Mining Smart Meter Data to Enhance Distribution Grid Observability for Behind-the-Meter Load Control

Sep 2021 IEEE Electrification Magazine Issue

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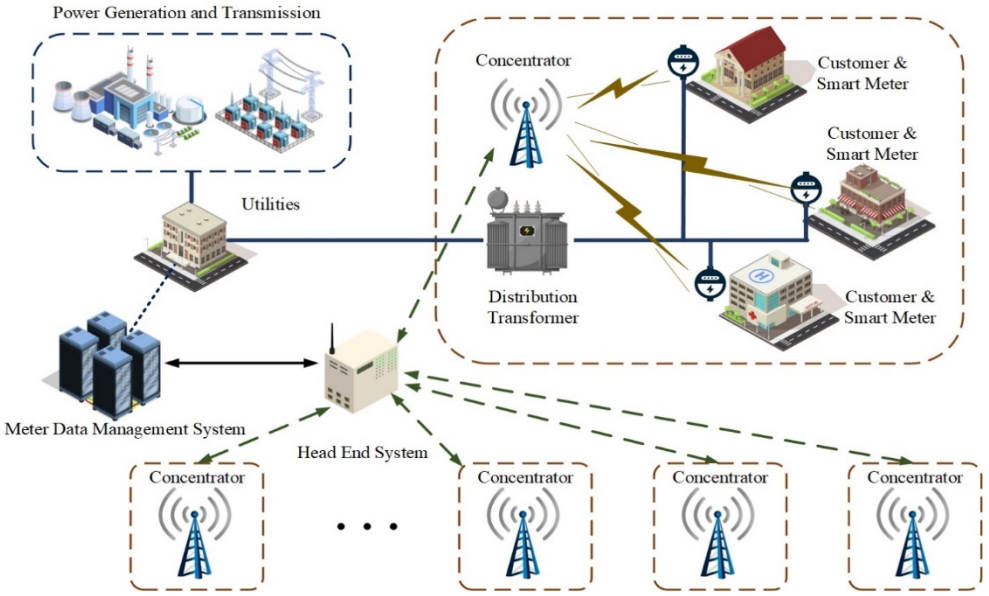
Background

- With the increasing integration of DERs in power distribution systems, utilities need to improve systematic situational awareness in order to execute behind-the-meter (BTM) load control strategies.
- In recent decades, the deployment of advanced metering infrastructure (AMI) in distribution systems has extended monitoring capability to grid edges.
- The core element of AMI is smart meter (SM) which is a device installed at customer house or facility.



SM data is a good resource for enhancing distribution grid monitoring and control thanks to extensive customer-side installations!

Available Utility Data

- **General Description:**

Utilities	Substations	Feeders	Transformers	Total Customer	Customers with Meters
3	5	27	1726	9118	6631

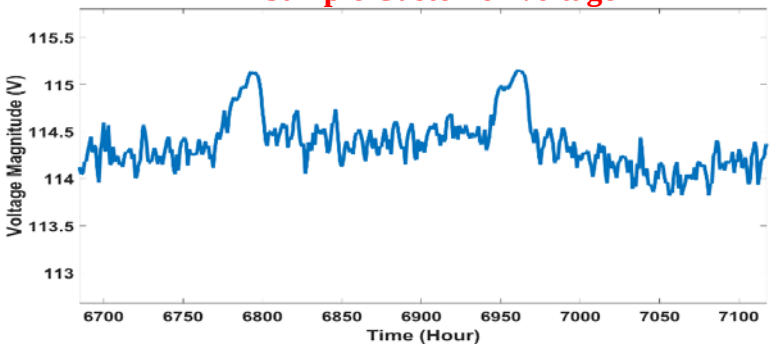
- **Duration:** 4 years (2014 - 2018)
- **Measurement Type:** Smart Meters and SCADA
- **Data Time Resolution:** 15 Minutes – 1 Hour
- **Customer Type:**

Residential	Commercial	Industrial	Other
84.67%	14.11%	0.67%	0.55%

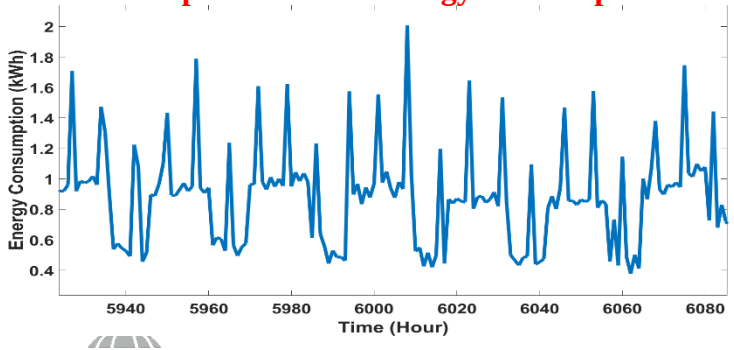
Available Utility Data

Smart Meter Data For Grid Observability

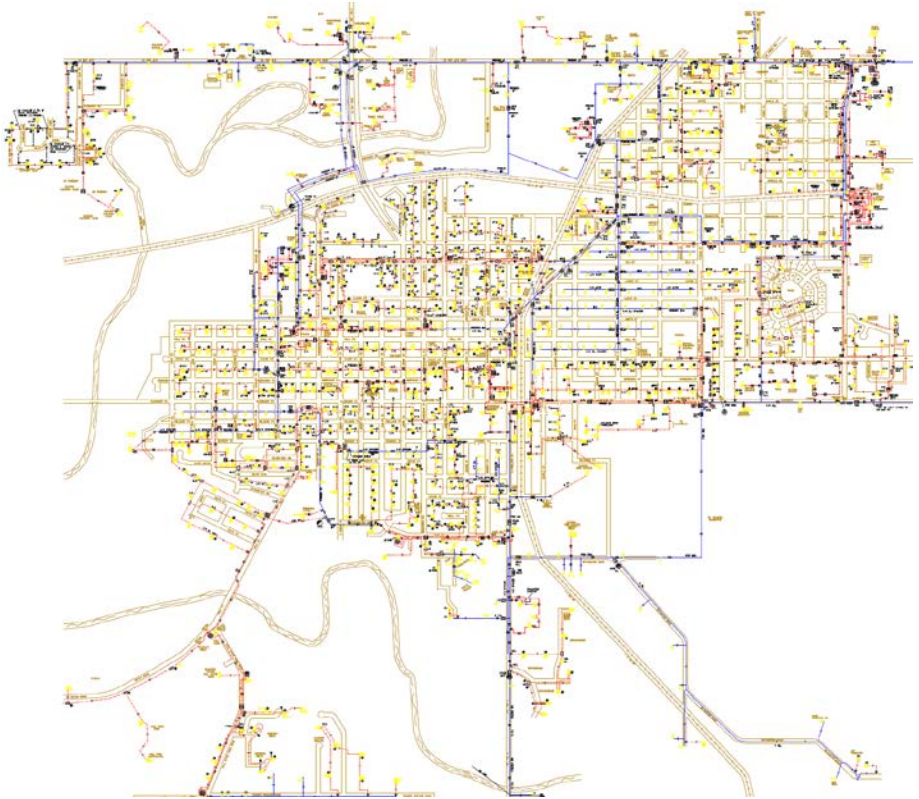
Sample Customer Voltage



Sample Customer Energy Consumption



Network Topology/Model Information



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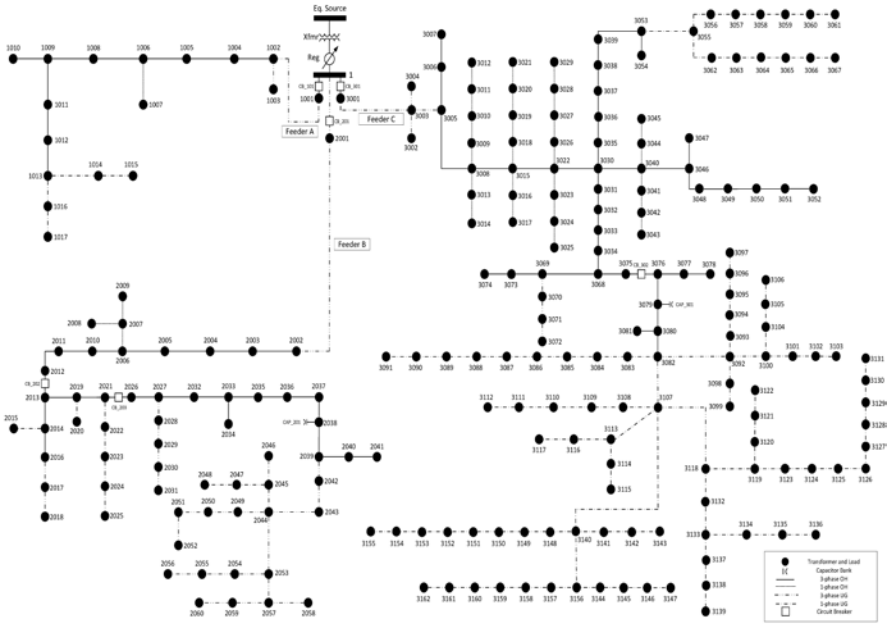
Distribution System Data Sharing

With permission from our utility partner, we share a real distribution grid model with one-year smart meter measurements. This dataset provides an opportunity for researchers and engineers to perform validation and demonstration using real utility grid models and field measurements.

- The system consists of 3 feeders and 240 nodes and is located in Midwest U.S.
- The system has 1120 customers and all of them are equipped with smart meters. These smart meters measure hourly energy consumption (kWh). We share the one-year real smart meter measurements for 2017.
- The system has standard electric components such as overhead lines, underground cables, substation transformers with LTC, line switches, capacitor banks, and secondary distribution transformers. The real system topology and component parameters are included.



Test system diagram

You may download the dataset at: http://wzy.ece.iastate.edu/Testsystem.html , including system description (in .doc and .xlsx), smart meter data (in .xlsx), OpenDSS model, and Matlab code for quasi-static time-series simulation!

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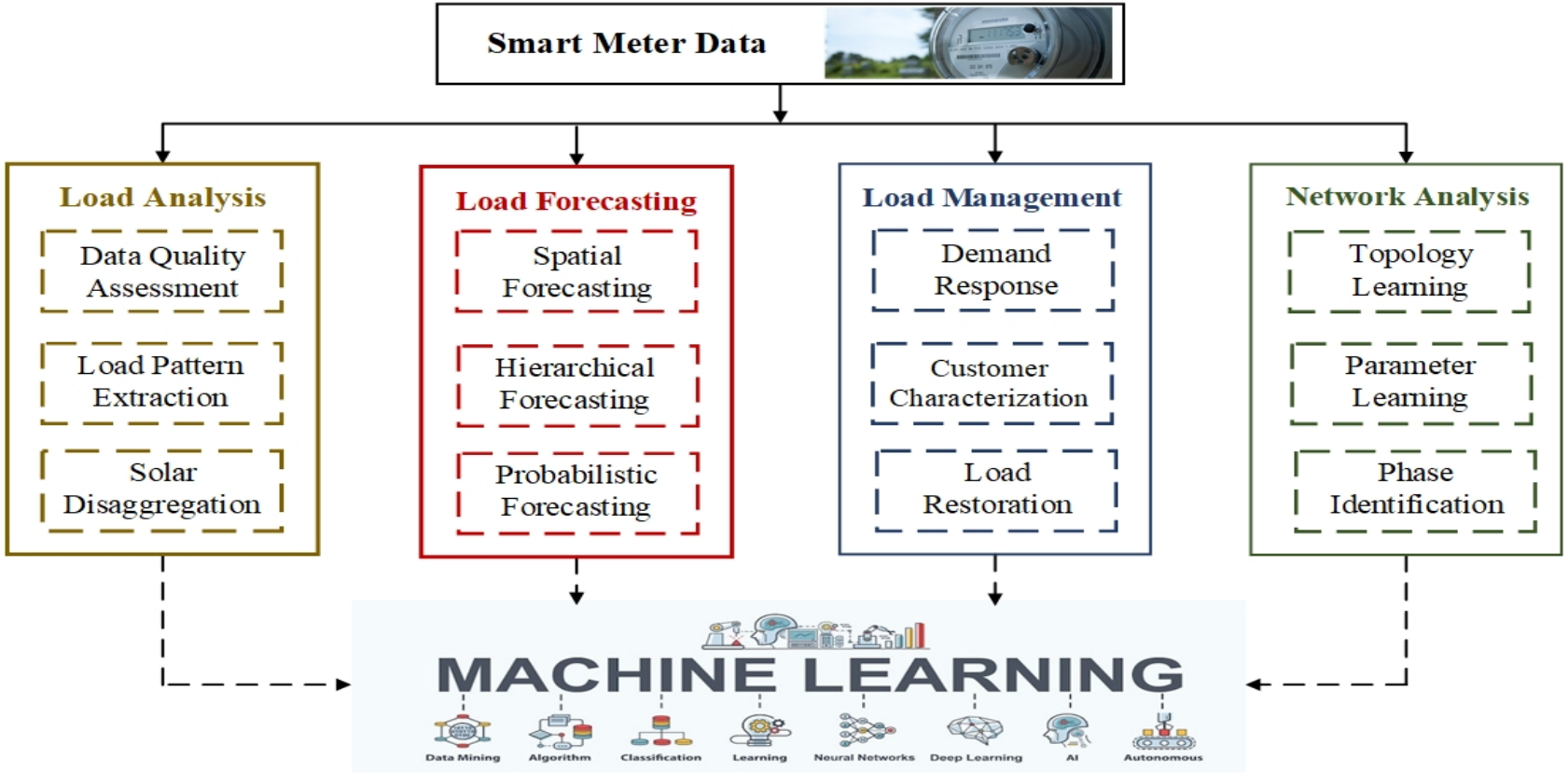
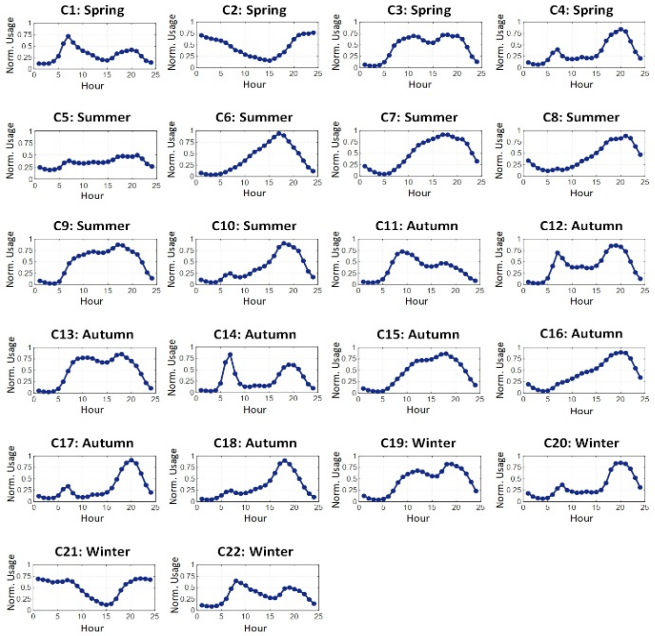
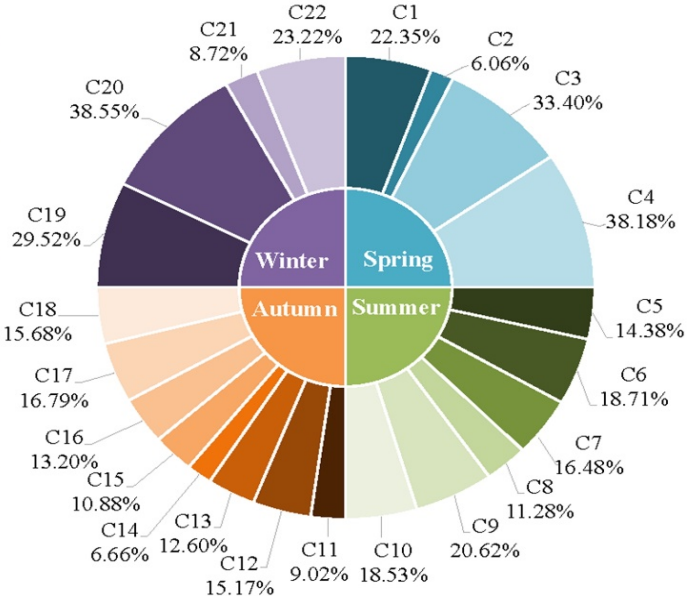
ADVANCED APPLICATIONS OF SMART METER DATA

Advanced Applications of SM Data



Customer Load Profiling



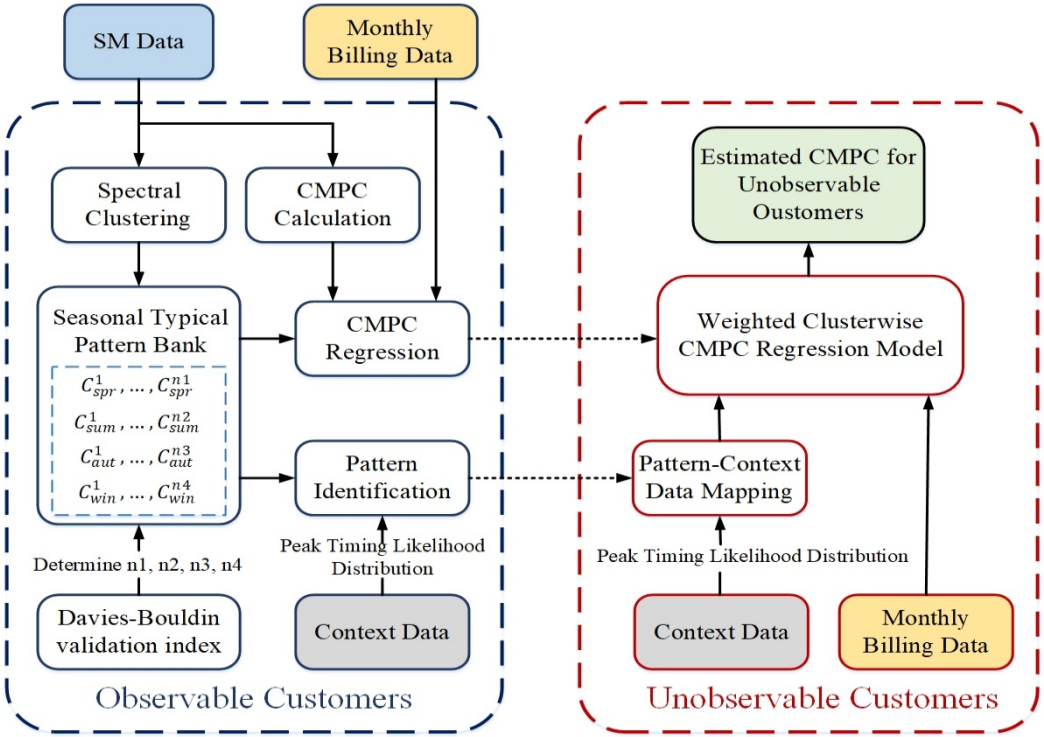


- Customer typical load profiles are valuable for utilities to understand customer consumption behaviors.
- By using machine learning techniques, load profiling can be cast as an unsupervised clustering problem.

➢ **Curse of Dimensionality** ➢ **Algorithm-specific Limitations** ➢ **Hyperparameter Calibration**

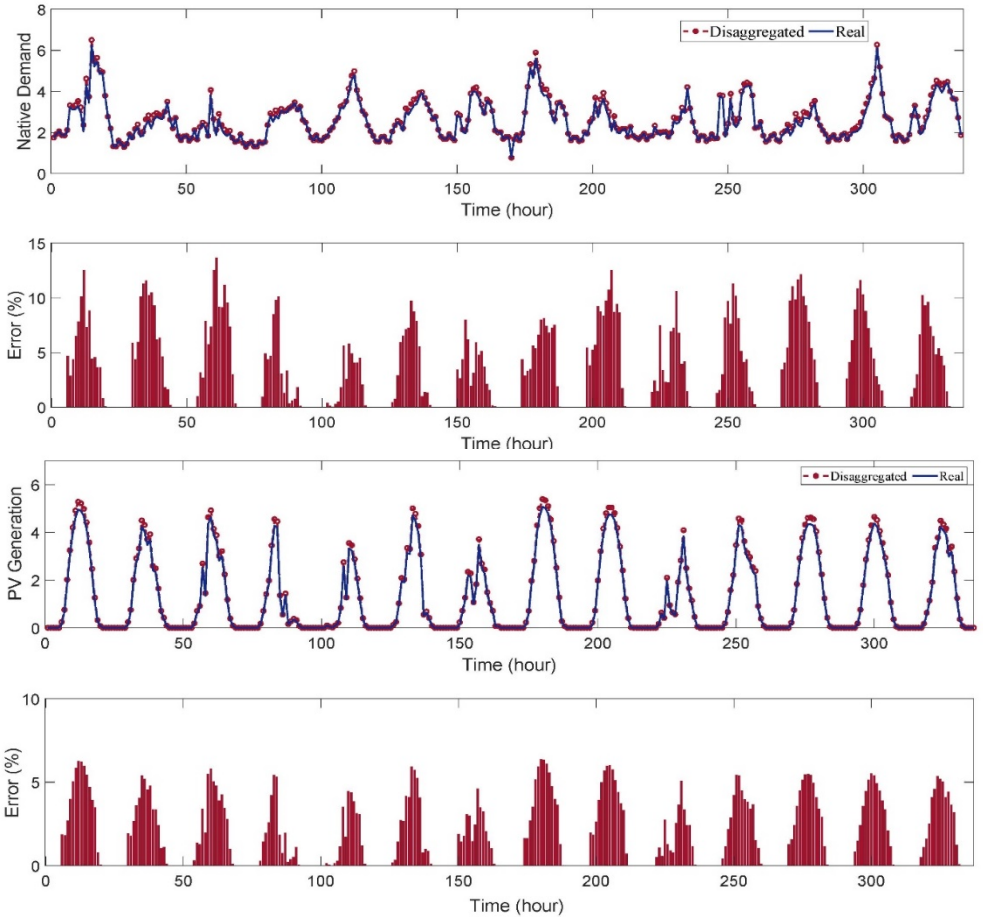
Demand-side Flexibility Quantification

- Coincident monthly peak contribution (CMPC): ratios of individual customers' demands during daily peak load times of the system to the daily system peak demand.
- For unobservable customers without SMs, a weighted clusterwise regression method can be used to estimate CMPC using their monthly billing information.
- The basic idea is to exploits the strong correlation between CMPC and monthly energy consumption when the customers' load profiles are similar.



BTM Solar Disaggregation

- While customers have SMs, PV generation and customer native demand remain invisible to utilities.
- Compared to model-based methods, data-driven methods do not require physical parameters and only rely on historical solar generation and customer consumption data to build the mapping functions.
- By designing a probabilistic learning-based model, we exploit the temporal correlation between nocturnal and diurnal native demands and the spatial correlation between unknown BTM PVs and solar examples in the same distribution system.



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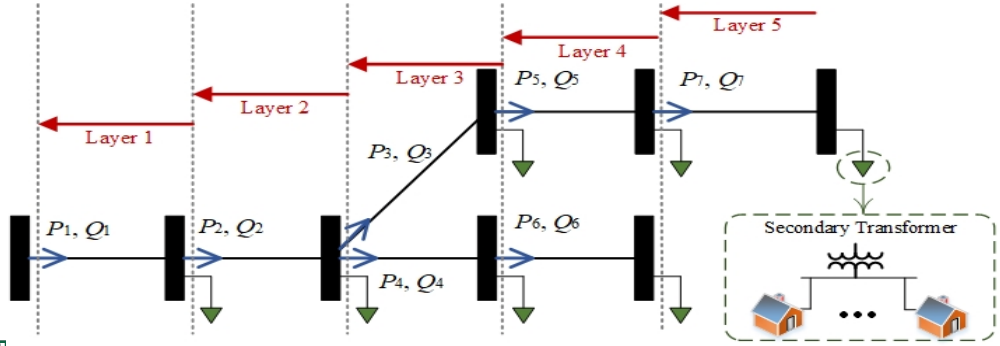
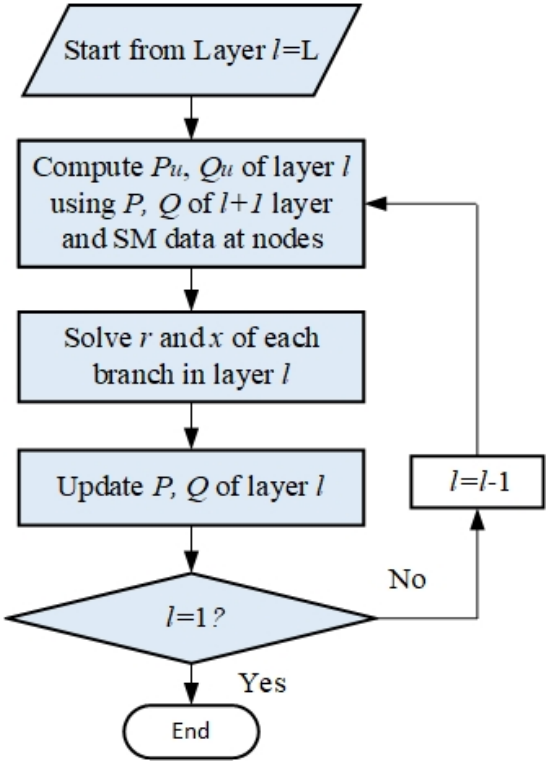
Topology and Parameter Identification

- A complete and accurate system model is essential for modern distribution system operations and BTM load control.
- The goal of our work is to capture the inherent dependencies among field measurements for topology and parameter identification.
- For topology identification, we model the distribution network as a graph and identify its weighted Laplacian matrix using SM data
- For parameter estimation, we design a bottom-up sweep algorithm with a least absolute deviations model.





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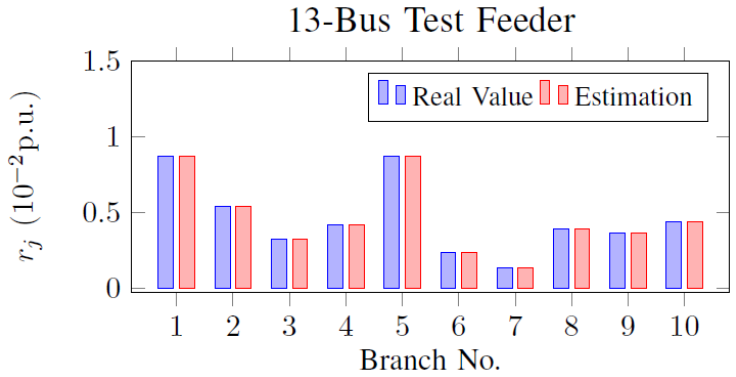
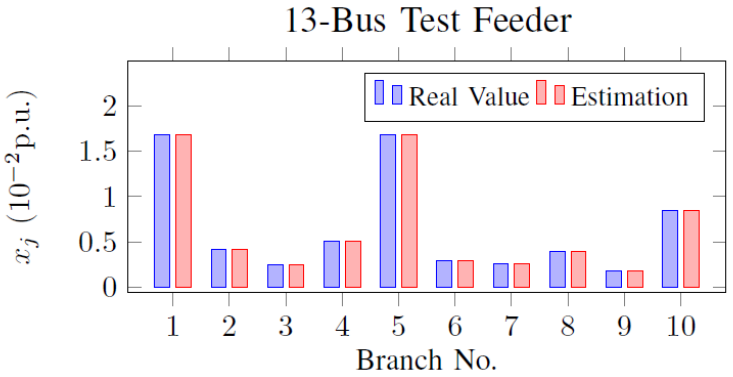
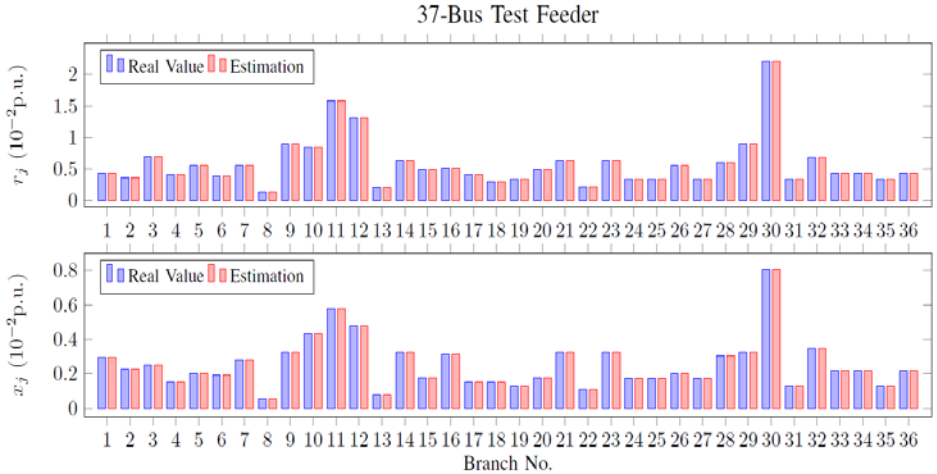
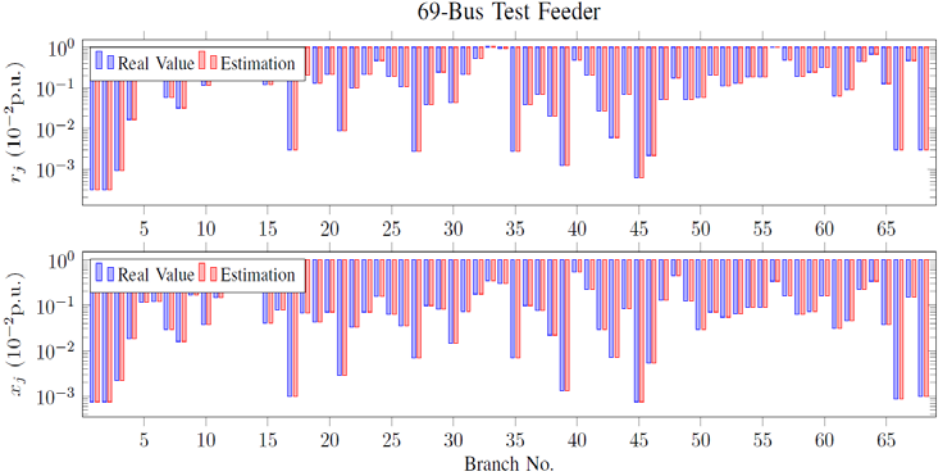
Topology and Parameter Identification









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Conclusion

- In this article, an overview of AMI is first presented, including concept, communications, and current applications.
- with permission from our utility partner, we have shared a real distribution grid model with one-year SM data for researchers and engineers to perform validation and demonstration.
- We introduce several advanced applications that allow unlocking the untapped potential of AMI data using machine learning techniques.
- The proposed solutions can significantly improve system situational awareness and provide valuable insights to better control BTM loads and DERs.

QUESTIONS?

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Presenter Bio

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- Yuxuan Yuan received the B.S. degree in Electrical Engineering from Iowa State University, Ames, IA, in 2017. He is currently pursuing the Ph.D. degree at Iowa State University. His research interests include distribution system state estimation, synthetic networks, data analytics, and machine learning.

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- Zhaoyu Wang is the Associate Professor with Iowa State University. He received the B.S. and M.S. degrees in electrical engineering from Shanghai Jiaotong University in 2009 and 2012, respectively, and the M.S. and Ph.D. degrees in electrical and computer engineering from Georgia Institute of Technology in 2012 and 2015, respectively. His research interests include optimization and data analytics in power distribution systems and microgrids. He is the Principal Investigator for a multitude of projects funded by the National Science Foundation, the Department of Energy, National Laboratories, PSERC, and Iowa Energy Center. He is an editor of IEEE Transactions on Power Systems, IEEE Transactions on Smart Grid, IEEE PES Letters and IEEE Open Access Journal of Power and Energy, and an associate editor of IET Smart Grid.