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Secondary Circuit Model Creation and Validation with AMI and Transformer Measurements

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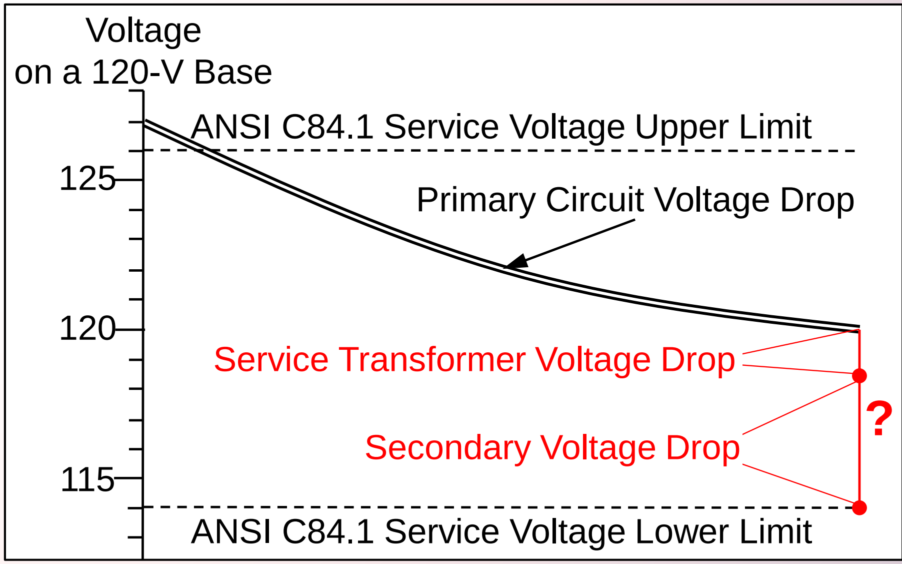
Motivation

* Vast majority of distribution models **do not** include secondary (low-voltage) circuits
* When modeled, **rough assumptions or default values** are used
* Accurate secondary modeling is becoming important
  * A large number of DERs and sensors in secondary circuits
  * A large share of the per-unit voltage drop/raise over the secondaries
* Can the secondary modeling be automated?
  * Manual inspections, utilizing added measurements, etc. require considerable man hours and extra resources
  * May be hard to perform in urban areas with wiring underground and in buildings



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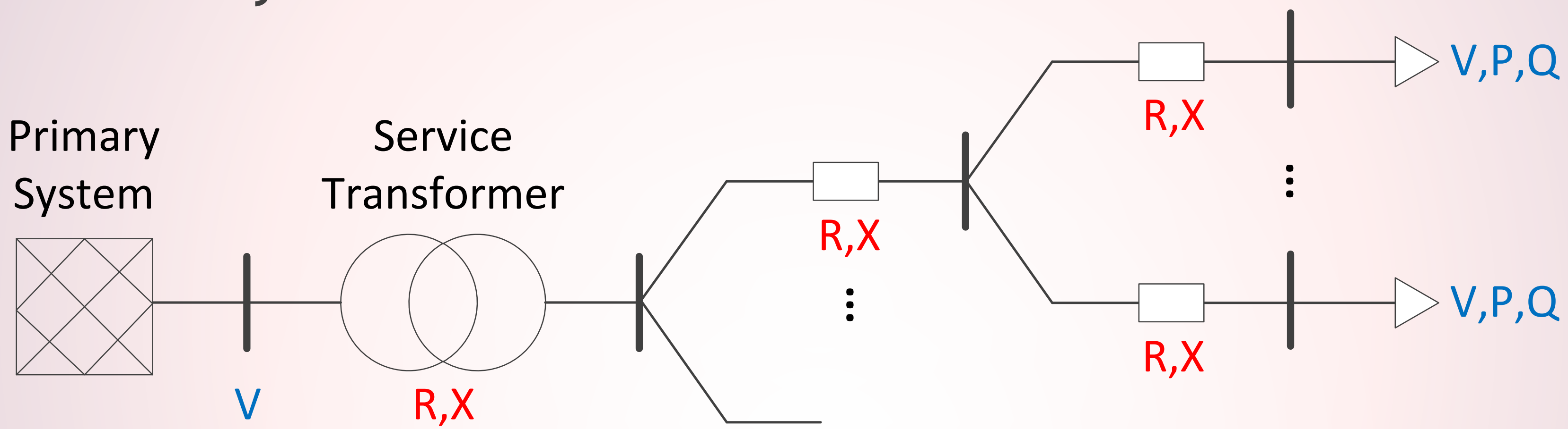
Automated Secondary Modeling

- Smart meter and DER data can be leveraged to create secondary models



- In our past work*, we have shown methods to create
  - Detailed models with **fully available AMI data**
  - Simplified models with **limited DER sensors**

Details in:
J. Peppanen, M. J. Reno, R. J. Broderick, and S. Grijalva, "Distribution System Model Calibration with Big Data from AMI and PV Inverters," in IEEE Transactions on Smart Grid, 2016.

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Linear Regression Parameter Estimation (LRPE) All Meters & Known Topology

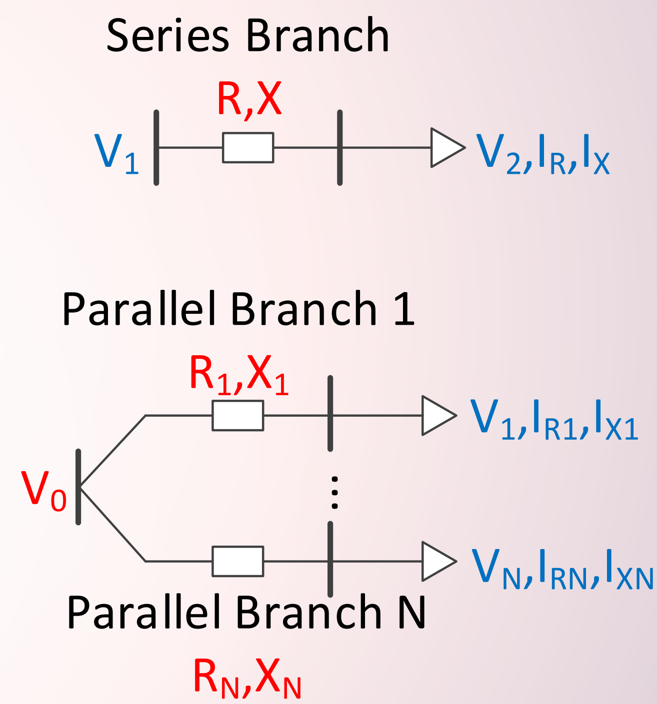
* Based on linearized voltage drop approximation

$$V_{drop} = V_1 - V_2 \approx RI_R + XI_X$$

* **Idea:** Estimate parameters with linear regression:

$$\boldsymbol{y} = \boldsymbol{X\beta} + \boldsymbol{\epsilon}$$

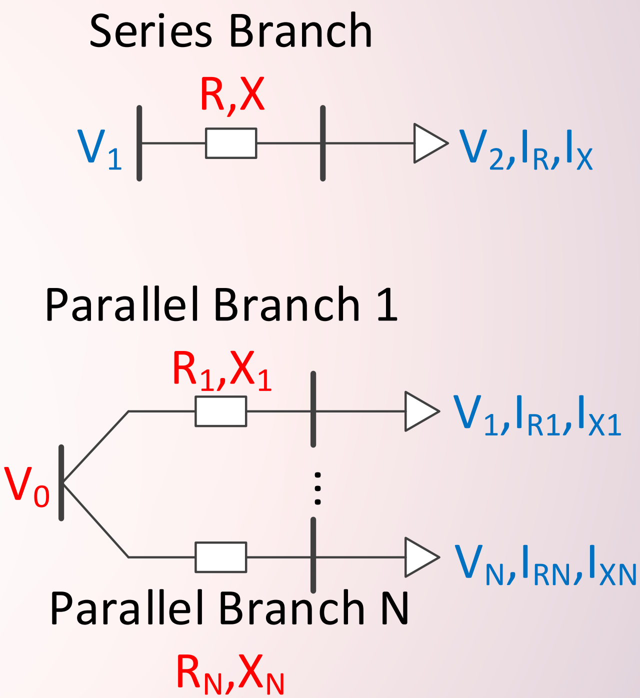
* **Algorithm:** At each iteration, estimate the parameters for a circuit subsection consisting of a series branch or N parallel branches



Details in:
J. Peppanen, M. J. Reno, R. Broderick, and S. Grijalva, “Distribution System Secondary Circuit Parameter Estimation for Model Calibration,” Sandia National Laboratories, SAND2015-7477, Sep. 2015.

Topology and Parameter Estimation (LRTE)
All Meters & Unknown Topology

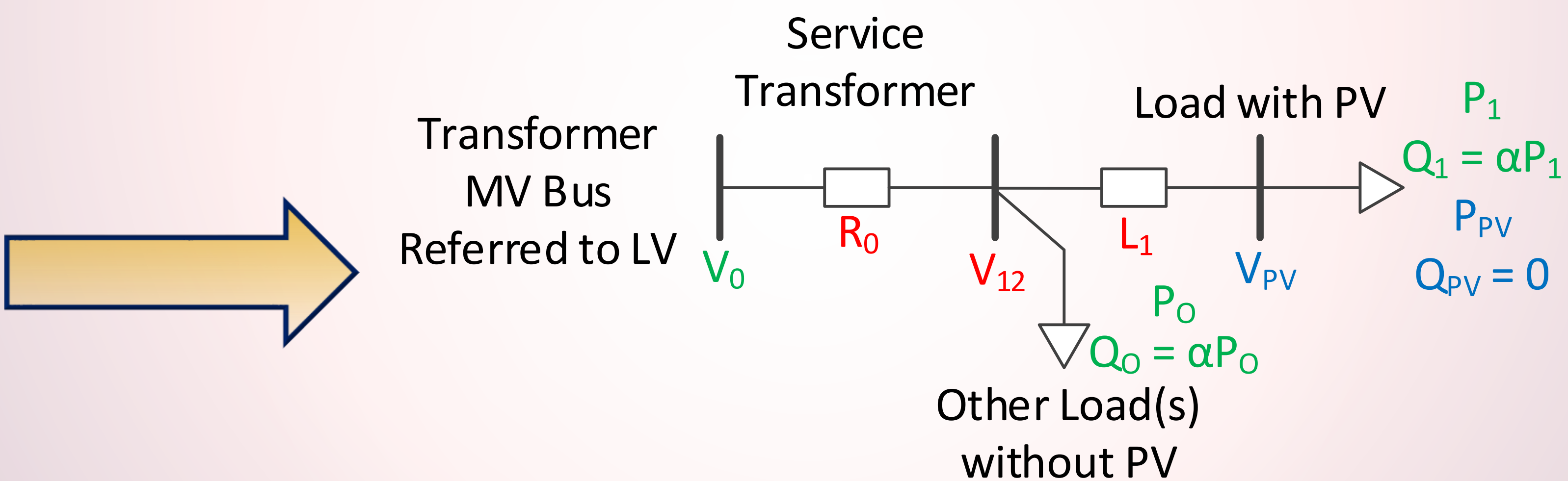
* **Idea:** Solve a linear regression problem for each meter pair for the series and parallel circuit subsection types
* **Algorithm:**
  * At each iteration, select the regression model (meter pair and circuit type) with the best fit
  * Stop with an estimated circuit that includes all the meters



Details in:
J. Peppanen, M. J. Reno, R. Broderick, and S. Grijalva, "Distribution System Low-Voltage Circuit Topology Estimation using Smart Metering Data," in IEEE PES T&D Conference & Exposition, Dallas, TX, USA, 2016.

Simplified Parameter Estimation (SLRPE) Few Meters & Unknown Topology

* Create simplified secondary circuit models to improve voltage simulation accuracy at the available sensor(s)
* If most loads/DERs are measured, this approach makes unnecessarily restrictive assumptions



Details in:

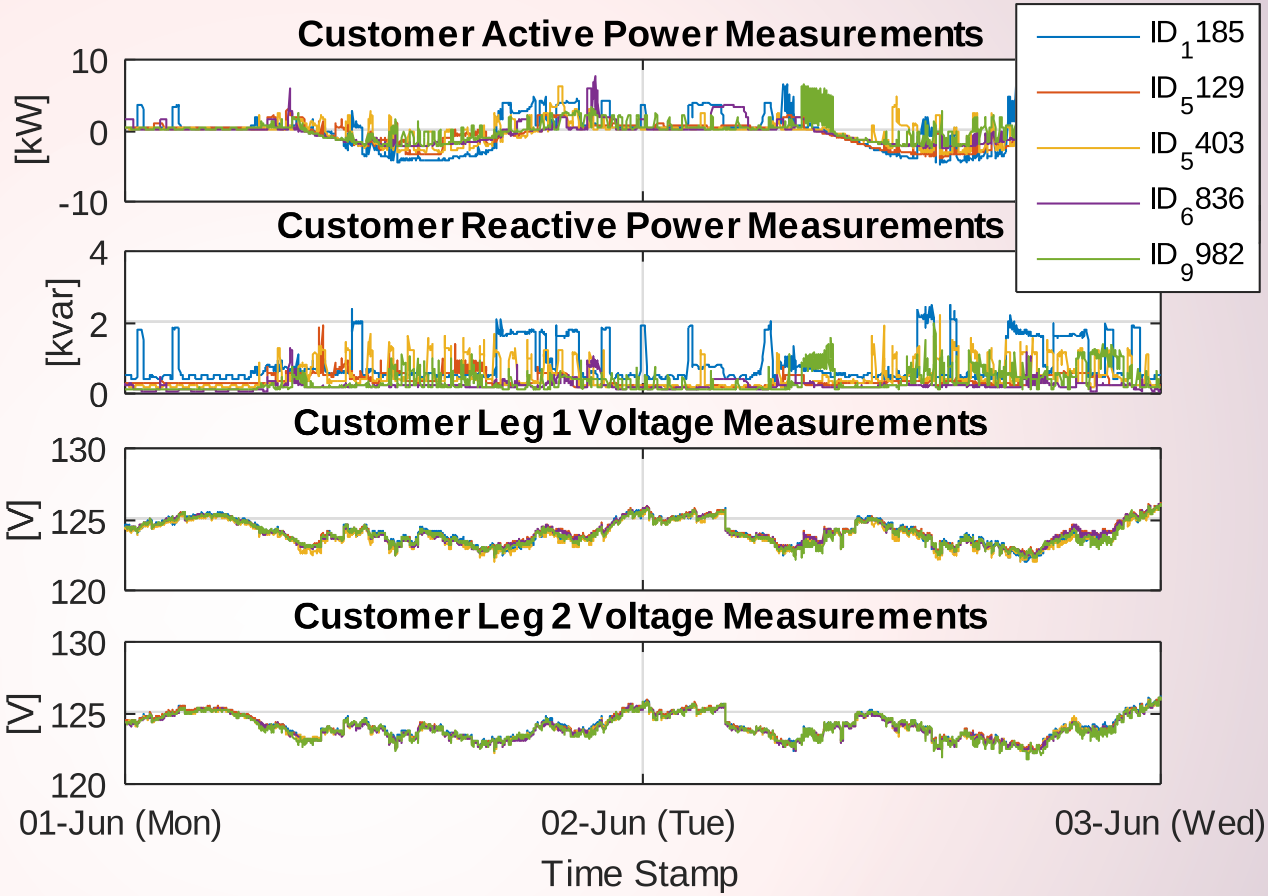
J. Peppanen, M. J. Reno, R. Broderick, and S. Grijalva, "Secondary Circuit Model Generation Using Limited PV Measurements and Parameter Estimation," in IEEE PES General Meeting, Boston, MA, USA, 2016.

This Paper: Most Meters & Unknown Topology

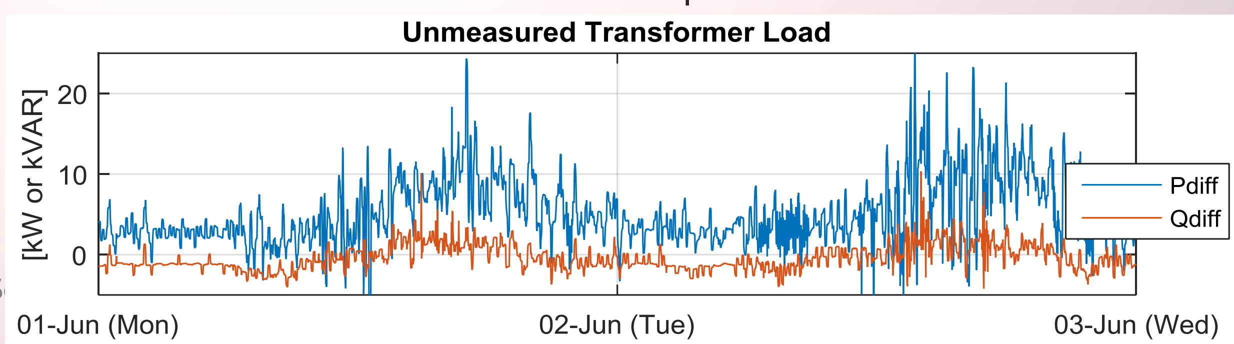
* This paper addresses the common case when the topology is unknown and **most but not all** loads/DERs are measured
* Three alternative approaches are compared:
  1. Conventional secondary modeling approach (a separate 100ft 1/0 drop for each customer)
  2. Ignore unmeasured loads/DERs, assume a topology (separate drop for each customer) and use LPRE
  3. Ignore unmeasured loads/DERs and use LRTE

Used Real Customer Measurements

* Month of 1-min P,Q,V measurements for 5 (of the total 8) customers
* ANSI C12.20 0.5% or ANSI 12.1 1.0% accuracy class (depends on the CT)

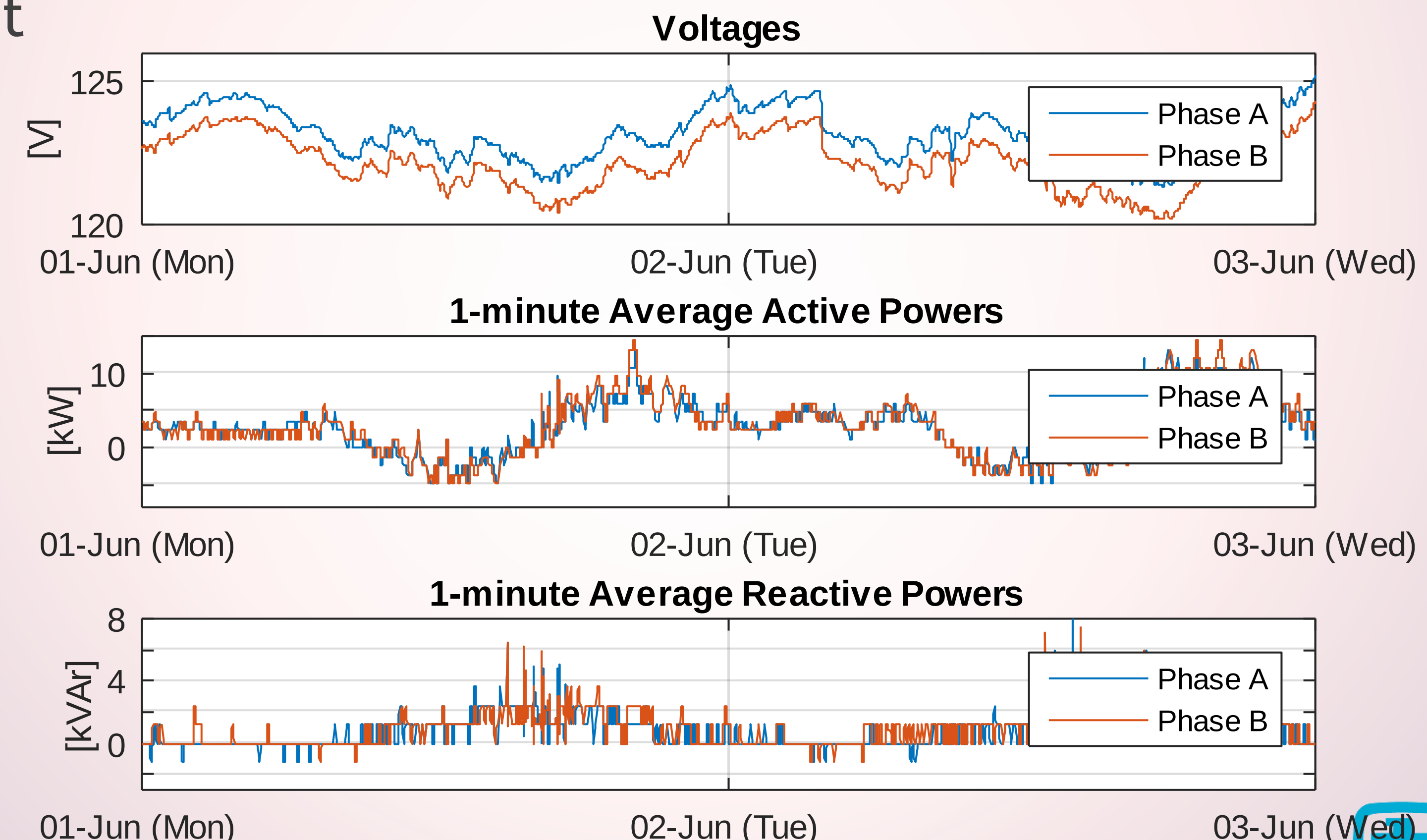


Share of average unmeasured load: 61.6% of kW and 49.7% of kVA!



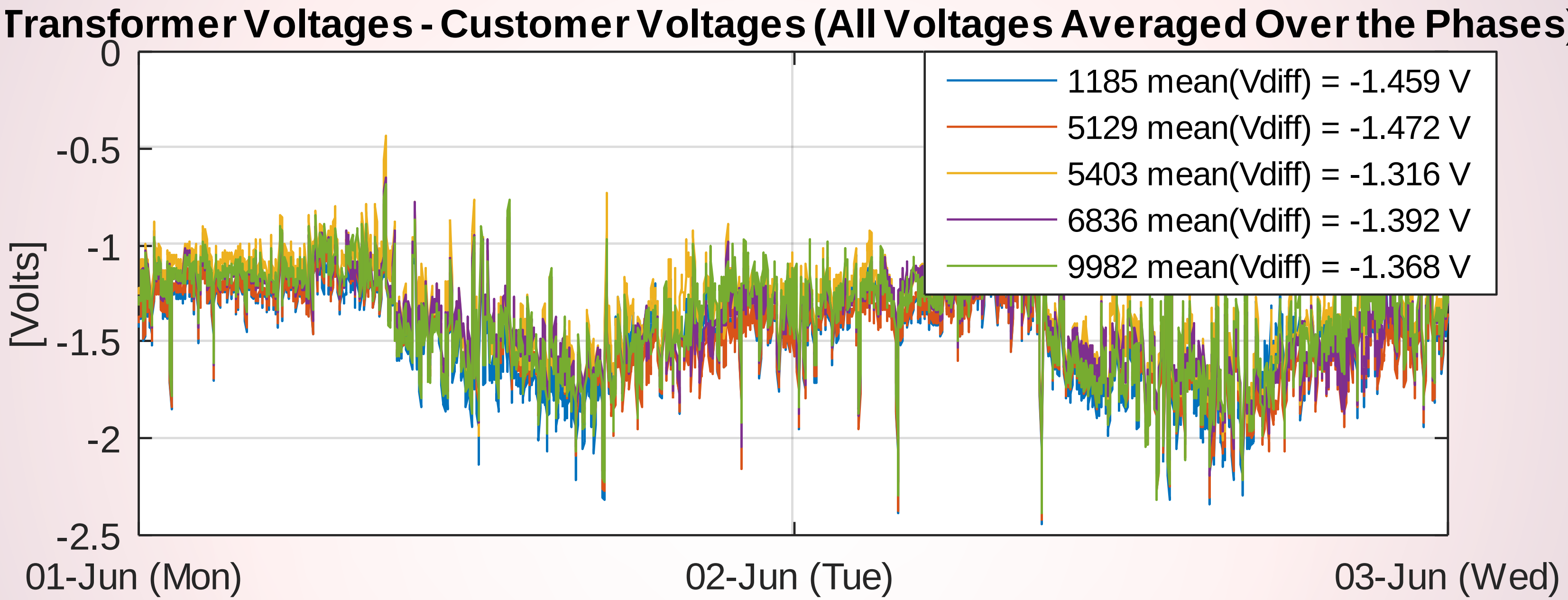
Used Real Transformer Measurements

- 1 month of 5-min service transformer low-voltage side P, Q, and V measurements for both legs
- ±0.5% accuracy with 0.1 V and 1.0A precision for voltage and current



Voltage Measurement Issues

* Measured voltage drops are **negative**!



* Most likely explained by **transformer voltage offset**
* Had to assume a **constant** offset
* **How to estimate the offset?**

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Estimating the Voltage Offset

1. Average voltage drop over the lowest 1% load time was: -1.3368 Volts
2. Assume a separate drop for each customer and use LRPE: the average (over the five meters) linear regression offset -1.4019 Volts
3. Ignore unmeasured load/DER and use LRTE: offset -1.5194 Volts. T<u>**his was assumed for generating the secondary model.**</u>

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Secondary Modeling Results

* The measured voltage drops correlate poorly with the voltage drops simulated with the all the generated secondary models
  * **Likely due to transformer voltage measurement offset problem**
* LRPE reduced the average voltage drop simulation errors but resulted in negative reactance estimates and very low simulated voltage drops
* LRTE resulted in unexpectedly low values for parameter estimates and simulated voltage drops

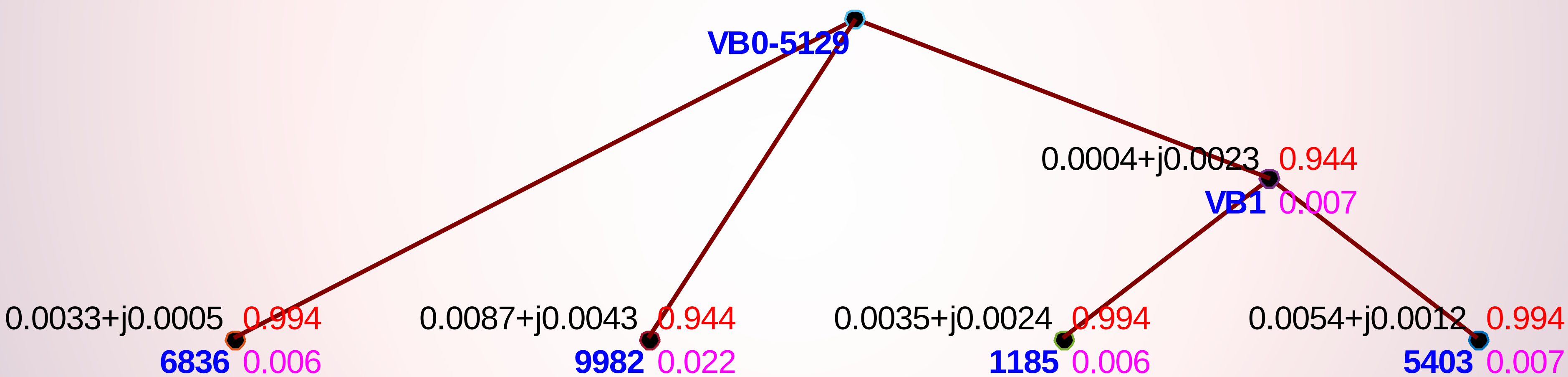
Secondary Modeling Results

Average Absolute Error in Simulated Voltage Drop (V)

Meter	1185	5129	5403	6836	9982
Conventional	0.5822	0.3757	0.4164	0.3682	0.2607
LRPE	0.1750	0.1750	0.1906	0.1704	0.1714
LRTE	0.5516	0.1840	0.1908	0.1790	0.1761

Secondary Modeling Results

* LRTE requires the secondary voltage measurements to be linearly independent (poorly correlated)
* Accuracy hindered by very low voltage drops and high relative voltage measurement errors



Meter name

Estimated node upstream branch impedance

Node upstream branch parameter estimation linear regression R^2

Node upstream branch linear regression RMSE

Conclusions

* Good secondary models are necessary to accurately
  * Utilize sensor data from secondary circuits
  * Control DERs connected to secondary circuits
* This paper compares approaches to create secondary models in a common case when most but not all loads/DERs are measured
* This paper underlines the importance of having high-quality measurement data to generate secondary models
* Future work will analyze more circuits and will address issues related to practical measurements and secondary circuits