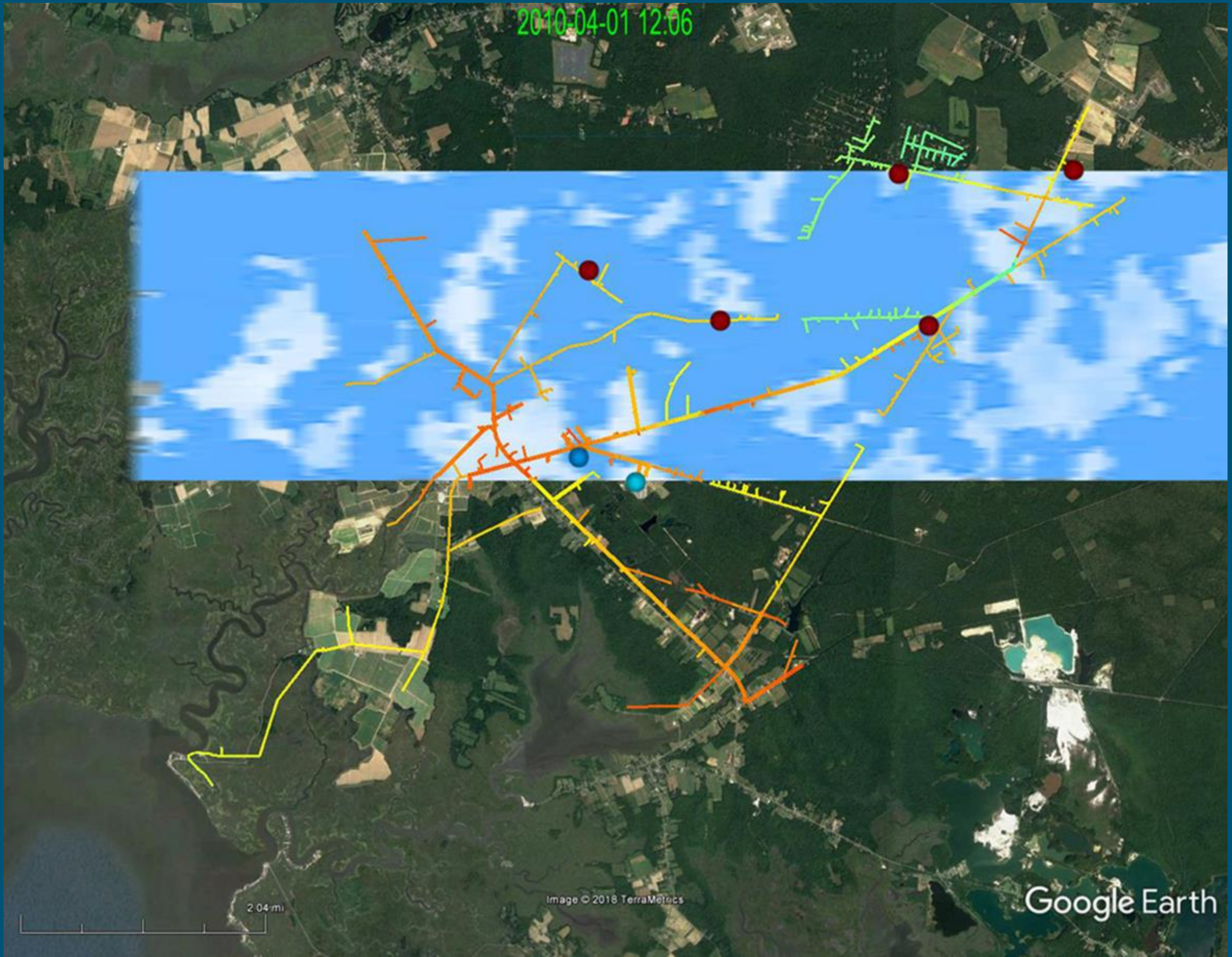




Lave, Matthew Samuel, Matthew J. Reno, and Robert Joseph Broderick. **Creation and Value of Synthetic High-Frequency Solar Simulations for Distribution System QSTS Simulations.** No. SAND2017-5646C.
URL: https://www.osti.gov/servlets/purl/1458093

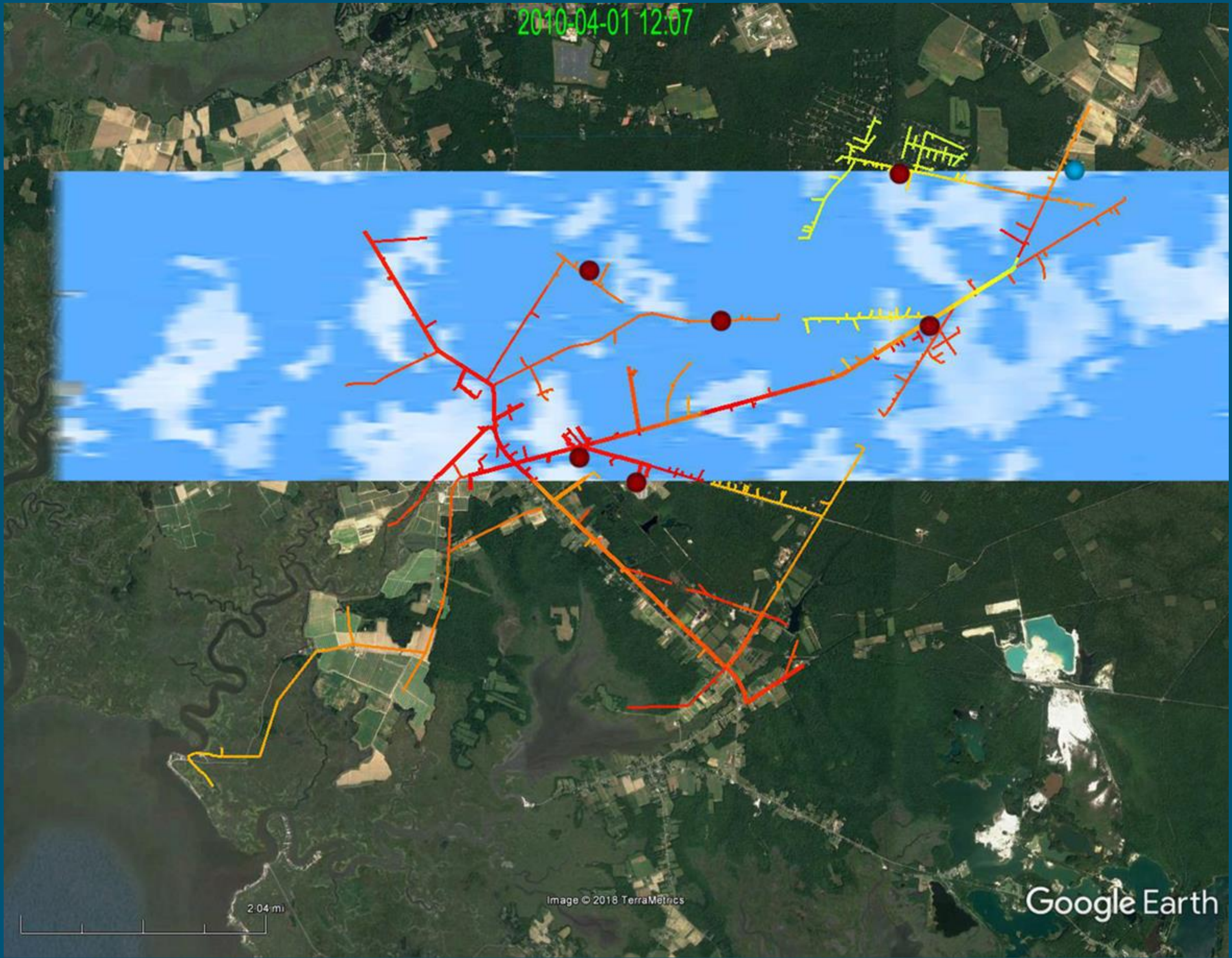
Synthetic Cloud Fields

Synthetic PV used as input to OpenDSS to find voltage profile.



Synthetic Cloud Fields

Synthetic PV used as input to OpenDSS to find voltage profile.



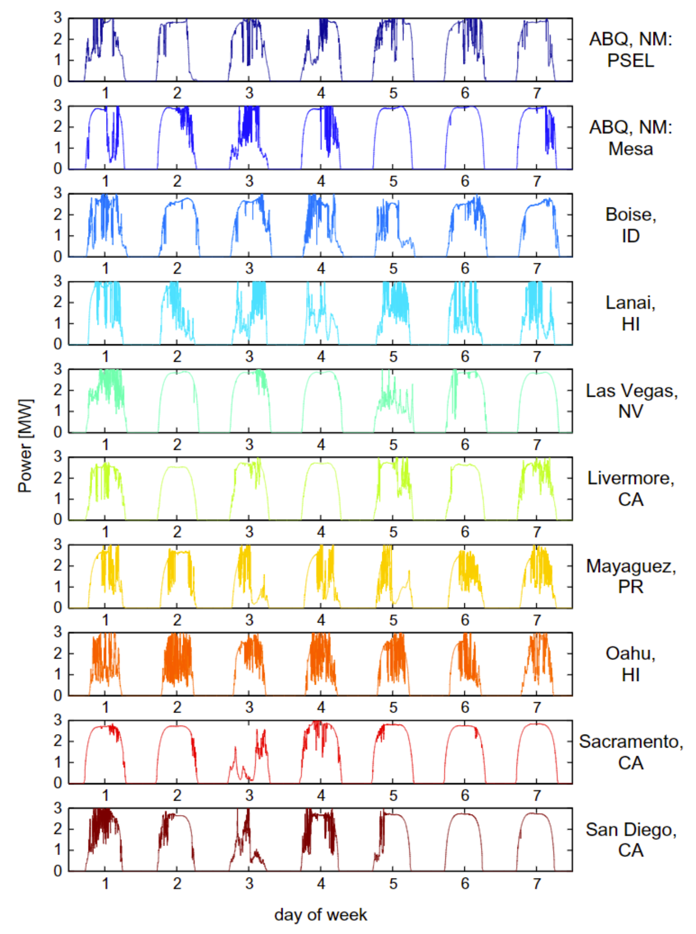
Long-Term Timeseries Analysis

- Daily/seasonal variability in generation and impact to grid operations
- Rapid QSTS

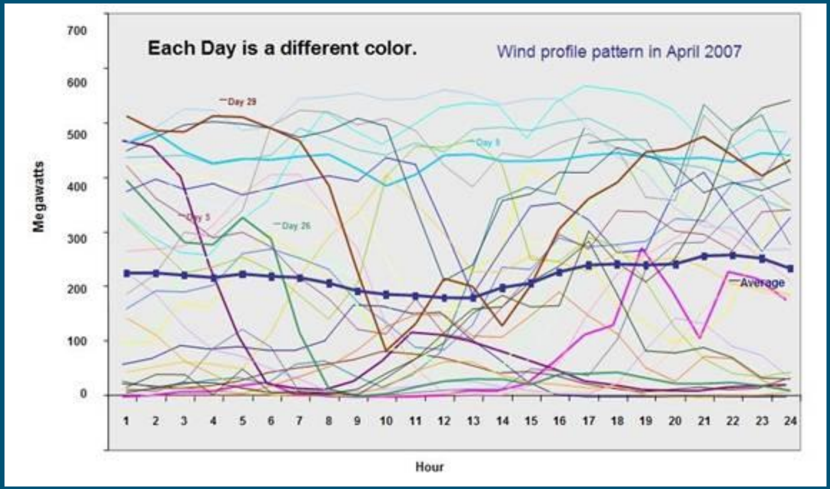
Variability in Generation and Impact to Distribution Grid

Many DERs have variable output that is not controlled by the grid operator.

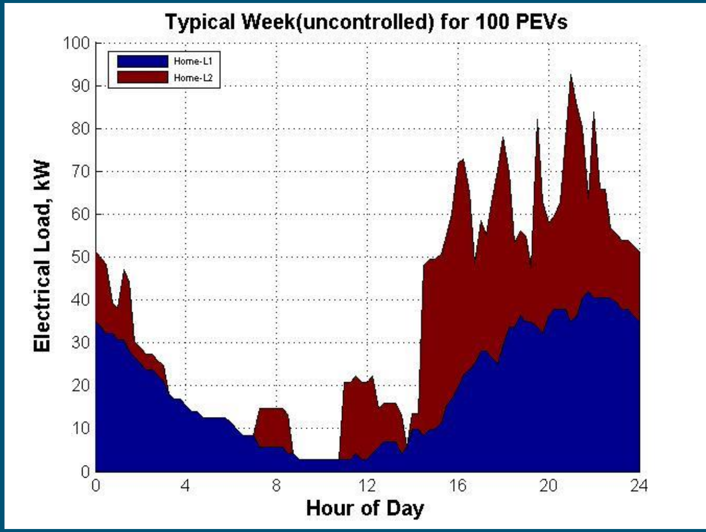
Solar



Wind

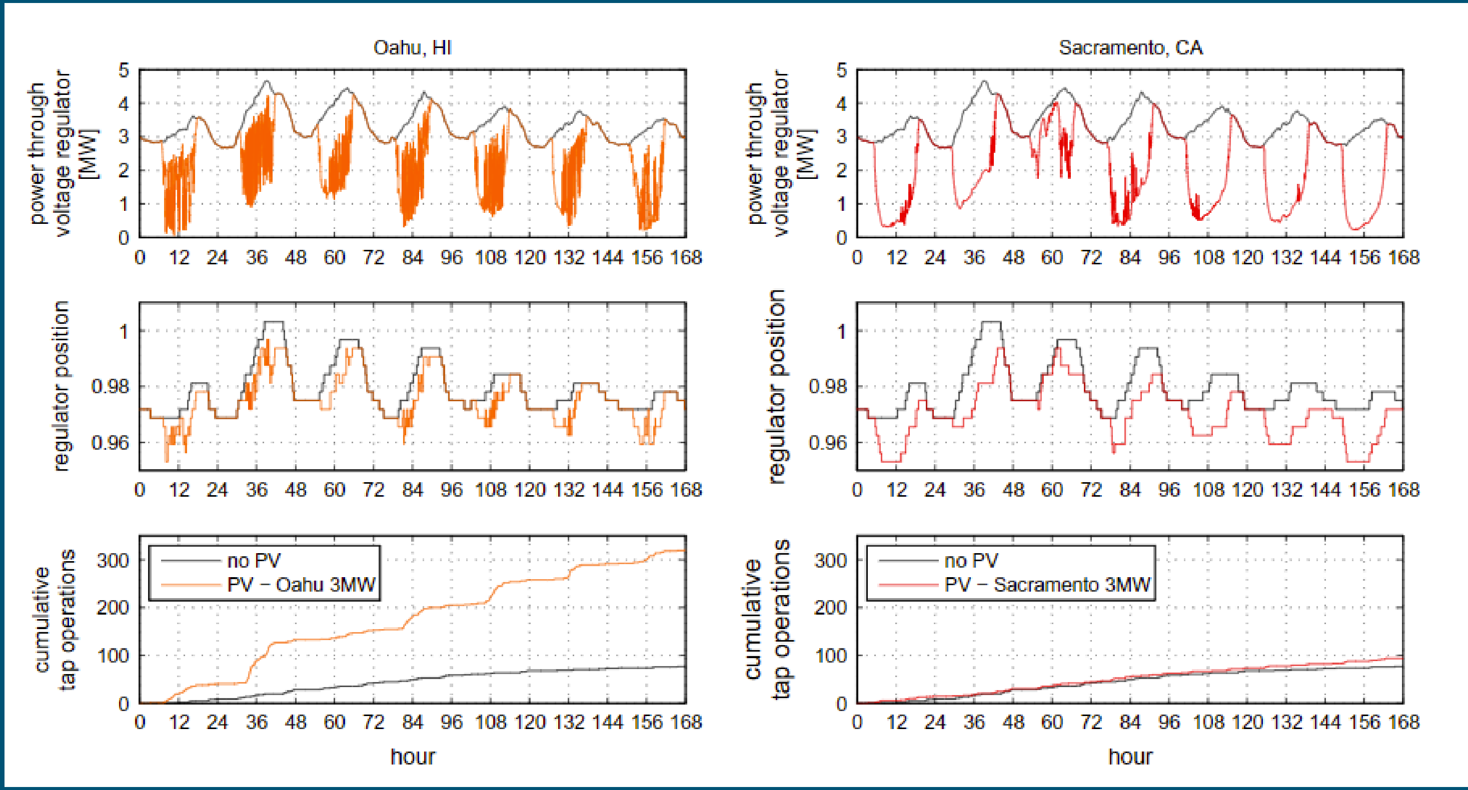


EVs



Variability in Generation and Impact to Distribution Grid

Timeseries analysis shows temporal impacts (e.g., voltage regulator tap change operations), and allows for full consideration of daily/seasonal trends.



Lave, Matthew, Matthew J. Reno, and Robert J. Broderick. **"Characterizing local high-frequency solar variability and its impact to distribution studies."** Solar Energy 118 (2015): 327-337. URL: https://www.sciencedirect.com/science/article/pii/S0038092X15002881

Rapid QSTS

Speed up Quasi-Static Time Series (QSTS) analysis to enable running 1-year distribution grid simulations on a desktop computer.

Time taken by QSTS:

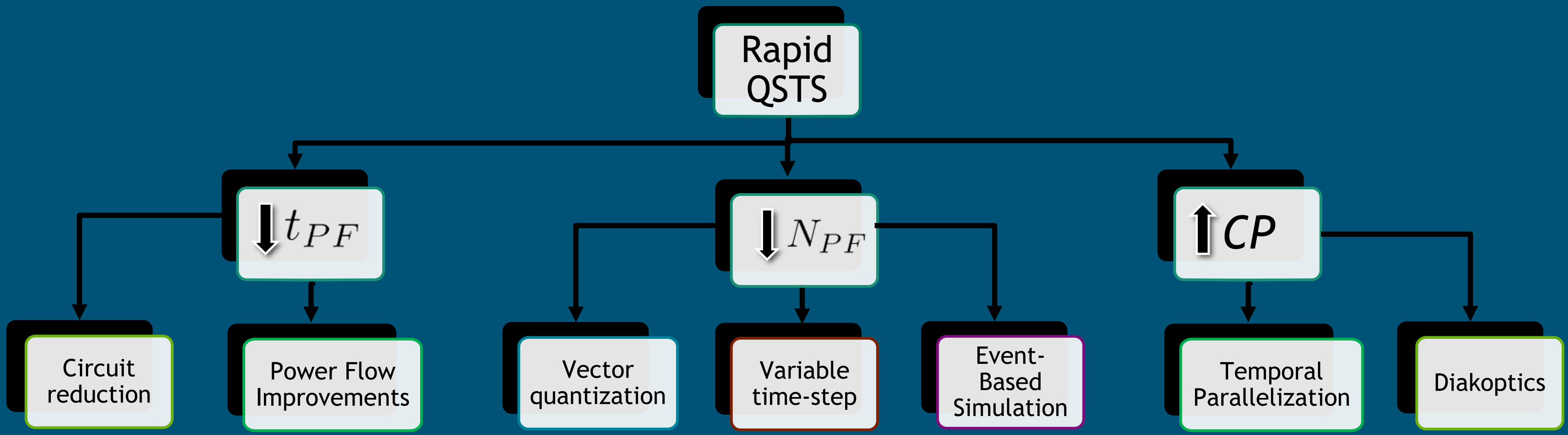
$$t_{sol} = \frac{t_{PF} * N_{PF}}{CP}$$

Time taken by a single PF

Total PFs solved

Computational Power

Reno, Matthew J. **Rapid QSTS Simulations for High-Resolution Comprehensive Assessment of Distributed PV**. No. SAND2018-3899C. URL:https://www.osti.gov/servlets/purl/1507939



Rapid QSTS

Speed up Quasi-Static Time Series (QSTS) analysis to enable running 1-year distribution grid simulations on a desktop computer.

	Extreme Voltages	Thermal Loading	Regulators Tap Changes	Capacitor Switching	Time outside ANSI	Losses	Computation Time[1]
Snapshot	Good	Good	-	-	-	-	<1 sec
Hourly Timeseries	Great	Great	-	-	Good	Great	5 sec
1 day QSTS	Poor	Poor	Decent	Decent	Poor	Poor	5 minutes
1 year QSTS	Great	Great	Great	Great	Great	Great	36 hours
New Rapid QSTS Algorithms	Great	Great	Great	Great	Great	Great	30 sec

Concluding thoughts

- Historic methods (snapshot, no secondary, limited measurements) are insufficient.
- AMI data and other grid edge sensing provide opportunities for deriving and validating system models.
- Developments in modeling methods are simultaneously enabling more accurate distribution grid modeling and faster simulations.
- Upcoming: "QSTS hosting capacity" will simultaneously consider locational and temporal impacts of DER integration.