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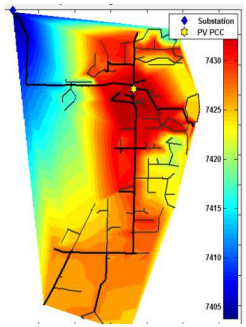

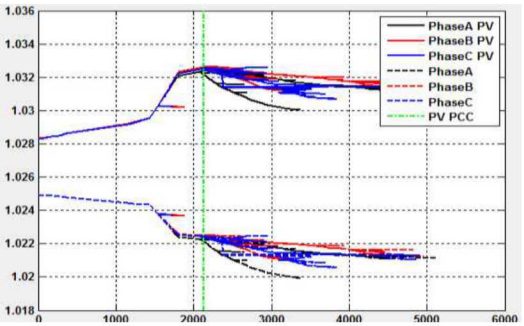

Parameter and Topology Estimation using Utility AMI Data

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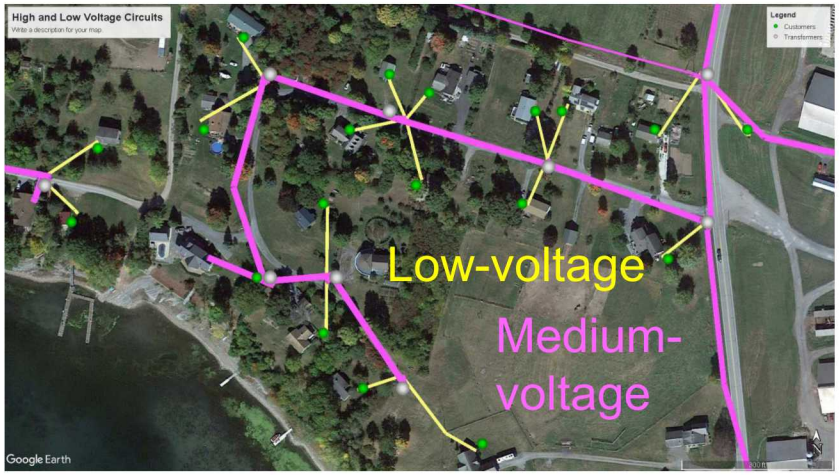
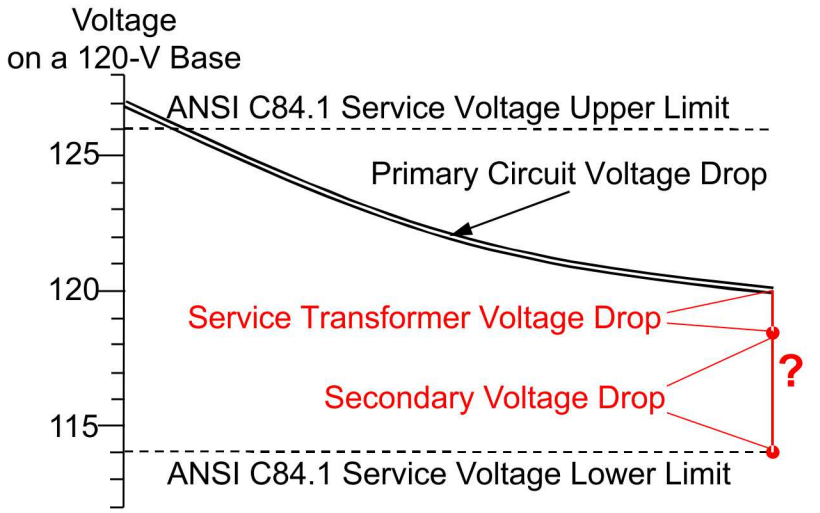
Parameter and Topology Estimation

- Utility customer meter (AMI) voltage and power measurements to resolve distribution grid secondary (low-voltage):
  - Parameters – resistance and reactance from transformer to customer
  - Topology – arrangement (series or parallel) of customers connected to the same transformer
- Result: more detailed and accurate distribution grid modeling
  - Hosting capacity
  - PV volt/var response
  - Conservation voltage reduction

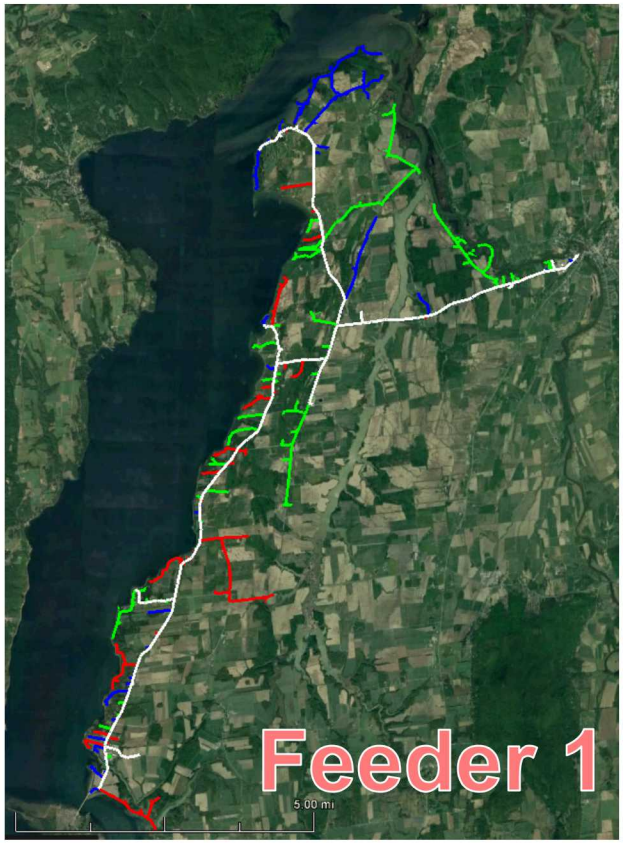


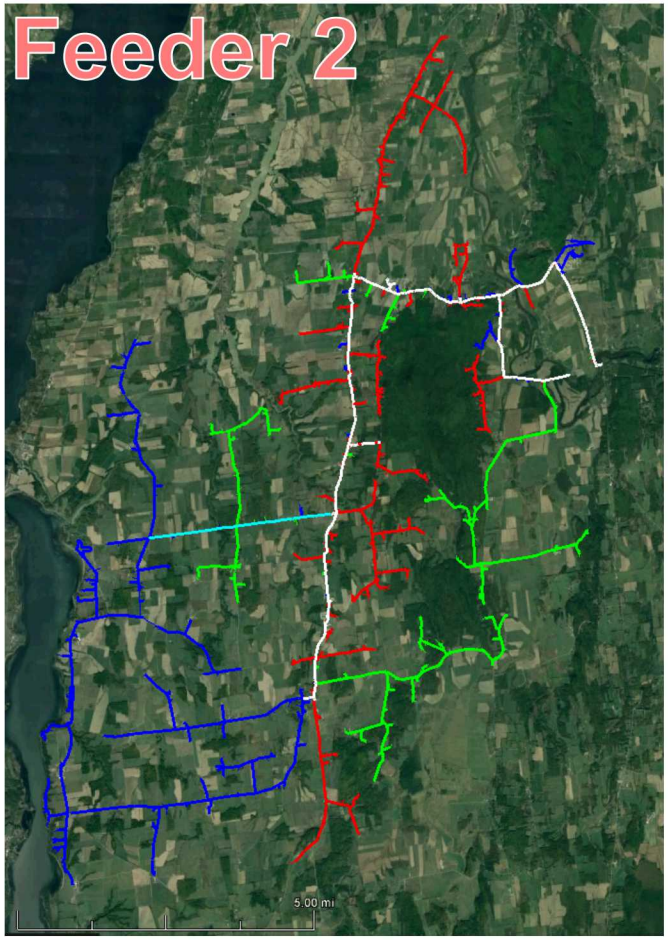
Need for Detailed Secondary Models

- Distribution system secondary (low-voltage) circuit models are typically not modeled or modeled with limited detail
- It is becoming important to have accurate secondary circuit models
  - A large number of DERs and sensors are connected to the secondary circuits
  - A large portion of the per-unit voltage drop/raise occurs over the secondaries
- Typical ways to enhance the GIS models
  - Manual inspections, utilizing added measurements, etc.
  - Require considerable man hours and extra resources ⇒ not cost-effective
  - May be hard to perform in urban areas with wiring underground and in buildings

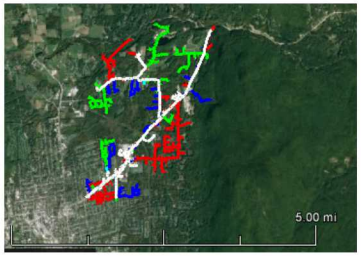


Three feeders evaluated

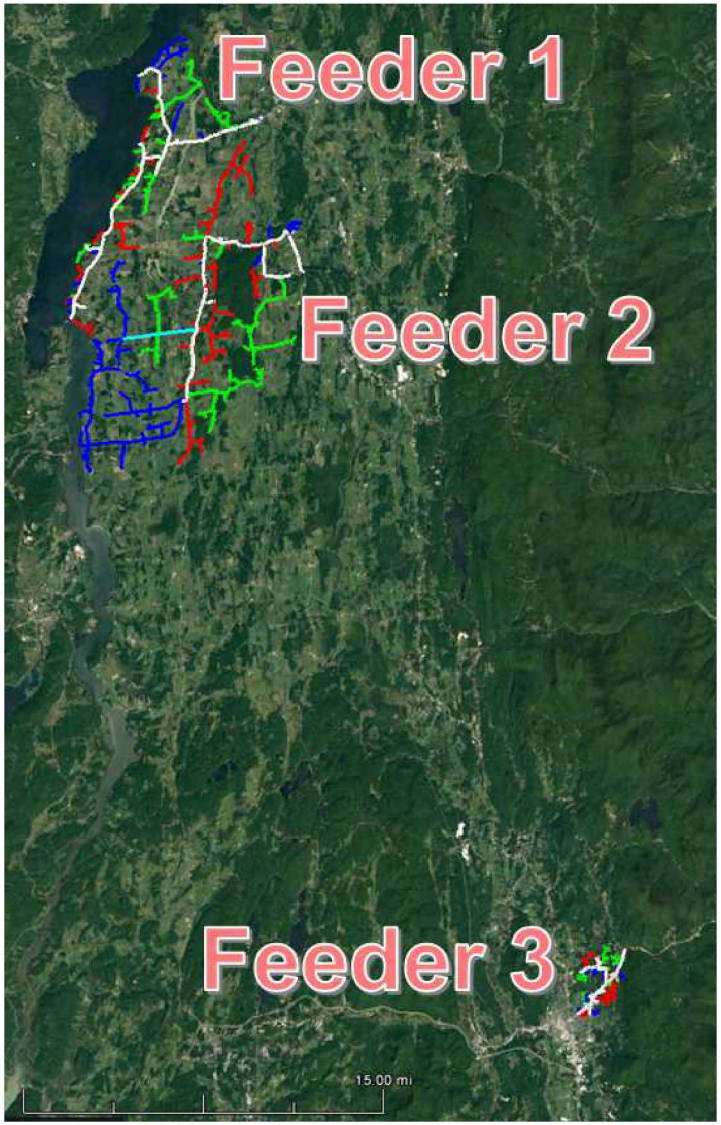


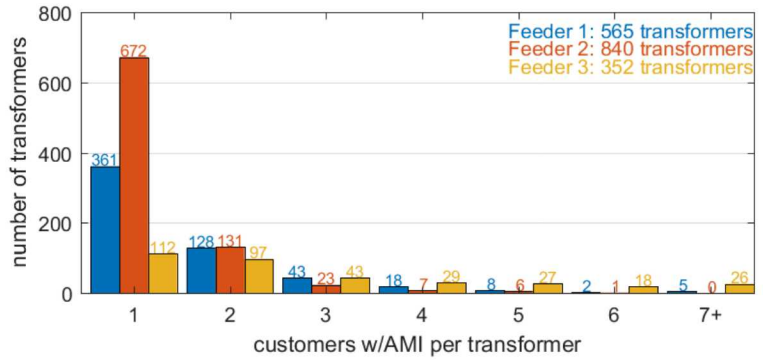


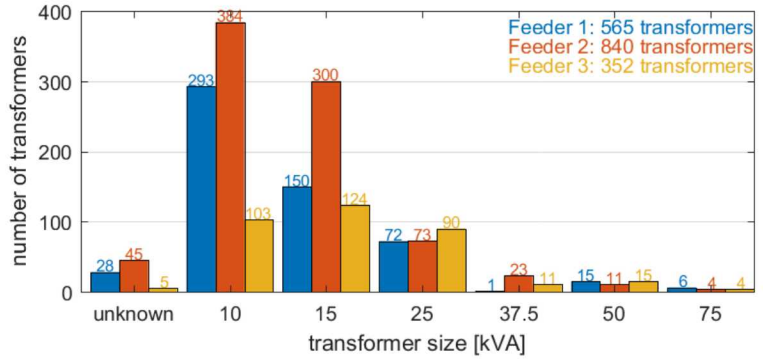
Feeder 3

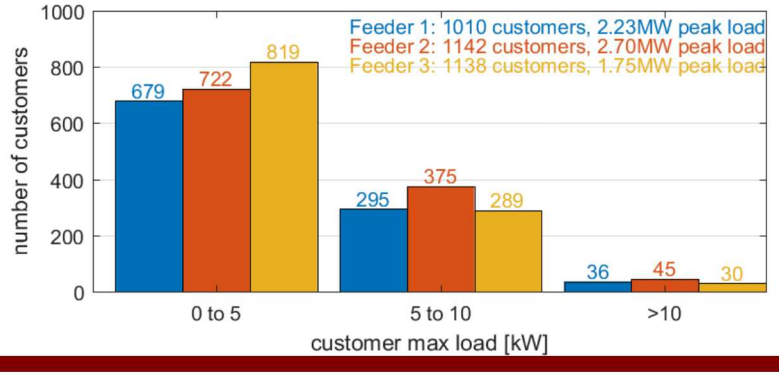


Three feeders evaluated









Data

- AMI data at 15-minute intervals for 6-months to 1-year
  - Voltage (V)
  - Real Power (kWh)
  - Reactive Power (kVArh)
- Transformer each customer is connected to
- Latitude and longitude of each customer and transformer
  - Generally accurate but not fully verified
- Utility's unverified, manually-entered secondary model
  - In many cases, matches actual wiring path
  - In other cases, simply a straight line from transformer to customer

Procedure

1. Resolve the parameters and topology for all transformers with 2+ customers.
2. Resolve the parameters for transformers with only a single customer by pairing them with other single-customer transformers.
3. Pair transformers resolved in step 1 with one another to resolve any additional parameters between the virtual nodes where the customers meet and the transformers.

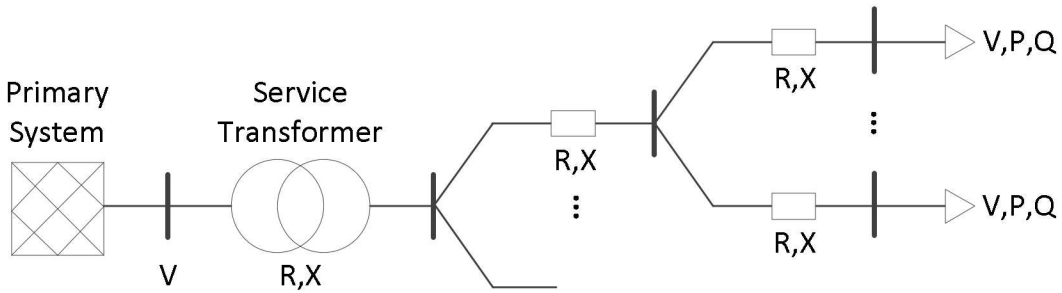
Step 1

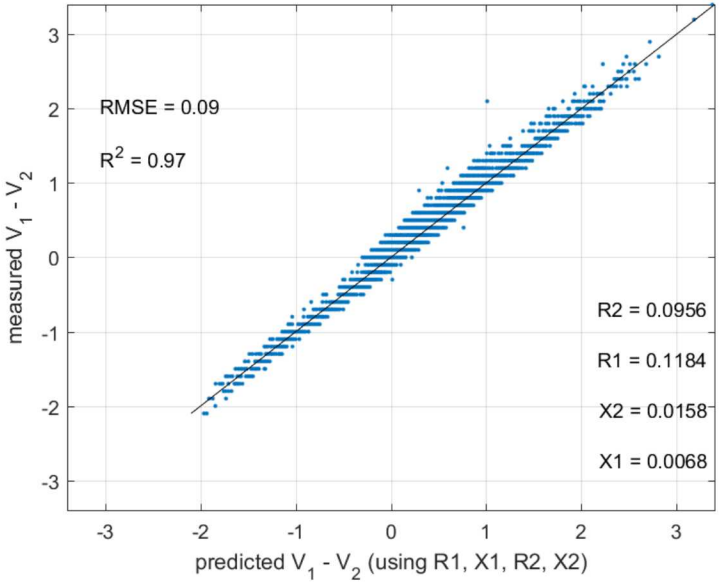
- For all customers on a transformer, find R1, R2, X1, X2

$$\boldsymbol{V}_1 - \boldsymbol{V}_2 = \boldsymbol{I}_{R1}R_1 + \boldsymbol{I}_{X1}X_1 + \boldsymbol{I}_{R2}R_2 + \boldsymbol{I}_{X2}X_2 + \boldsymbol{\epsilon}$$

Known Unknown

- Basic concept
  - Fit R1, R2, X1, X2 values which best fit the V1-V2 fluctuations

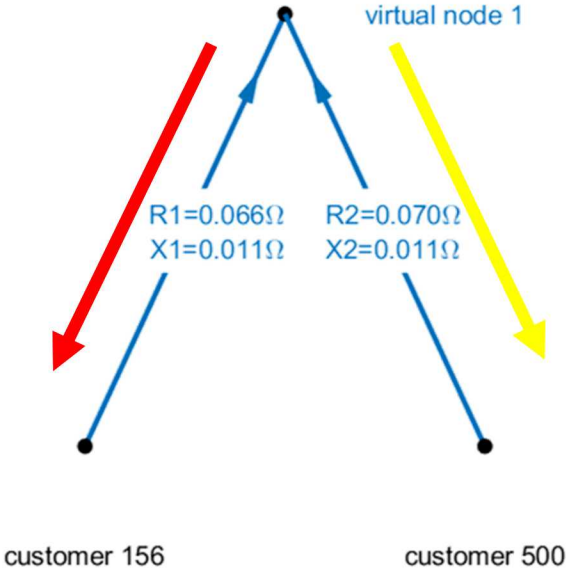




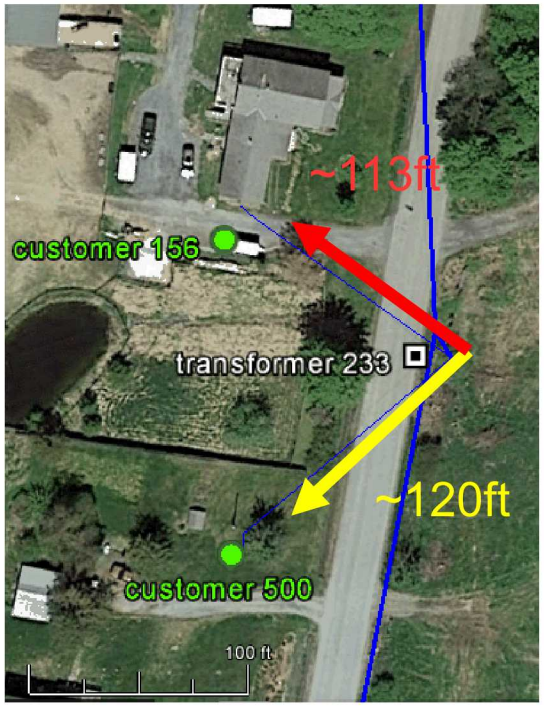
- For comparison to utility model
  - R values were used to compute a distance in feet of triplex cable for various types of cable (#2, 2/0, 4/0)

Transformer 233 on Feeder 1

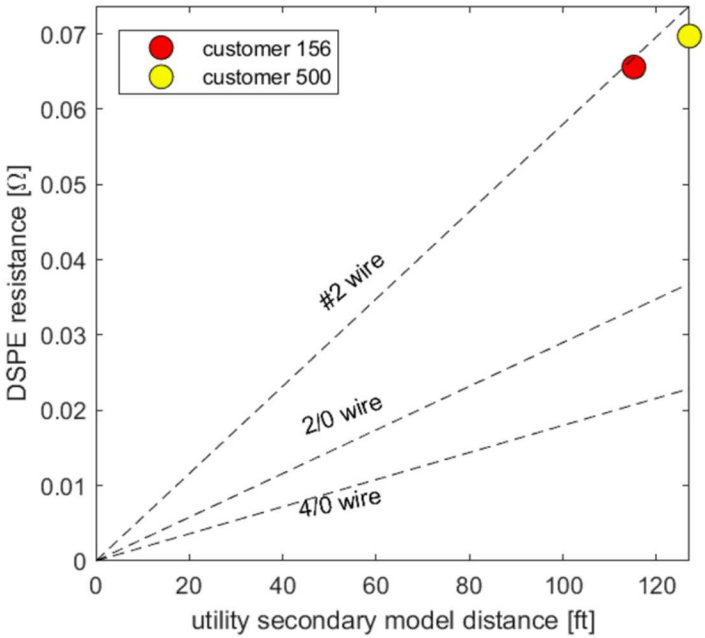
Distribution System Parameter Estimation



Imagery/Model



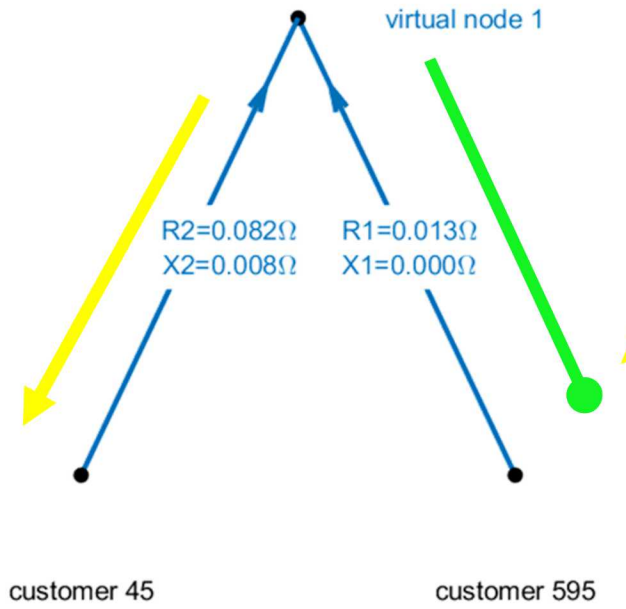
DSPE vs. Model



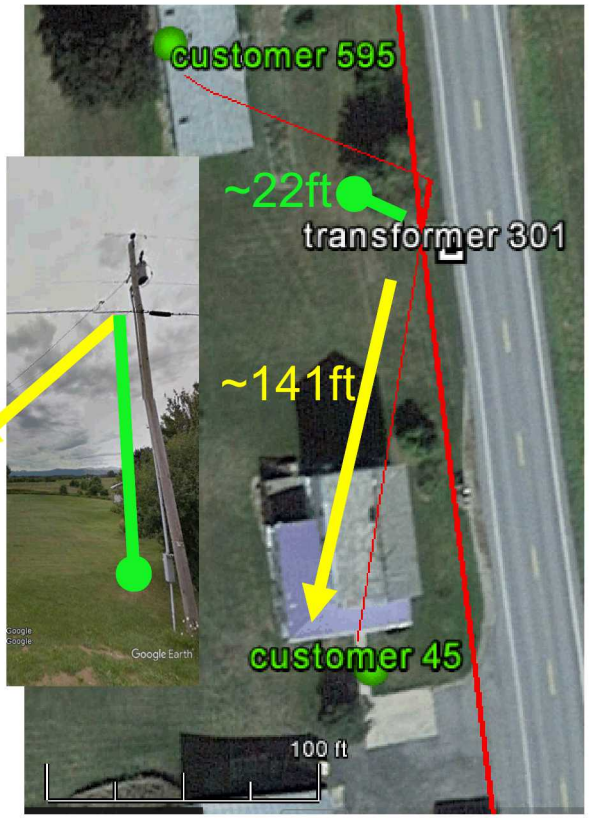
DSPE results match utility model well, consistent with #2 wire.

Transformer 301 on Feeder 2

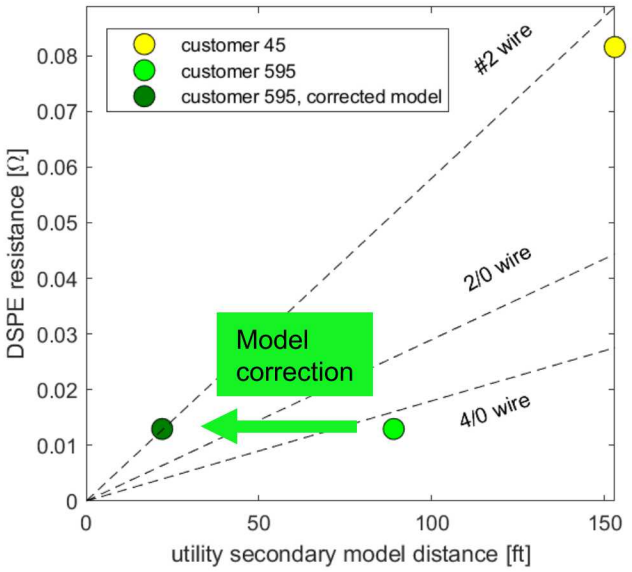
Distribution System Parameter Estimation



Imagery/Model

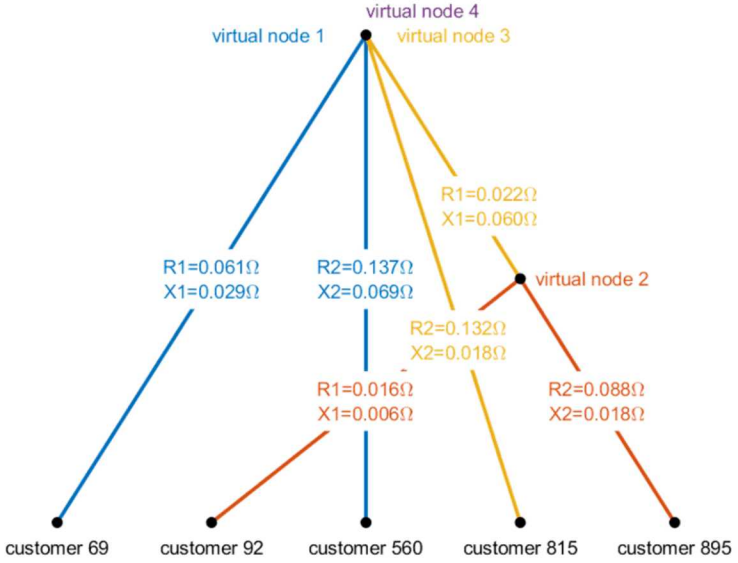


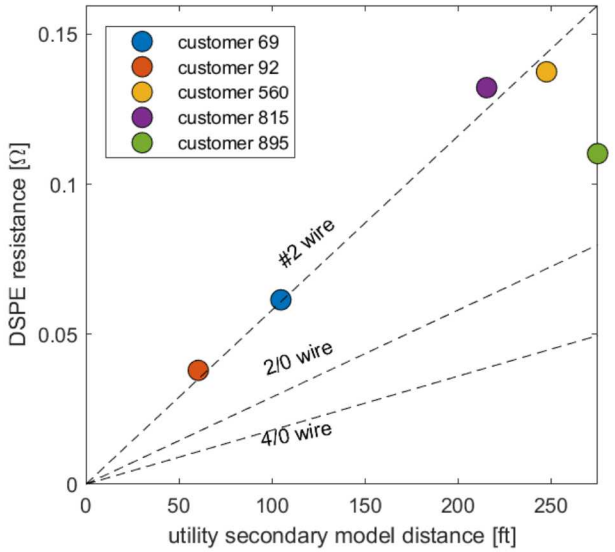
DSPE vs. Model

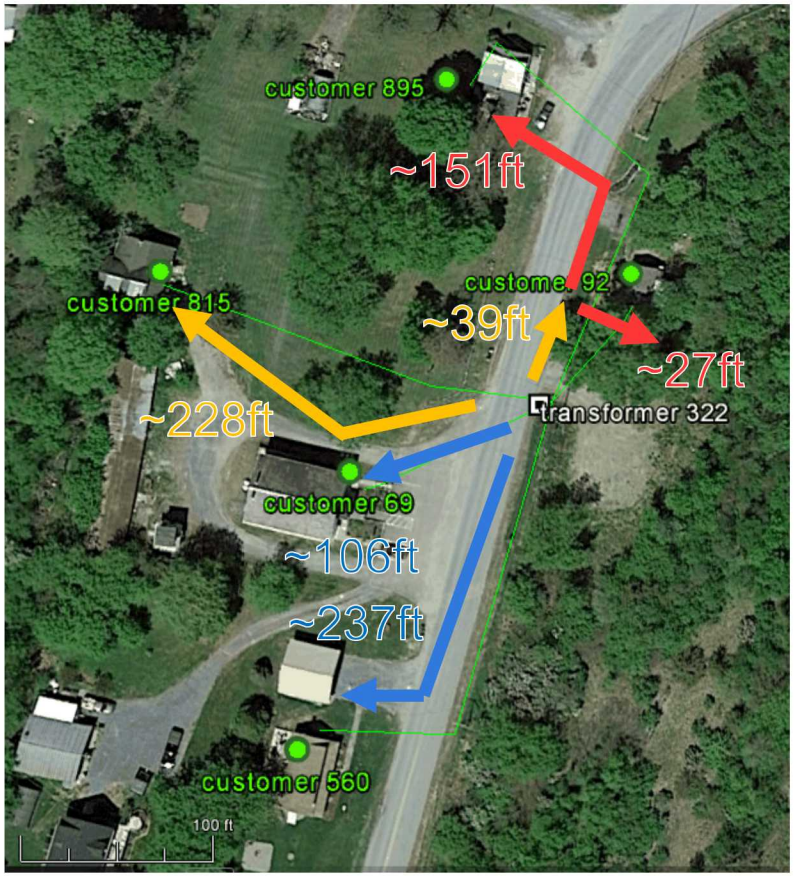


DSPE results indicate error in utility model: customer 595's meter is actually at the bottom of the utility pole, not at the house.

Transformer 322 on Feeder 1



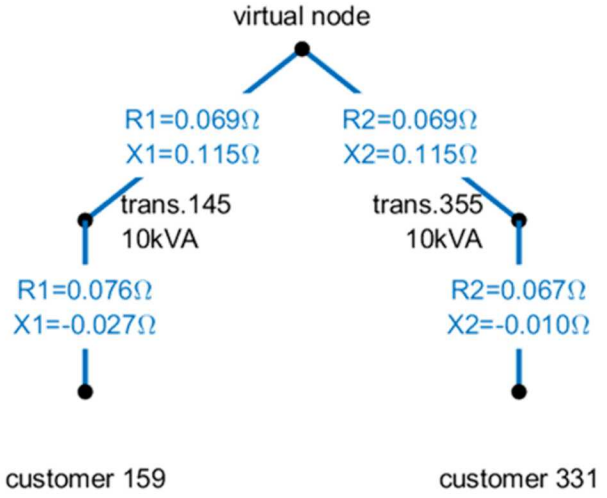


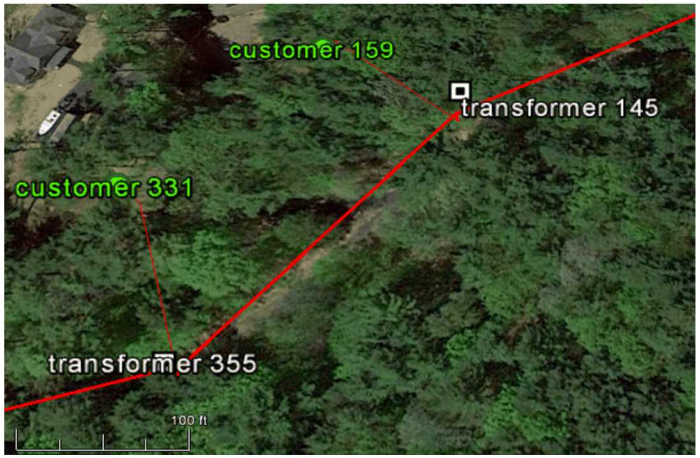


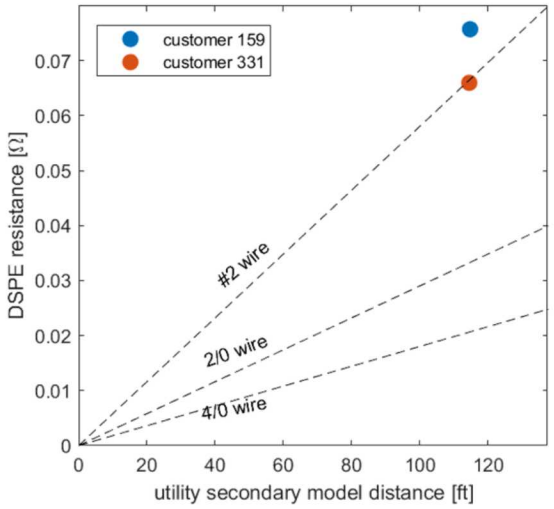
DSPE results consistent with utility model for several customers with complicated topology.

Step 2

- Pair customers on transformers with only one customer with other solo customers
  - Topology is always parallel – step 3 virtual node is on primary
  - Should always be additional resistance beyond the transformer due to the customer being located away from the transformer







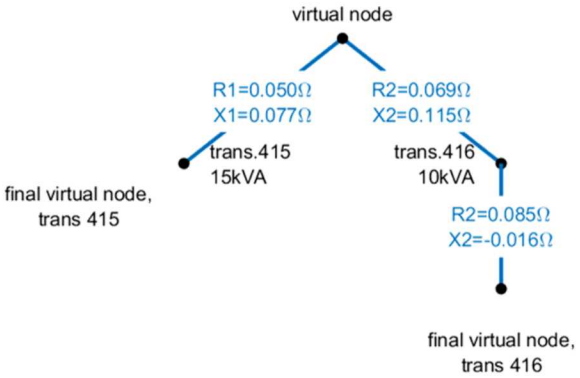
Step 3

- Pair transformers with one another, run parameter estimation on virtual nodes created in step 1
  - Topology is always parallel – step 2 virtual node is on primary
  - Most likely scenario is that virtual node from step 1 is at transformer low side and any found impedance will be due to transformer impedance
  - In some cases, step 1 virtual node will be away from transformer
    - Serial connection between customers
    - Parallel connection that meets before the transformer
    - It is important to derive the additional impedance to fully resolve the secondary circuit

Transformer size (kVA)	3	5	10	15	25	37.5	50	75
Assumed resistance	1.5%	1.5%	1.2%	1.3%	1.16%	0.96%	1%	0.87%

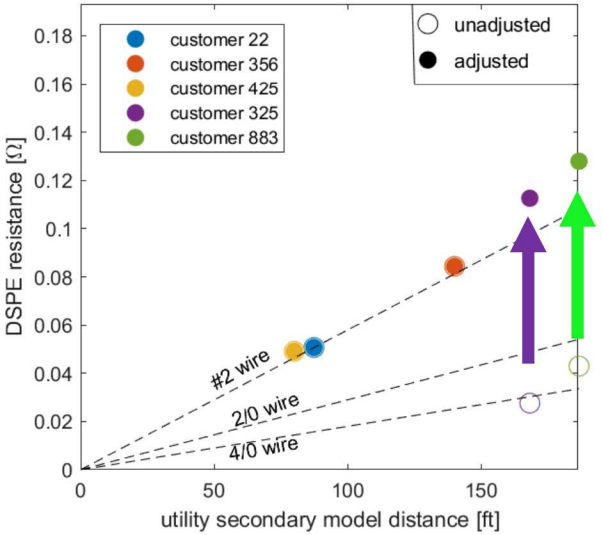
Transformers 415 and 416

Distribution System Parameter Estimation



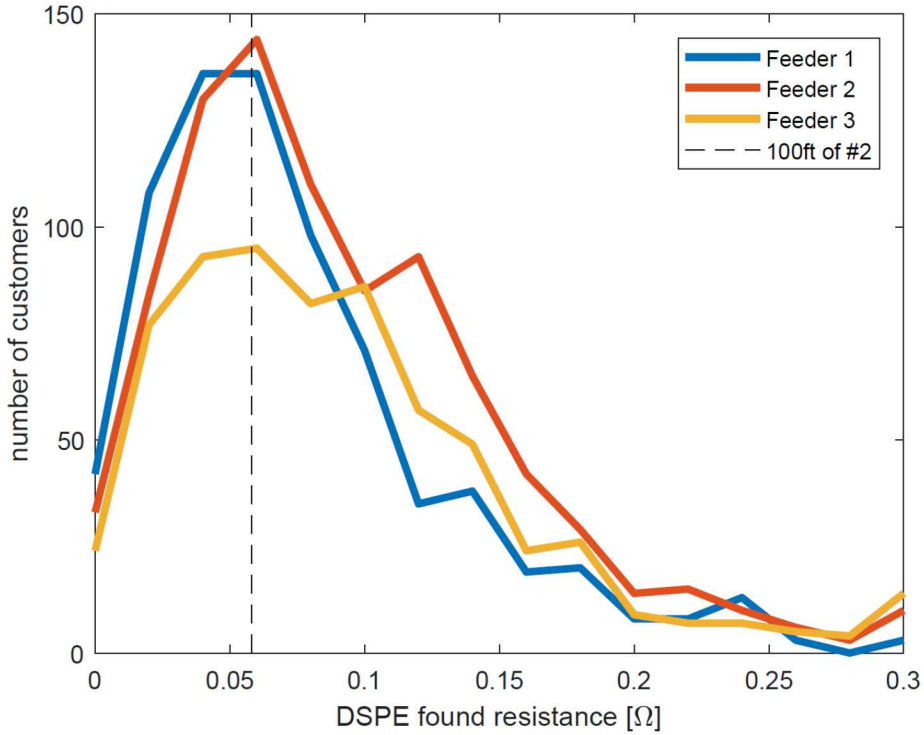
Imagery/Model

DSPE vs. Model



Customers 325 and 883 (on transformer 416) had a virtual node away from the transformer, which is accounted for by pairing transformer 415 with 416.

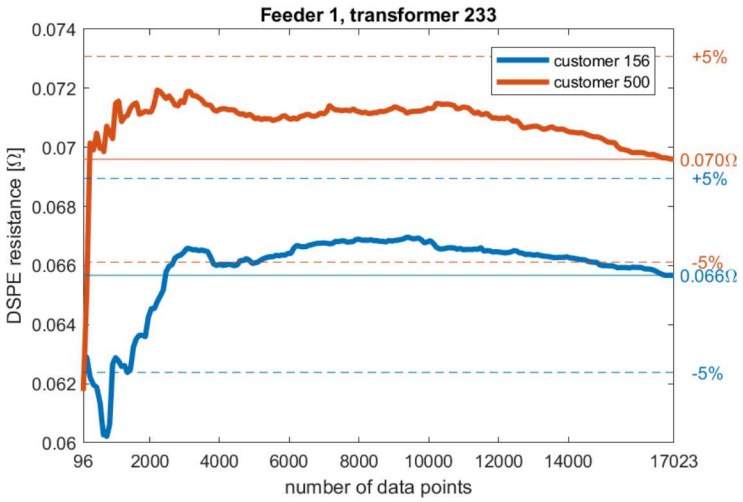
Results for Entire Feeders



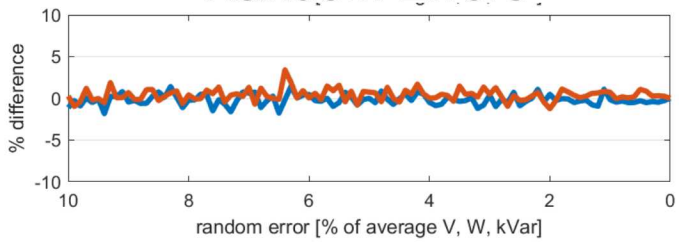
Customers often vary significantly from a simple 100ft of #2 assumption: up to three times this value was common.

Sensitivity Analysis

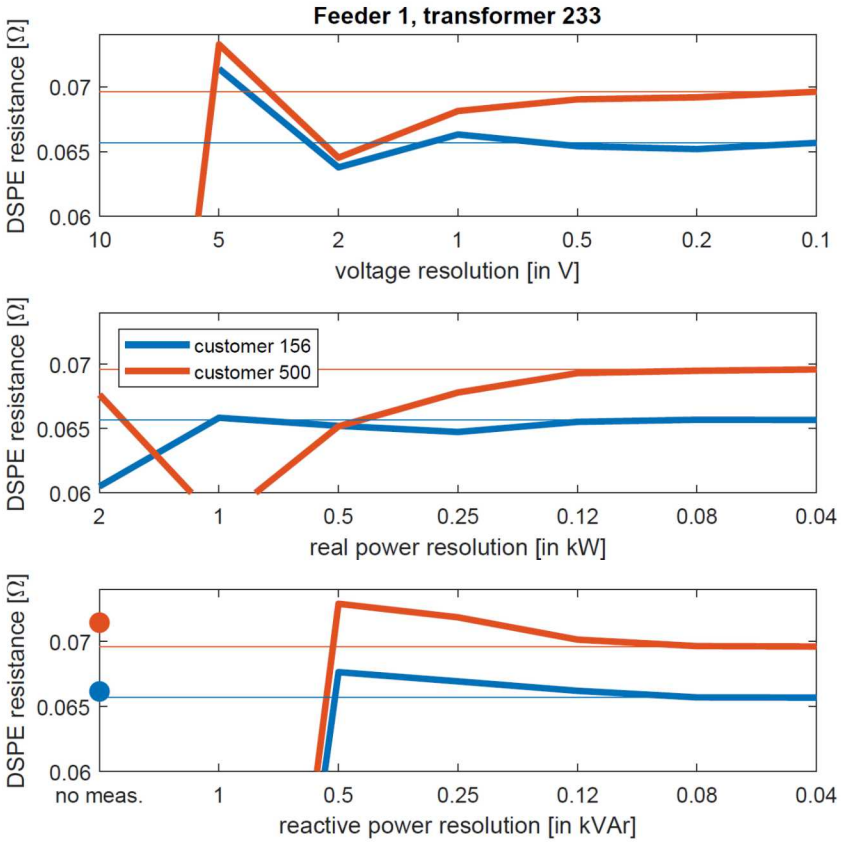
Amount of Data



Random Errors



Data Resolution



- Over all customers, found ~8,000 data points (<3 months of 15-min data) sufficient to accurately derive parameters and topology.
- Need about 2V and 0.25kW or better resolution; low kVAr sensitivity
- Random errors in measurements => random errors in DSPE

Summary

- Parameter and topology method successful in creating an enhanced model of the low-voltage secondary system for three distinct feeders
- Results highlighted potential errors in the existing secondary model
- If no secondary model exists results could have been used to create one
- Enhanced secondary models enable more accurate hosting capacity analysis, better understanding of advanced inverter actions such as volt/var, and efficient operational strategies such as conservation voltage reduction

- Ongoing challenges/additional work
  - Data availability: need power and voltage at regular intervals (some utilities do not have AMI or only measured power)
  - How to handle bad/missing data
  - Validation (manually intensive – satellite imagery / street view)
  - Accurate transformer -> customer and transformer phase details
  - Implementation into feeder models