Sandia National Laboratories

# Machine Learning of Distribution System Planning Models

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Sandia National Laboratories

IEEE PES General Meeting
Panel: “Deep Learning for Power System Operation and Planning”

IEEE PES Power & Energy Society®

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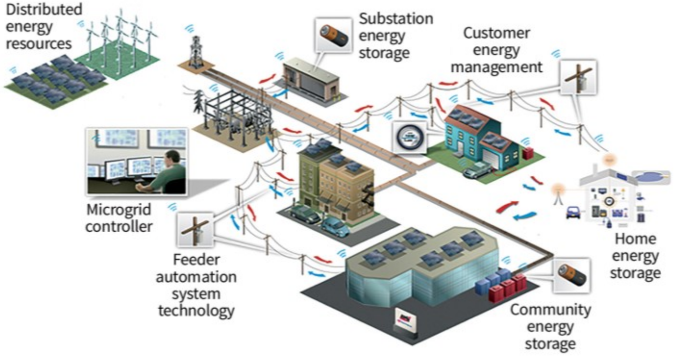
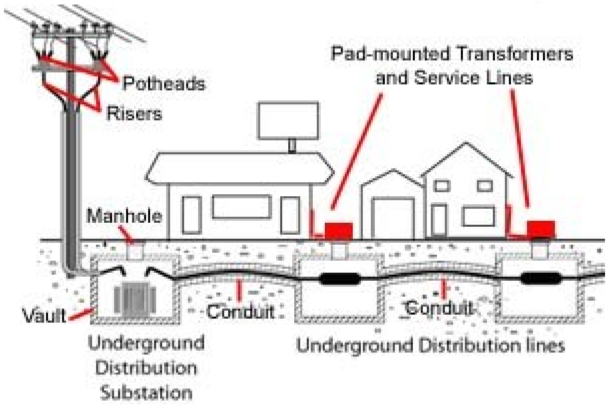
# Electric Power Distribution Systems

- Historically, distribution system model accuracy was of little concern, rarely validated, and had limited measurements.
- Many of the recent advances in smart grid technologies, proliferation of distributed energy resources (DER), and new control strategies are on the distribution system – electric vehicles, rooftop PV, energy storage, microgrids, etc.
- With new smart grid technologies, accurate models are critical
  - Accurate PV interconnection analysis and screening
  - Optimal operations and control
  - Investment planning and decisions
  - Improved reliability and resilience (fault location, isolation, and service restoration)
- Modern distribution system algorithms and tools are continually improving, but their functionality is only as good as the utility's model of their grid.



# Common Distribution System Model Errors

- **System State and Setting Errors**
  - State of switches
  - Capacitor States
  - Voltage Regulator Settings
  - Switching Capacitor Settings
- **Phase Label Errors**
  - Individual transformer phase label error
  - Lateral Phase Label Error
  - Three-phase Customer Labeled as Single-Phase
  - Single-phase Customer Labeled as Three-phase
- **Data Missing From the Model**
  - Missing or Incorrect GIS coordinates
  - Unmarked Transformers
  - Unmarked PV Installations
  - Unmetered Load
- **PV Installations**
  - PV kW Rating
  - Tilt
  - Azimuth
  - Volt/VAr Settings
  - Connection (LN or LL)
  - Connect or Disconnect Dates
- **Meter Configuration**
  - PT or CT Ratios
  - Units (kW vs MW)
  - Time Zone
  - Measurement Location
  - Collection Type (time-avg vs instantaneous)
- **Model Parameters**
  - Wire types and Lengths
  - Overhead Line Configuration
  - Underground Cable Insulation
  - Transformer Rating, connection, or Turns Ratio
  - Substation Short Circuit Impedance
  - Meter to Transformer Connection Errors
- **Equipment Addition or Replacement**
  - New Home Construction
  - Reconductoring of Lines
  - New Voltage Regulation Equipment
  - Service Transformer Replacement

L. Blakely, M. J. Reno, and J. Peppanen, “Identifying Common Errors in Distribution System Models,” IEEE Photovoltaic Specialists Conference (PVSC). 2019.

# Project Overview

- DOE EERE Solar Energy Technologies Office (SETO) funded project "Physics-Based Data-Driven Grid Modelling to Accelerate Accurate PV Integration"
  - Physics-based – using known electrical equations and models that work with today's power systems simulation software (not black box)
- FY19 - FY21 project to efficiently process grid measurements and Big Data to provide a more granular understanding of the distribution system and to substantially increase the precision and accuracy of distribution system models – creating a fundamental change from models based on manual entry to data-driven modeling.
- Project led by Sandia National Labs, partnering with Lawrence Livermore National Laboratory, Electric Power Research Institute, Georgia Tech, and CYME/Eaton

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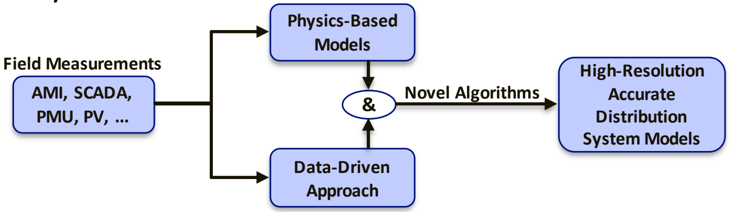


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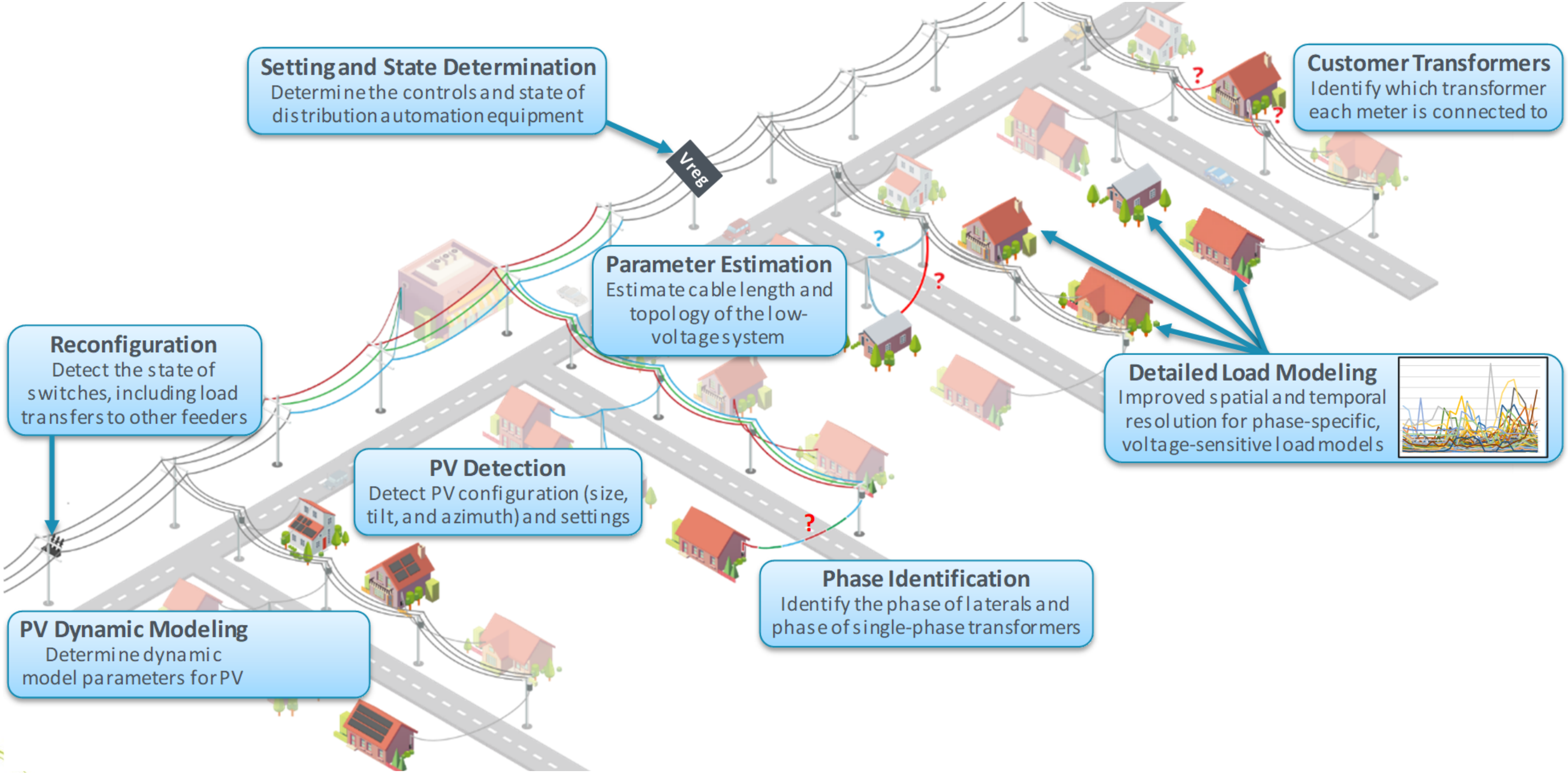
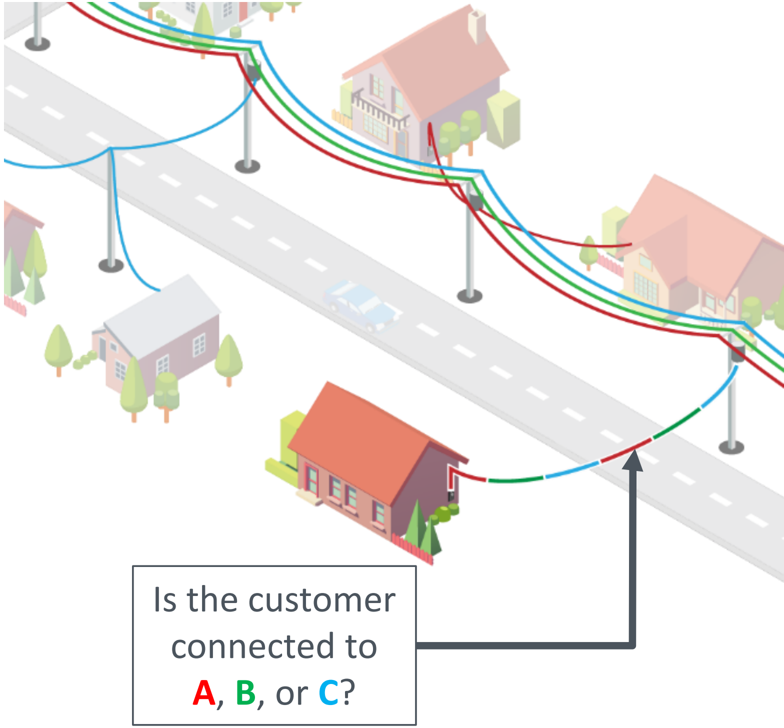
# Data-Driven Distribution Model Calibration



# ML for Model Calibration – Phase Identification

- **Motivation**: For distribution system planning and operations, especially with high penetrations of DER, accurate multi-phase distribution models are important, but utility models often have many errors
  - Customer transformer phase connections
  - Single-phase laterals connected to different phases
- **Problem**: Manually calibrating using PhaseTrakkers is time consuming
- **Objective**: Use machine learning and Big Data from grid edge measurements to identify the phase of each customer
- **Hypothesis**: If customer voltage timeseries are correlated, they are likely to be on the same phase

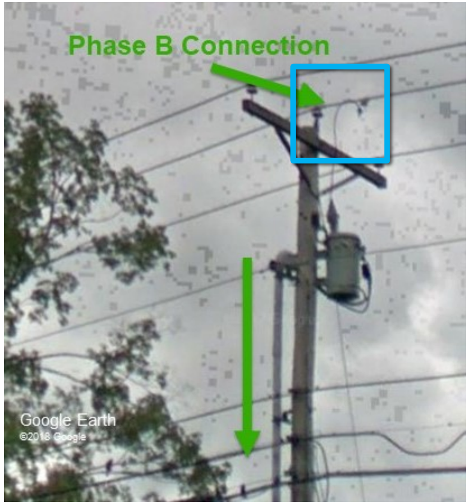


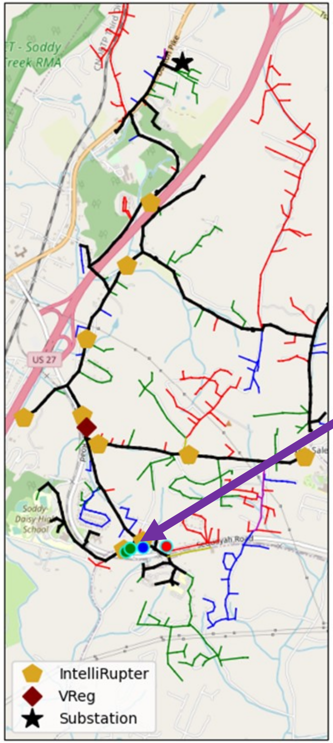


- F. Therrien, L. Blakely, and M. J. Reno, "Assessment of Measurement-Based Phase Identification Methods," IEEE Open Access Journal of Power and Energy, 2021.
- L. Blakely and M. J. Reno, "Phase Identification Using Affinity Matrix Ensemble Clustering," IET Smart Grid, 2020.
- L. Blakely, M. J. Reno, and W. Feng, "Spectral Clustering for Customer Phase Identification Using AMI Voltage Timeseries," Power and Energy Conference at Illinois (PECI), 2019.

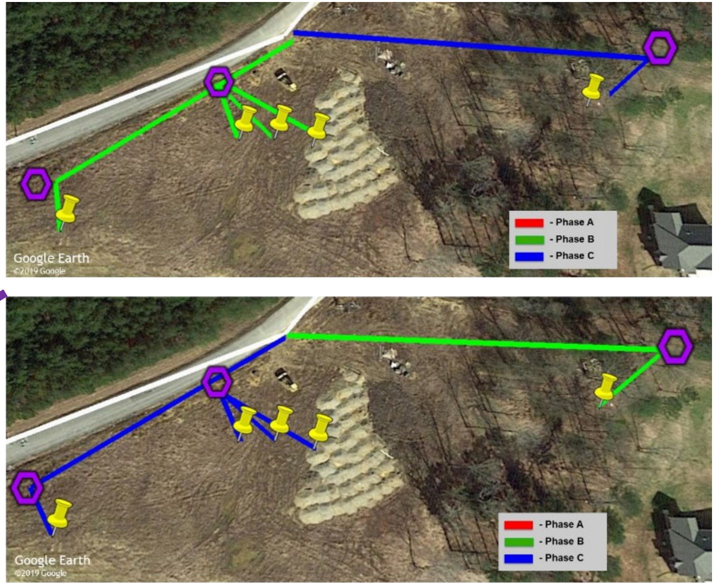
# ML for Model Calibration – Phase Identification

**Results**: The Sandia algorithm was implemented with our utility partner into their system. Utility performed field verification by sending crew out to several feeders – 100% accuracy track record so far!



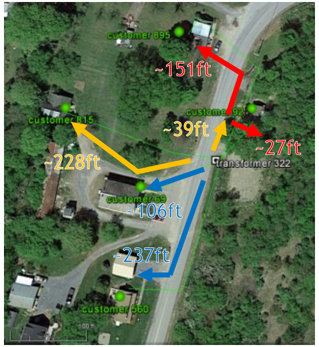

**In the two laterals shown below, the phase labels were switched**



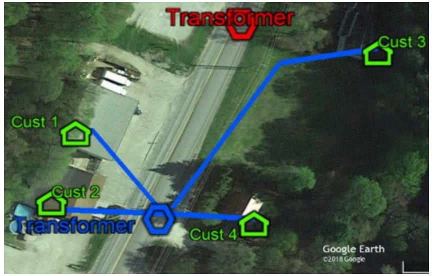

- L. Blakely, M. J. Reno, C. B. Jones, A. Furlani-Bastos, D. Nordy, "Leveraging Additional Sensors for Phase Identification in Systems with Voltage Regulators," IEEE Power and Energy Conference at Illinois, 2021.

# Secondary System Parameter and Topology Estimation

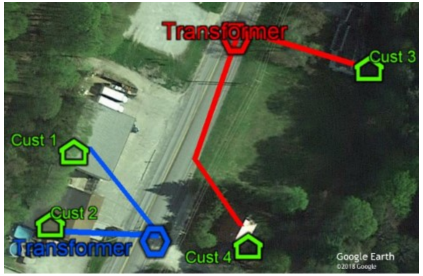
- **Background**: Multiple customers are generally connected through a service transformer and a low-voltage secondary system
- **Problem**: Secondary circuits are typically not modeled or modeled with limited detail. Manual inspections require considerable man hours, and may be hard to perform in urban areas with wiring underground and in buildings
- **Approach**: Use customer meter (AMI) voltage and power measurement to resolve secondary system parameters and topology
- **Results**: ML can determine which transformer customers are connected to, and determine the cable length with accuracy of a few feet.

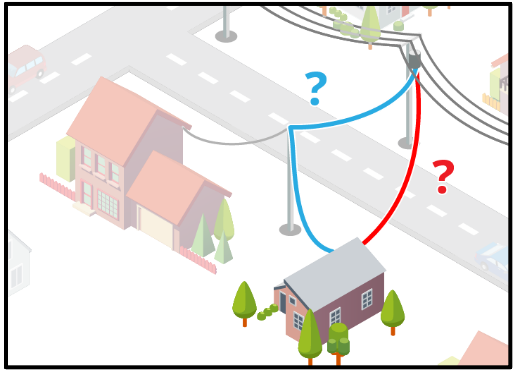


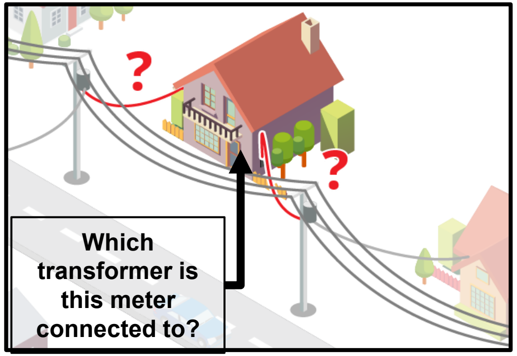

Original Model




Predicted and Actual Connection





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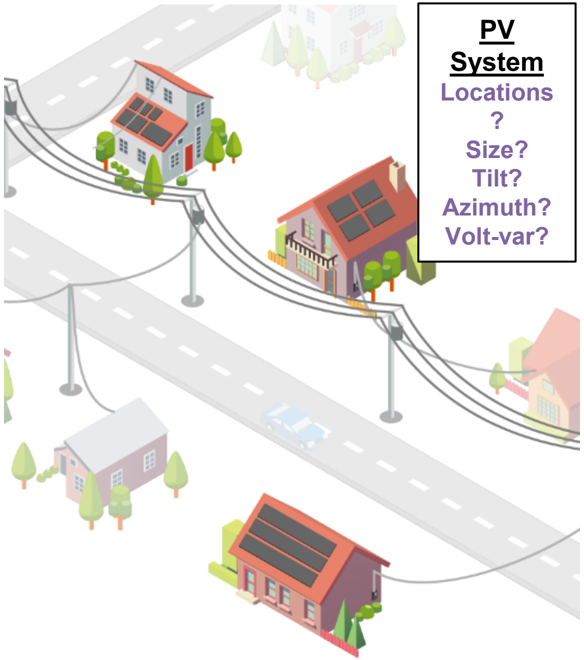
- K. Ashok, M. J. Reno, D. Divan, "Secondary Network Parameter Estimation for Distribution Transformers," IEEE Innovative Smart Grid Technologies (ISGT), 2020.
- L. Blakely and M. J. Reno, "Identification and Correction of Errors in Pairing AMI Meters and Transformers," IEEE Power and Energy Conference at Illinois (PECI), 2021

# PV System Identification

- **Background**: PV systems may vary from the interconnection plan - not interconnected, project delayed, changed size, shading issues, gradual soiling, or module/string failures
- **Problem**: Keeping PV interconnection databases updated is a major challenge. Many utilities do not record parameters for distributed PV such as their DC power rating, tilt, or azimuth. Residential solar PV systems are generally behind-the-meter (BTM), lacking direct measurements or observability.
- **Approach**: For BTM PV, solar disaggregation methods can separate the PV from the load measurements. Deep Neural Network used to learn the signature of BTM PV to detect if there is PV, along with its size, tilt, and azimuth.
- **Results**: ML accurately identifies PV locations, size, tilt, and azimuth of the system. Even without measurements from dedicated sensors for the PV, ML can determine inverter controls, such as volt-var.



**PV System**
Locations?
Size?
Tilt?
Azimuth?
Volt-var?


- K. Mason, M. J. Reno, L. Blakely, S. Vejdan, and S. Grijalva, "A Deep Learning Approach for Residential PV Size, Tilt and Azimuth Estimation," Solar Energy, 2020.
- S. Grijalva, A. U. Khan, J. S. Mbeleg, C. Gomez-Peces, M. J. Reno, L. Blakely, "Estimation of PV Location in Distribution Systems based on Voltage Sensitivities," IEEE North American Power Symposium, 2021.
- C. Gomez-Peces, S. Grijalva, M. J. Reno, and L. Blakely, "Estimation of PV Location based on Voltage Sensitivities in Distribution Systems with Discrete Voltage Regulation Equipment," IEEE PowerTech, 2021
- S. Talkington, S. Grijalva, and M. J. Reno, "Estimation of DER Power Factor Using Voltage Magnitude Measurements" Journal of Modern Power Systems and Clean Energy, 2021.

# QUESTIONS?

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