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# Data-Driven Grid Integration of PV

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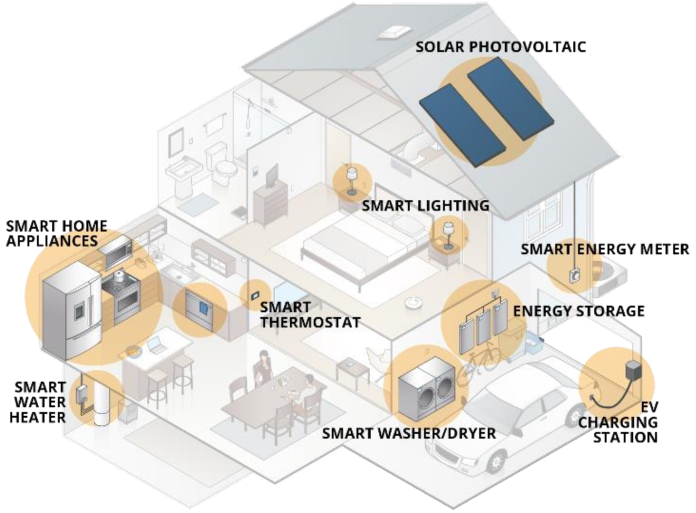
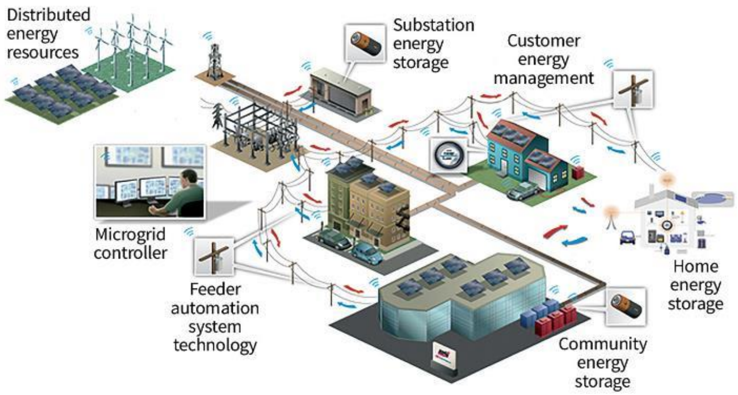
# Introduction

- Distributed Energy Resource (DER) integration is reliant on 1) data, 2) power system models, and 3) software tools for planning or implementing controls
- Recent additions of Advanced Metering Infrastructure (AMI), or smart meters, provide measurements of each customer's power consumption, and possibly other quantities, such as voltage and reactive power
  - Brings new opportunities and new challenges
  - What does this mean for integration of DER?
- The distribution system is getting more complicated with the proliferation of DER, and new control strategies applied to the distribution system with participation from electric vehicles, rooftop PV, energy storage, microgrids, etc.
- Power Systems—and specifically distribution systems— are a perfect application for Machine Learning due to their complexity and large amounts of data




**How do we leverage sensor data for rapid and reliable integration of DER into the distribution system?**

# Practical Considerations for Real Data

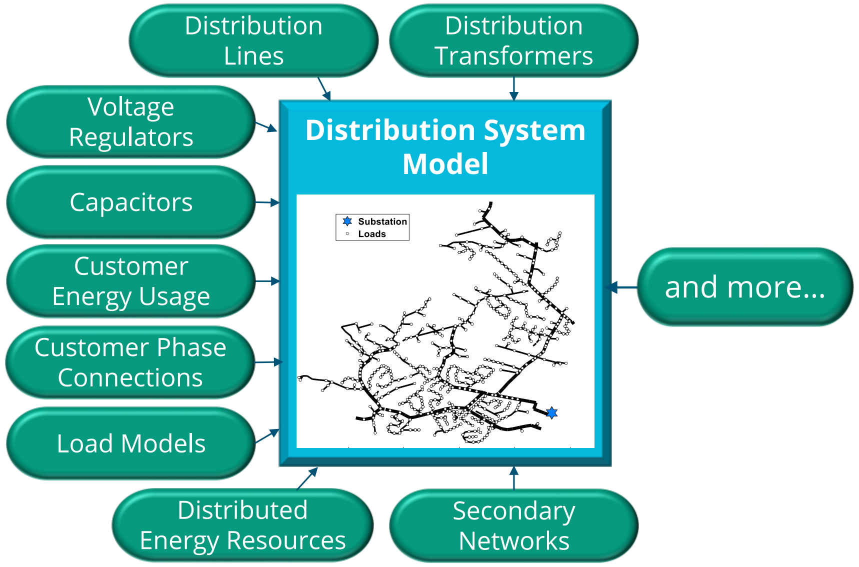


Data includes both real-time measurements and grid parameters

- System measurements include things like SCADA, AMI, and phasor measurement unit (PMU) data that are constantly streaming and updating. Issues incorporating these data streams include:
  - Data quality issues such as missing data
  - Big data problems for storing and accessing (many utilities have not updated their database structures, which makes data queries incredibly slow)
  - Communication network constraints
  - Limitations based on initial use (for example AMI that was installed for billing, so many not be useful to real-time applications).
- Grid parameters such as line lengths, transformer impedances, and governor settings do not change as often
  - Challenging to exactly match all the values that are in the field
  - Errors due to manual data entry or unknown estimated values is common

**Other Data Quality Issues:**

- ❖ Measurement Interval and Time Synchronization
- ❖ Measurement Type (instantaneous vs. average)
- ❖ Meter Resolution (decimals)
- ❖ Measurement Noise
- ❖ Missing Data
- ❖ Erroneous Data
- ❖ Calibration or Installation Errors



# Using Data for Analyzing DER Interconnections

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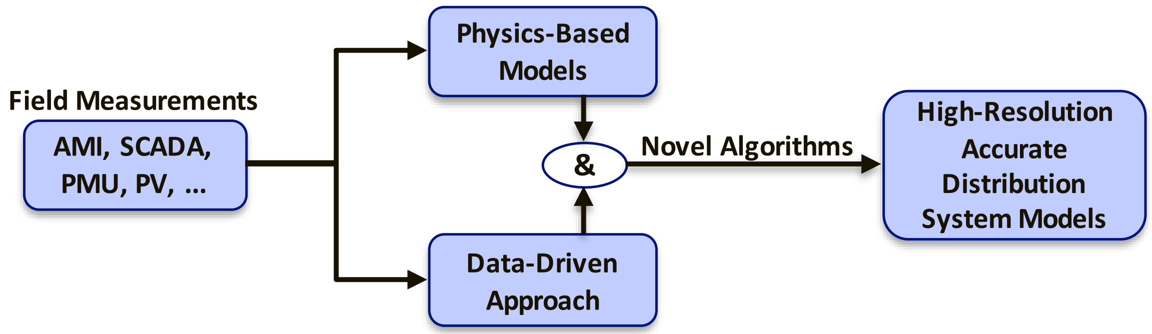
- For improved DER interconnection planning and control, we need new tools that will incorporate data into the physics-based models
- We can now move well beyond conventional static peak load DER studies to include historical feeder data and detailed models of DER controls and expected behavior

Use Cases Presented Today:

- Data-driven model calibration
- Algorithm scaling challenges
- Detecting PV settings and mis-operations
- Model-free hosting capacity analysis



# Distribution Modeling Methods

## Conventional Methods

- Manual data entry – compiling records of installations, upgrades, and maintenance over decades
- Prone to errors – unlogged or erroneous maintenance reports or entry into the model
- Little validation with measurements
- Often out of date with a list of changes to add to the model

## Physics-Based Data-Driven Modeling

- Leveraging AMI data and other grid edge sensing to derive and validate system models
- High accuracy and fidelity – a reproduction faithful to the original
- Granular and high resolution, multi-phase model down to the low-voltage system
- Model dynamically adapts and automatically updates based on system conditions

Key Takeaway: **Conventional distribution modeling methods are no longer sufficient for high penetrations of DER**

# Data-Driven Model Calibration

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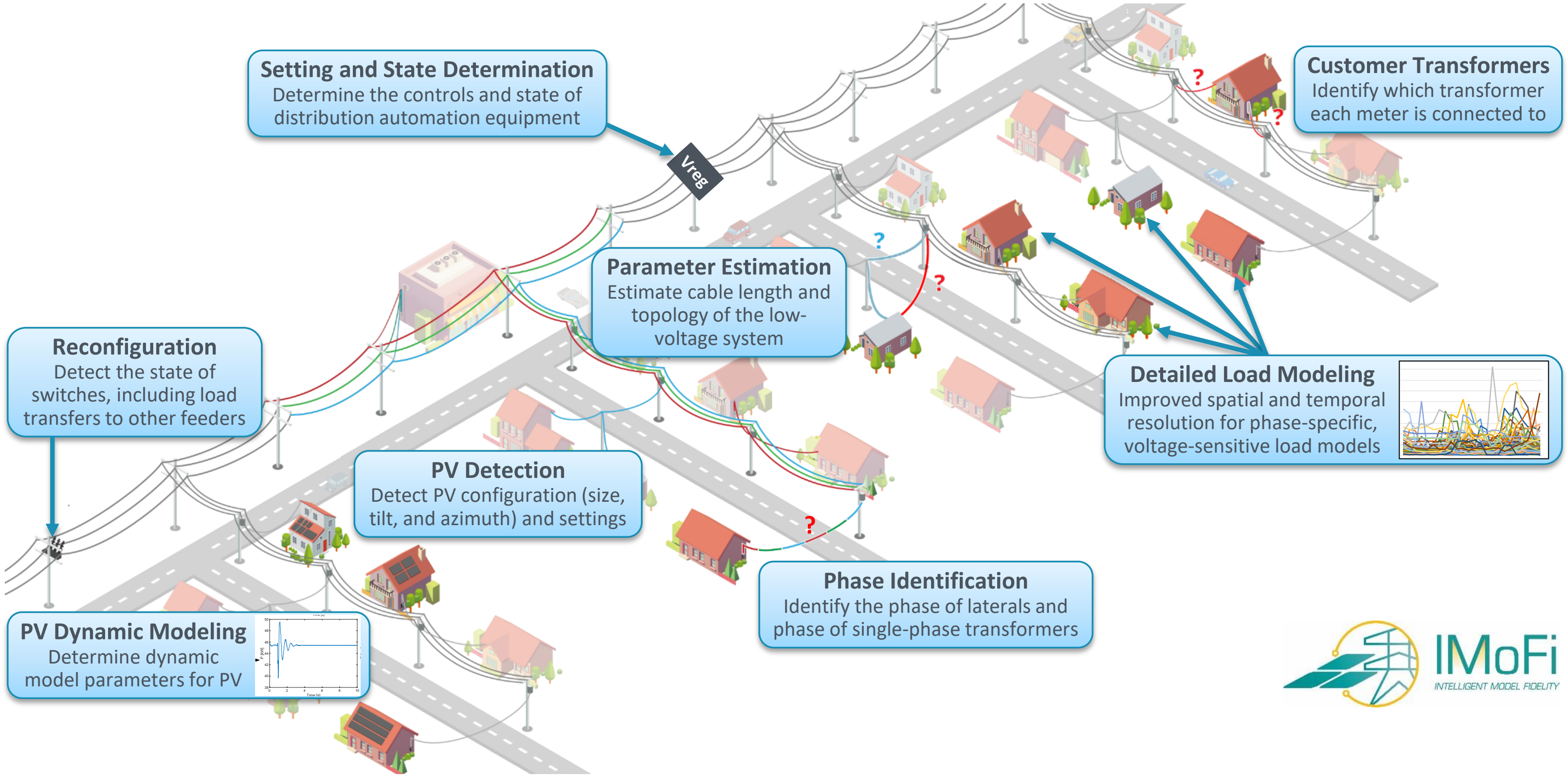
- **Challenge** – Modern distribution analysis algorithms and tools are continually improving (hosting capacity analysis, QSTS, and DERMS) but use feeder models based on manual data entry that is prone to error and often out of date with little validation or calibration
- **Need** – Models that provide a more granular understanding of the distribution system and substantially increase the precision and accuracy of planning and operation tools
- **Solution** – Use sensors and historical measurements through the distribution system, combined with physics-based machine learning, to detect modeling errors and calibrate parameters




IMoFi INTELLIGENT MODEL FIDELITY

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# Implementing Phase Identification

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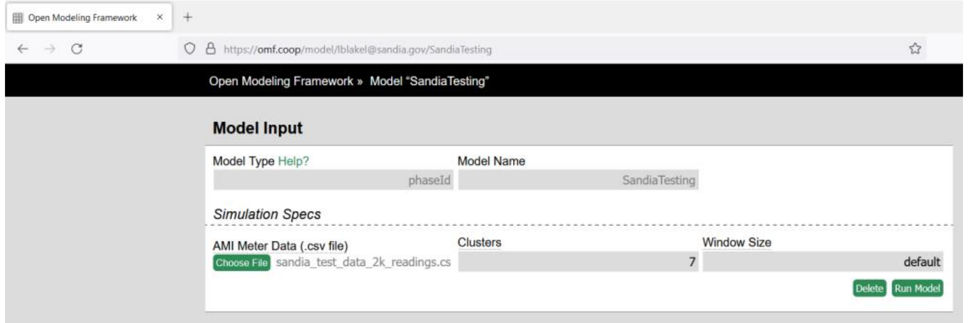
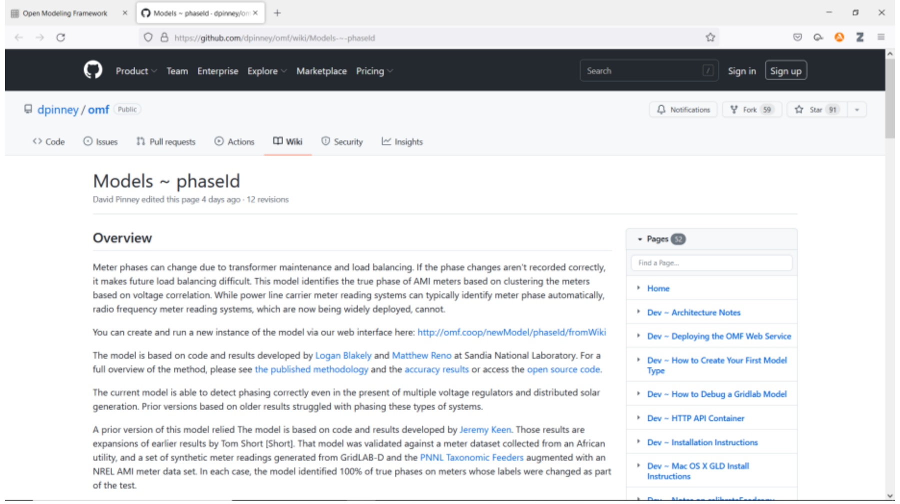
- **Need** – Data-driven algorithms need to be accessible by the stakeholders
- **Challenge** – Algorithm implementation interfaces and real-world data problems
  - Input checking (parameters and data)
  - Database infrastructure and query speed
  - Data issues – missing data, meter resolution, customers on wrong feeder, changing meter/customer numbers
  - Field verification is difficult, especially underground areas and areas with a large number of meters
  - Uncertainty quantification for confidence in predictions is key
- **Solution** – Phase identification algorithms have been implemented with NRECA in the Open Modeling Framework (OMF) at [http://omf.coop](http://omf.coop), and working with a utility to get it directly into their operational software

**Phase Identification Dashboard Interface**




**Phase Identification Wiki in the open-source github repository for OMF**



# Simulation vs. Measured Data

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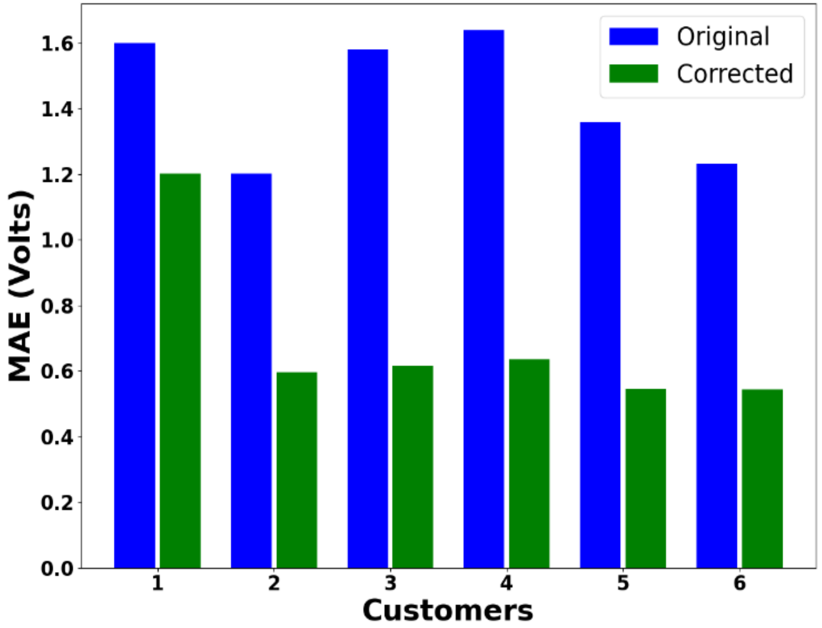
- What are the quantifiable benefits of correcting errors in the distribution system model?
- Comparing measured AMI voltage and estimated AMI voltage
  - Measured Voltage: The collected AMI voltage measurements
  - Estimated Voltage: The voltage measurements estimated by running a QSTS simulation using the distribution system model and the collected AMI power measurements
- Demonstrates the improvements in estimated voltage due to correcting phase labels (~0.75V on average) when doing QSTS simulations for planning, or other purposes
- Shows that there are still opportunities for further improvements to the model




Mean Absolute Error (MAE) for the voltage difference between the measured and simulated voltages at 15-minute resolution over a year

**Provides quantifiable analysis of the impact of improvements to the distribution system model and thus DER planning tasks that use that model**

# Model Errors Impact DER Integration

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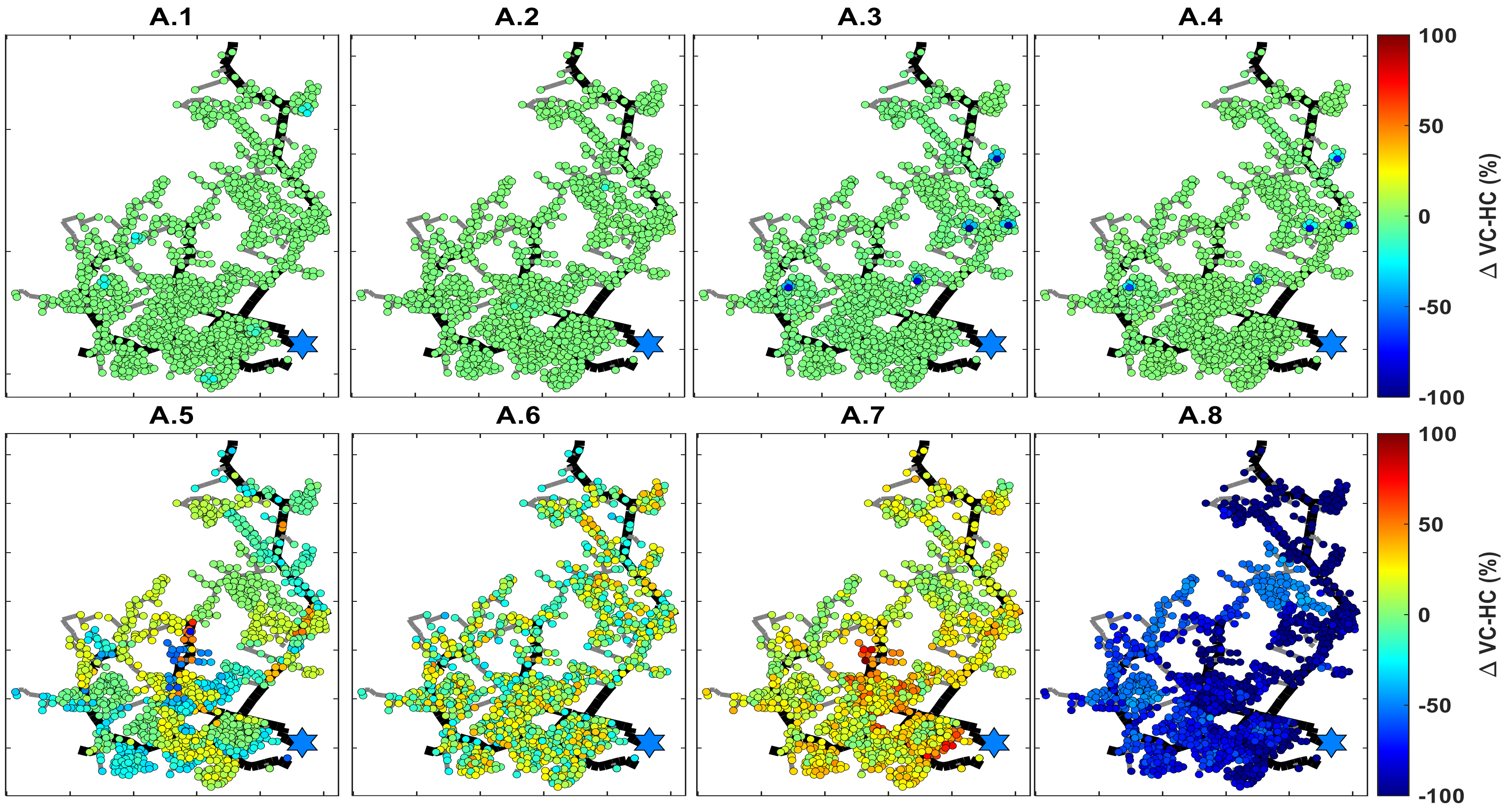
- Errors in the distribution system model that cause small changes to voltage can have significant impacts on hosting capacity
- Below is shown the change in voltage-constrained hosting capacity (VC-HC) for each customer location due to a modeling error



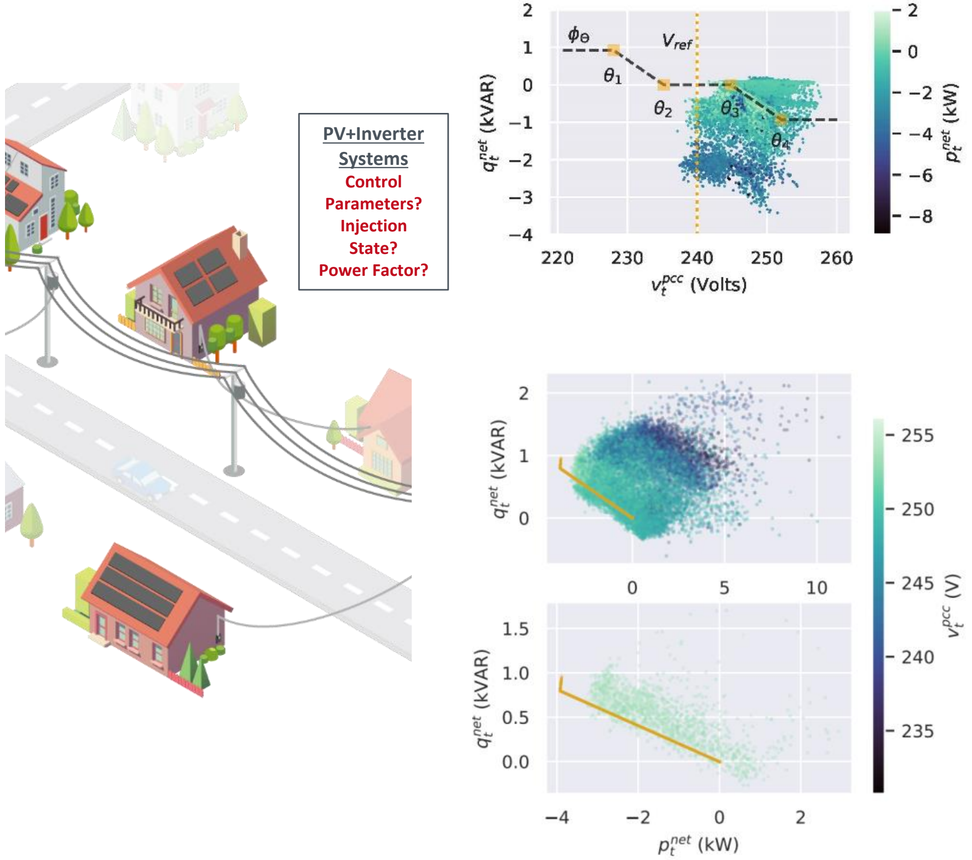

| # | Error Type |
|---|---|
| A.1 | Service Xfmr Size |
| A.2 | Xfmr/Customer Pairing |
| A.3 | Missing Existing PV |
| A.4 | Missing Existing PV w/ Volt-VAR |
| A.5 | Phase Labeling Errors |
| A.6 | Service Line Lengths |
| A.7 | Substation LTC Malfunction |
| A.8 | Capacitor Malfunction |

**Data-driven methods can help to improve the accuracy of DER integration**

J. A. Azzolini, S. Talkington, M. J. Reno, S. Grijalva, L. Blakely, D. Pinney, and S. McHann, “Improving Behind-the-Meter PV Impact Studies with Data-Driven Modeling and Analysis”, IEEE Photovoltaic Specialists Conference (PVSC), 2022.

# Detecting PV Settings and Mis-Operations

- **Challenge** – PV systems may vary from the interconnection plan - not interconnected, project delayed, changed size, shading issues, gradual soiling, or module/string failures.
  - Information for existing PV system may not be known (DC power rating, tilt, or azimuth) and settings like power factor, volt-var, and ride-throughs may change
- **Need** – Methods to keep PV interconnection databases updated and extract parameters for behind-the-meter PV systems that are lacking direct measurements or observability
- **Solution** – For BTM PV, solar disaggregation methods can separate the PV from the load measurements. Machine learning can detect if there is PV, along with size, tilt, azimuth.
  - Identifying advanced inverter control parameters, behavior, and dynamic response characteristics, including any mis-operations that are different than planned





- C. C. Sun, M. Korkali, E. M. Stewart, V. Donde, and M. J. Reno, "Optimization-Based Calibration of Aggregated Dynamic Models for Distributed Energy Resources" IEEE PES General Meeting, 2021.
- S. Talkington, S. Grijalva, M. J. Reno, and J. A. Azzolini, "Solar PV Inverter Reactive Power Disaggregation and Control Setting Estimation", IEEE Transactions on Power Systems, 2022.
- 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.


**Precise detection of BTM PV settings is key under high-penetrations of DER and increasing usage of volt-var control**

# Model-free Hosting Capacity Analysis

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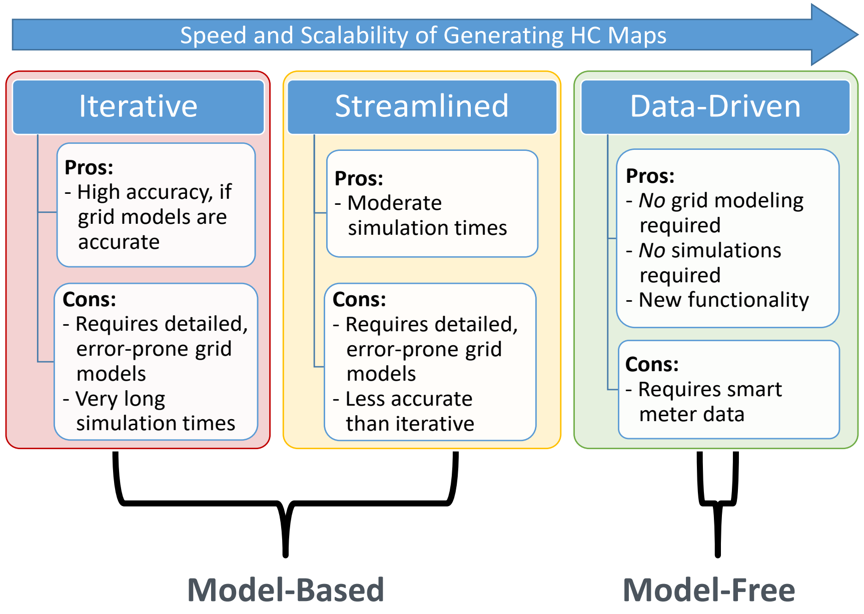
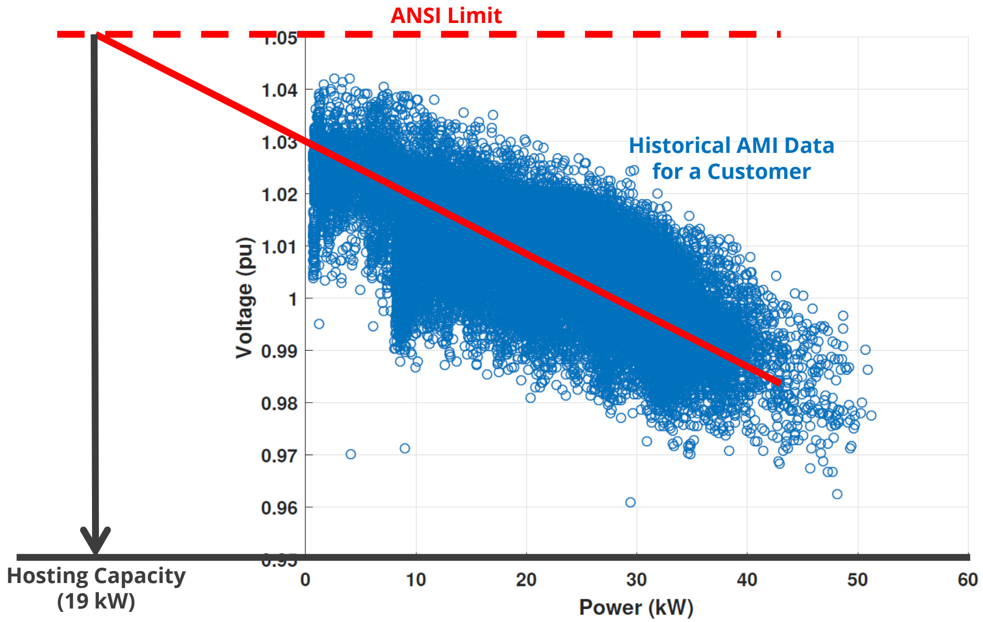
- **Challenge** – Distributed Energy Resource (DER) interconnection has been significantly improved by access to hosting capacity maps, but these maps are time-consuming and computationally intensive.
- **Need** – Methods that are more accessible to utilities and coops to produce hosting capacity maps that update more regularly and are less reliant on having detailed power flow models
- **Solution** – Data-driven hosting capacity maps based on learning historical correlations between load and voltages throughout the distribution system




**Accurate knowledge of the ever-evolving hosting capacity maps is crucial for rapid DER interconnection**

# Conclusions

- Big Data, Machine Learning, and advanced software tools are significantly improving the accuracy of DER interconnection planning and visibility into operations.

- Data introduces a lot of challenges (communication, storage, bad data detection), but provides avenues for entirely data-driven algorithms that improve efficiency

- We need more automated software tools for processing interconnections and handling data

# Questions?

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