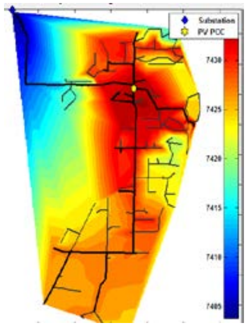

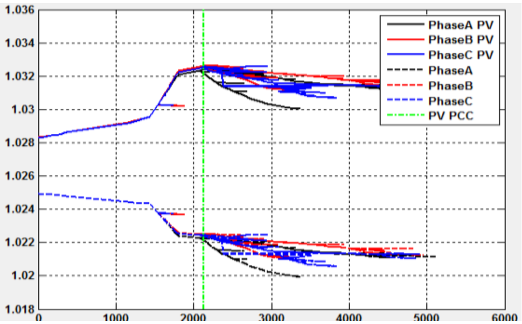

Exceptional service in the national interest

Parameter and Topology Estimation using Utility AMI Data

Matthew Lave

Sandia National Laboratories

Grid Integration Track of PV Systems Symposium

May 3rd, 2018

Albuquerque, NM

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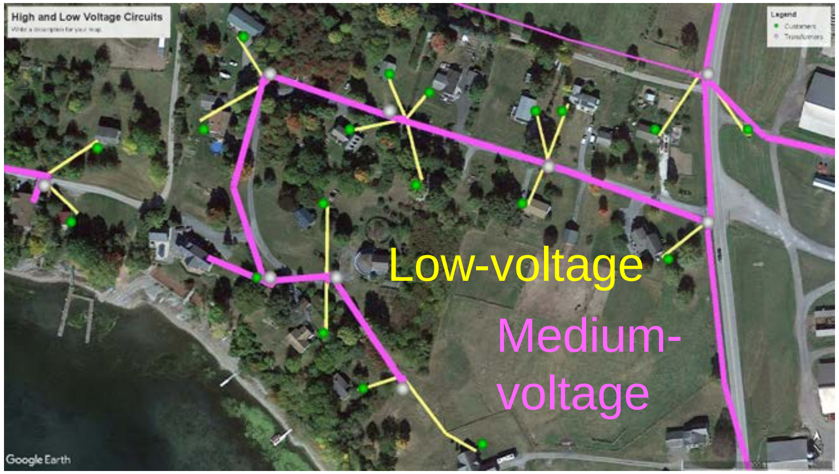
Parameter and Topology Estimation

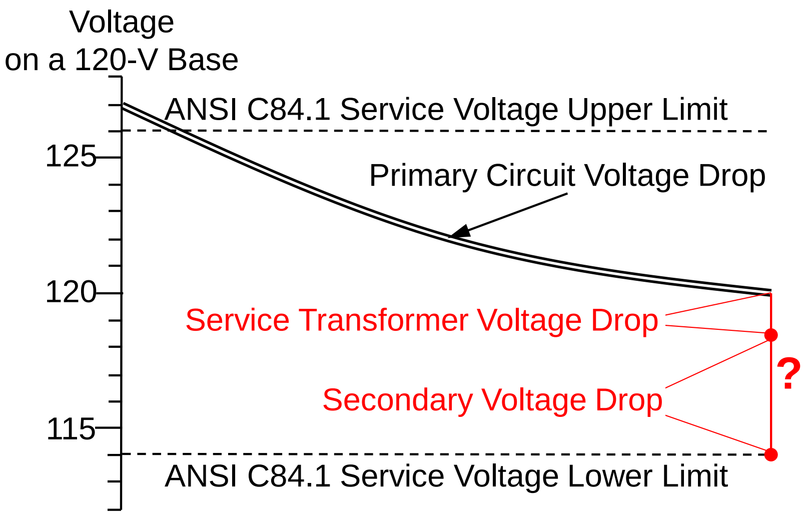
- Utility customer meter (AMI) voltage and power measurements to resolve distribution grid secondary (low-voltage):
  - Parameters – resistance and reactance from transformer to customer
  - Topology – arrangement (series or parallel) of customers connected to the same transformer

- Result: more detailed and accurate distribution grid modeling
  - Hosting capacity
  - PV volt/var response
  - Conservation voltage reduction

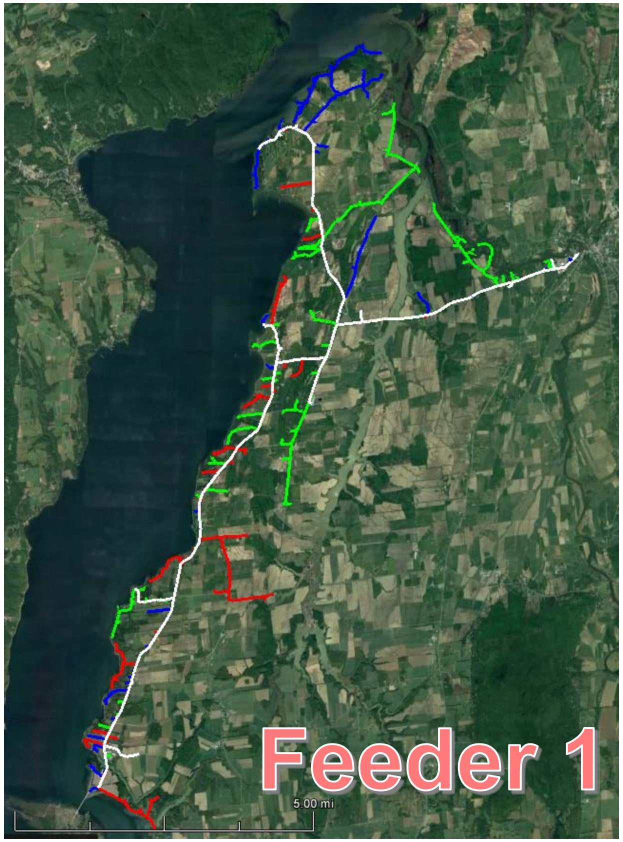


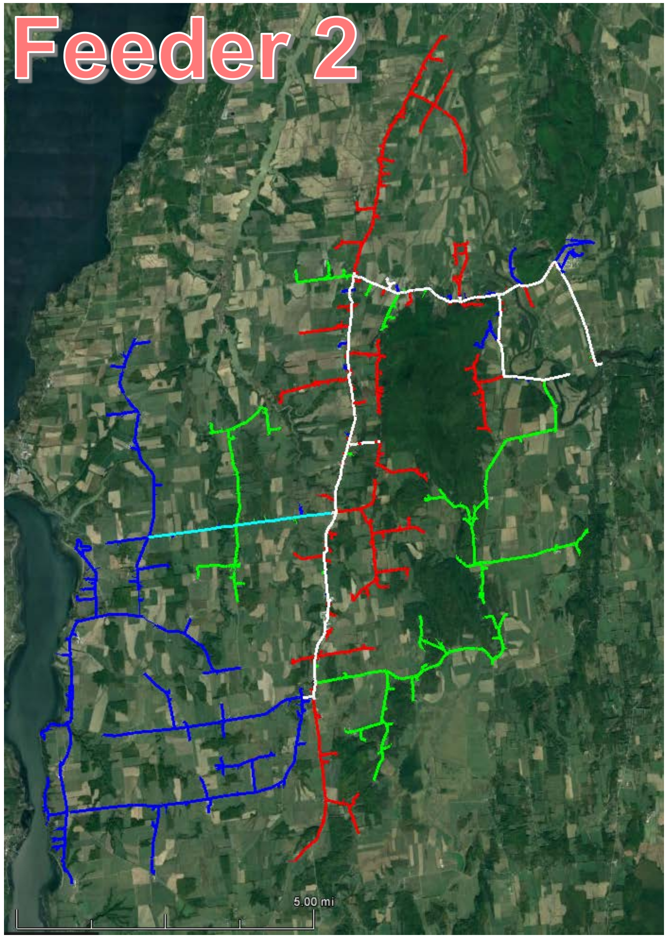
Need for Detailed Secondary Models

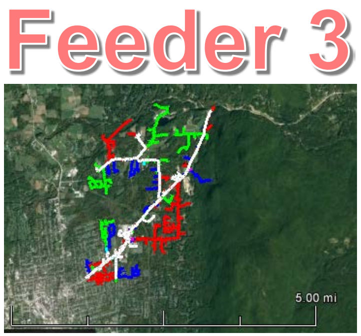
- Distribution system secondary (low-voltage) circuit models are typically not modeled or modeled with limited detail
- It is becoming important to have accurate secondary circuit models
  - A large number of DERs and sensors are connected to the secondary circuits
  - A large portion of the per-unit 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







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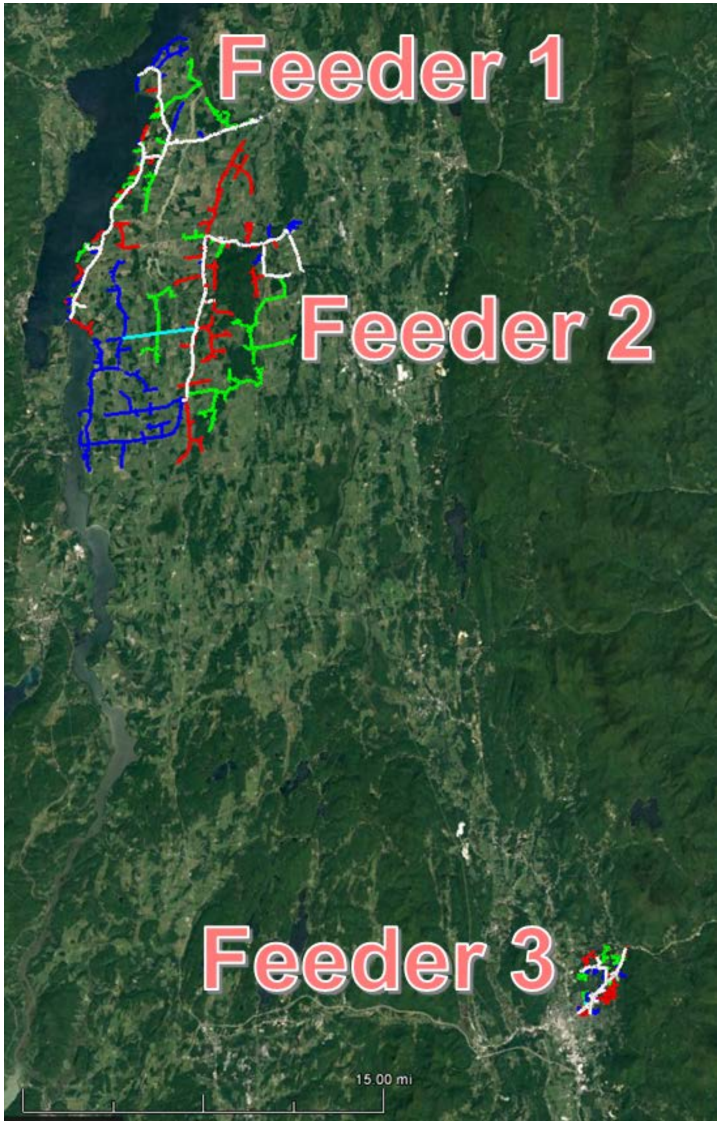
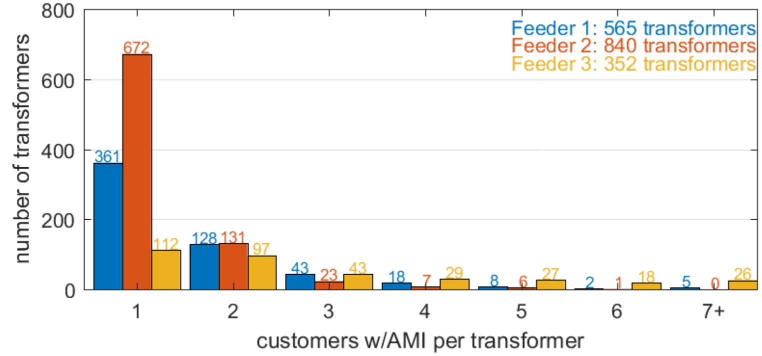
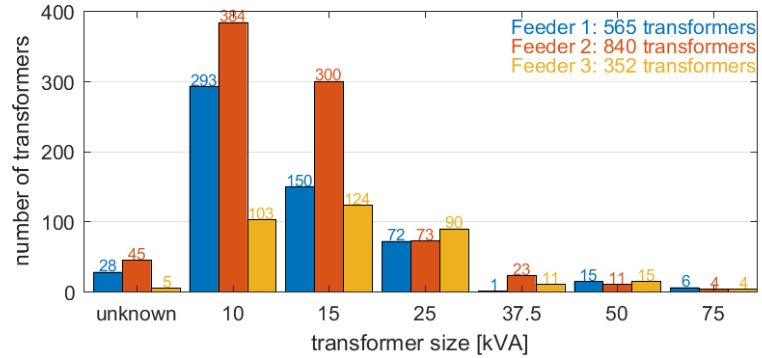
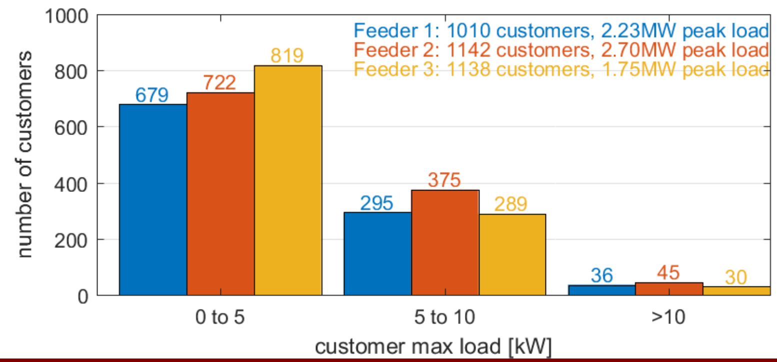


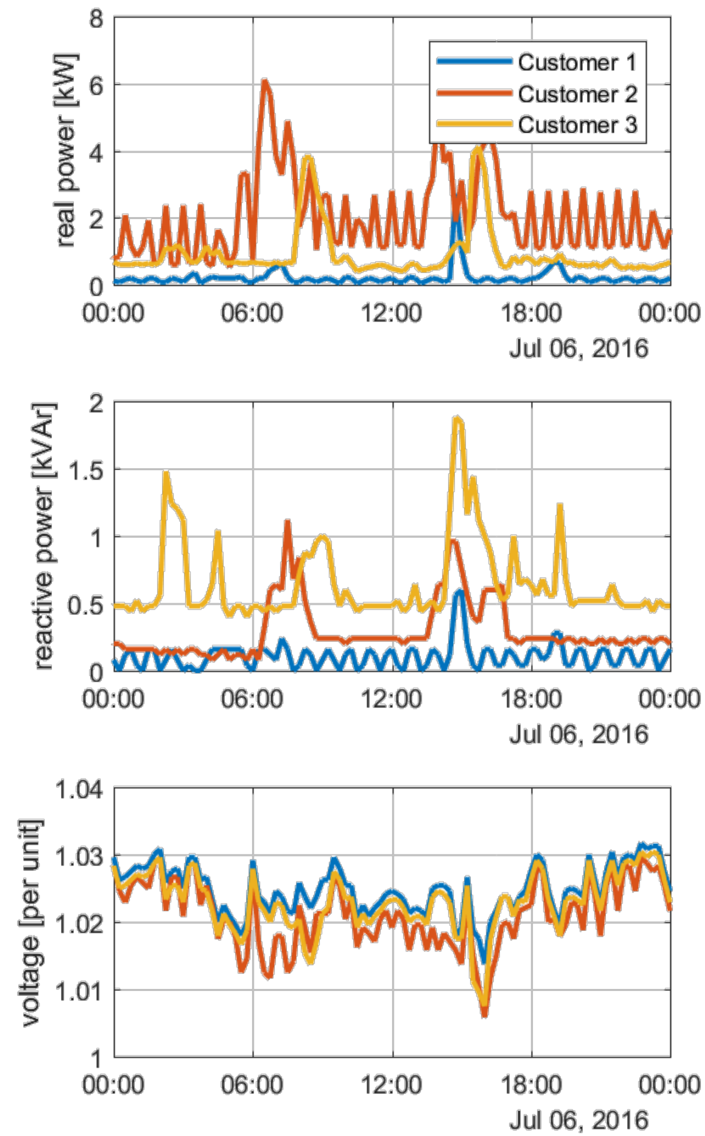






Data

- 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 some 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.

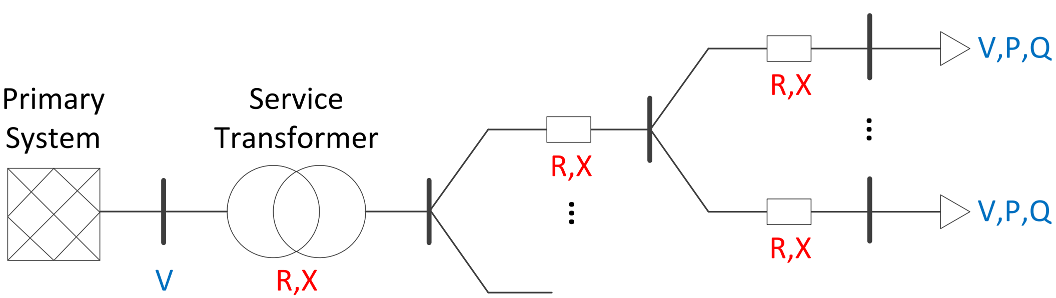
Step 1

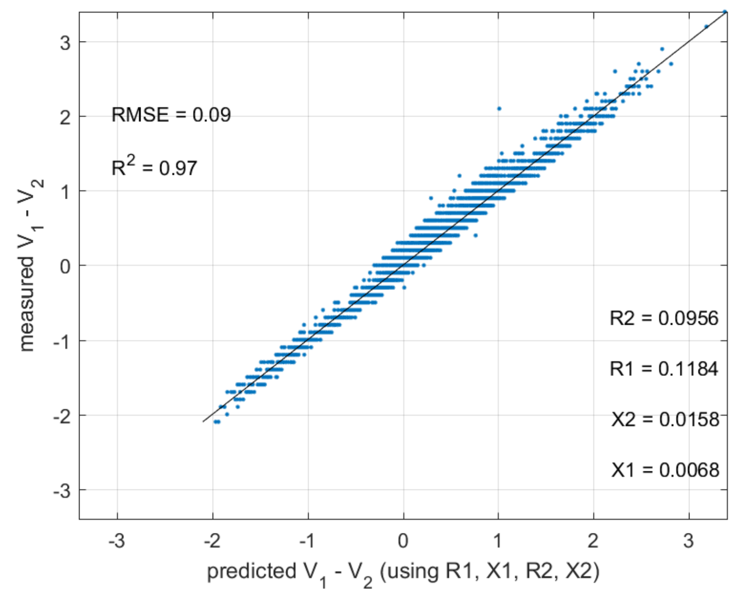
- For all customers on a transformer, find R1, R2, X1, X2

$$V_1 - V_2 = I_{R1}R_1 + I_{X1}X_1 + I_{R2}R_2 + I_{X2}X_2 + \epsilon$$

Known Unknown

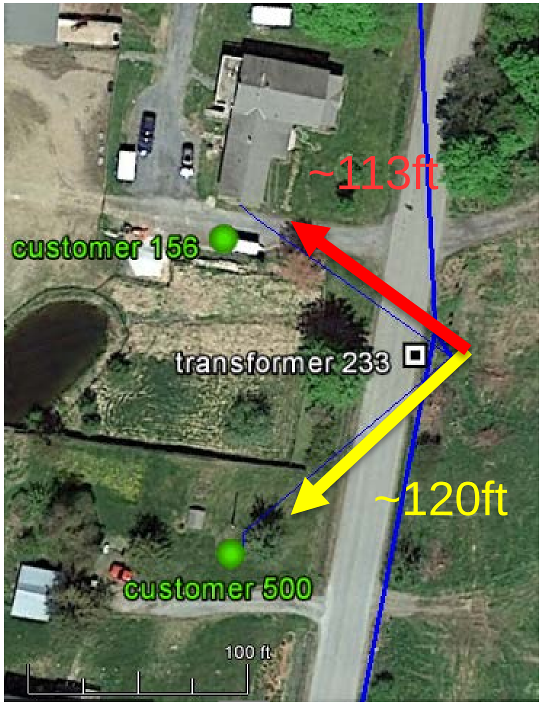
- Basic concept
  - Fit R1, R2, X1, X2 values which best fit the V1-V2 fluctuations

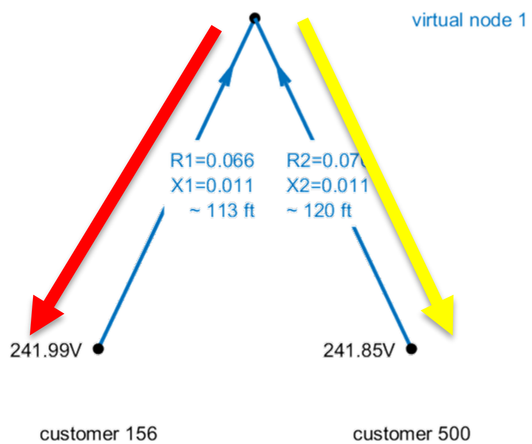


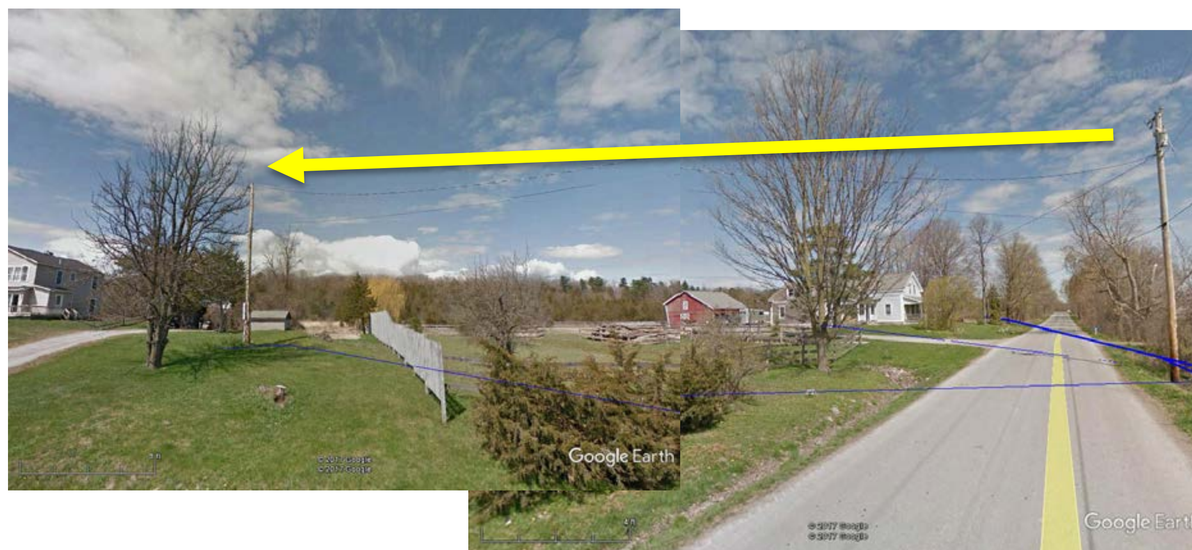


- For comparison to satellite imagery
  - R values were used to compute a distance in feet of triplex cable, assuming 0.058Ω/100ft (2/0 triplex)

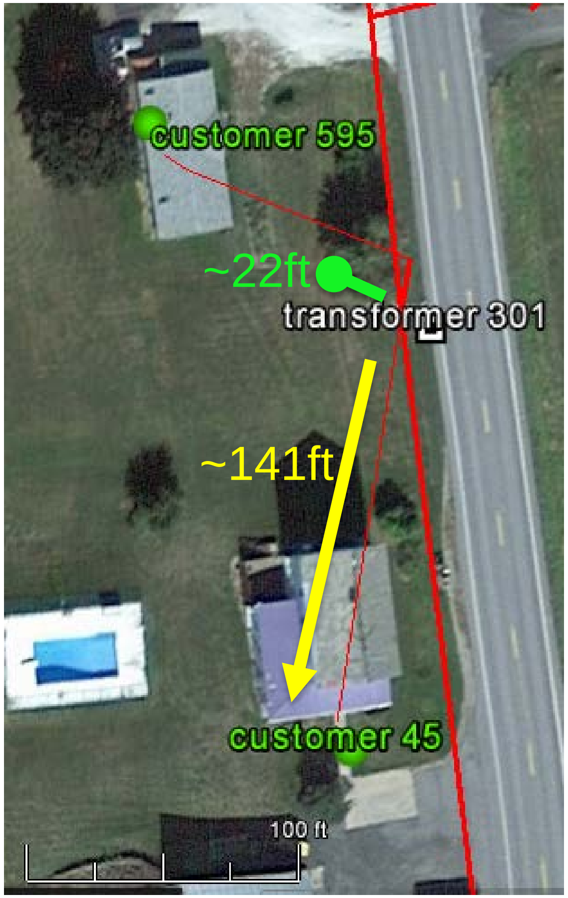
Transformer 233 on Feeder 1

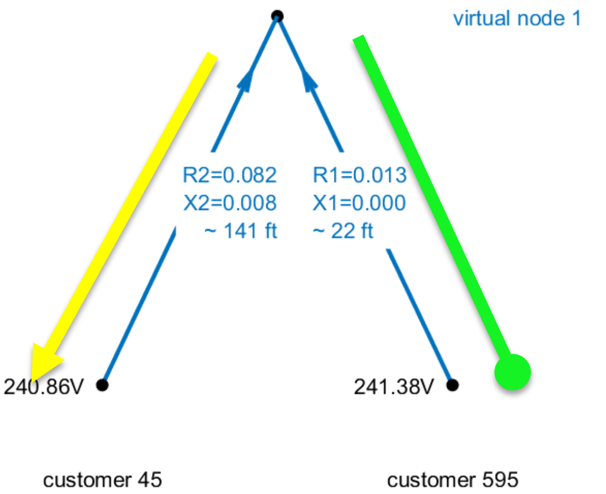




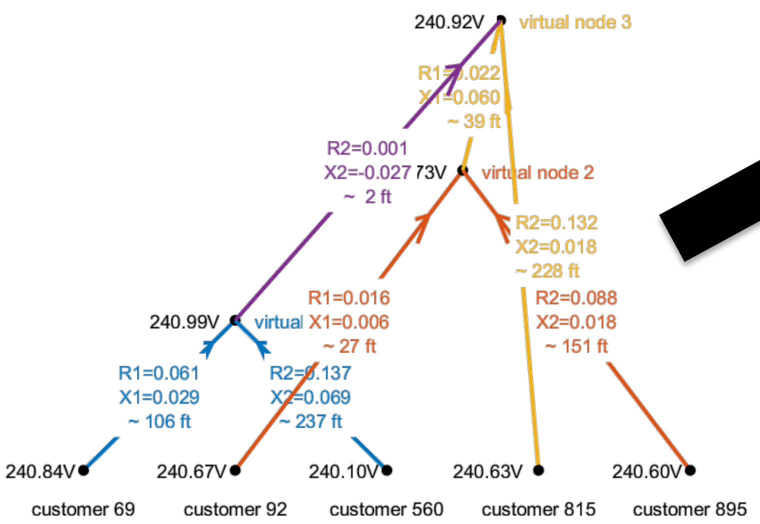


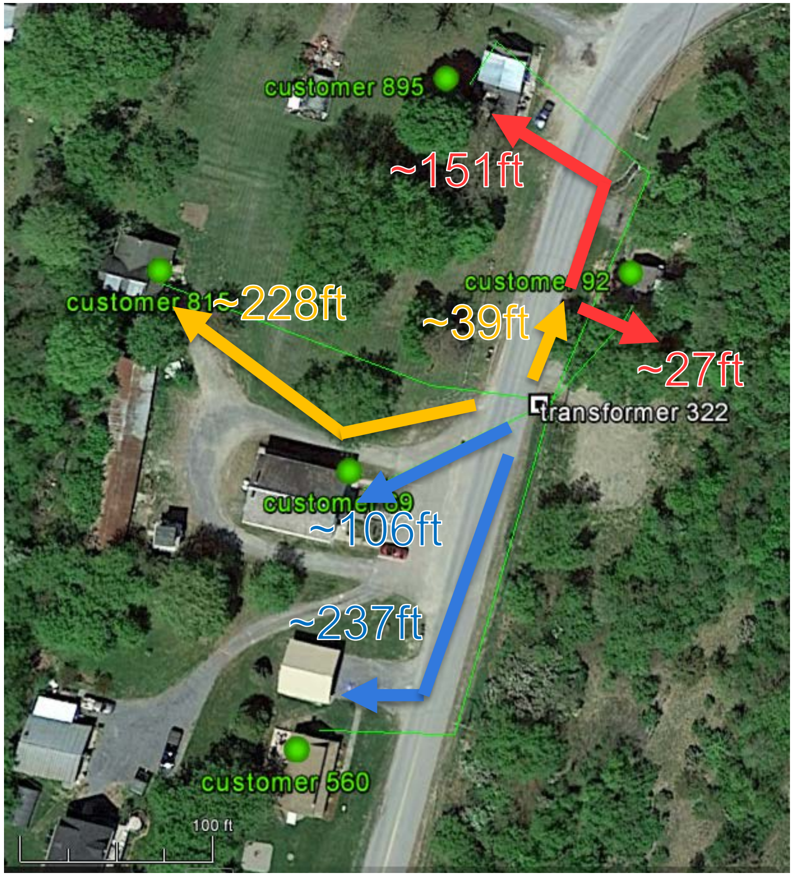
Transformer 301 on Feeder 2





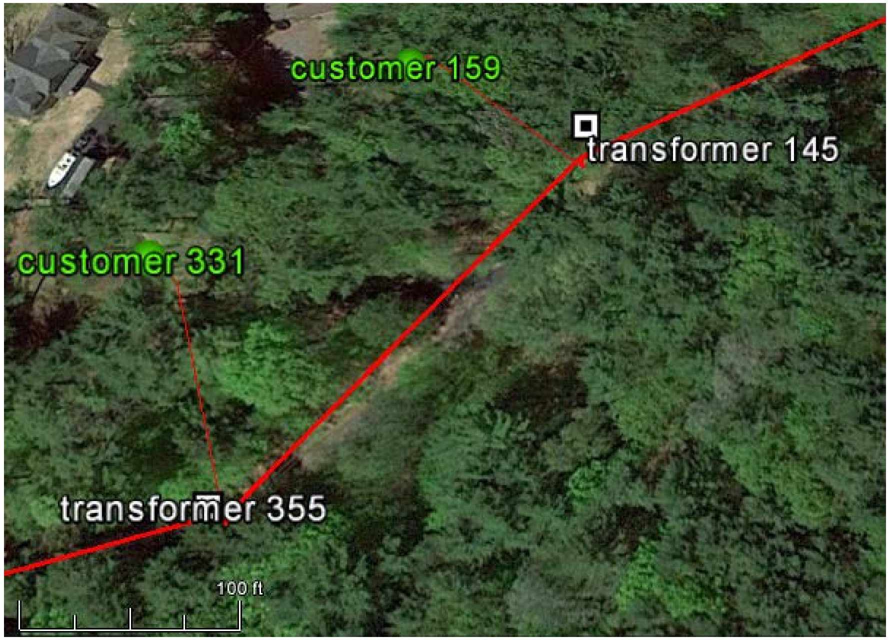
Transformer 322 on Feeder 1

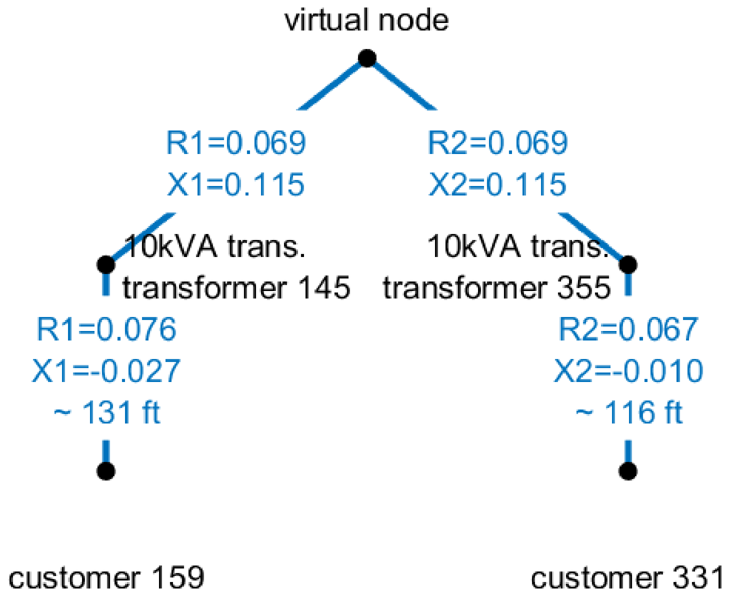




Step 2

- 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



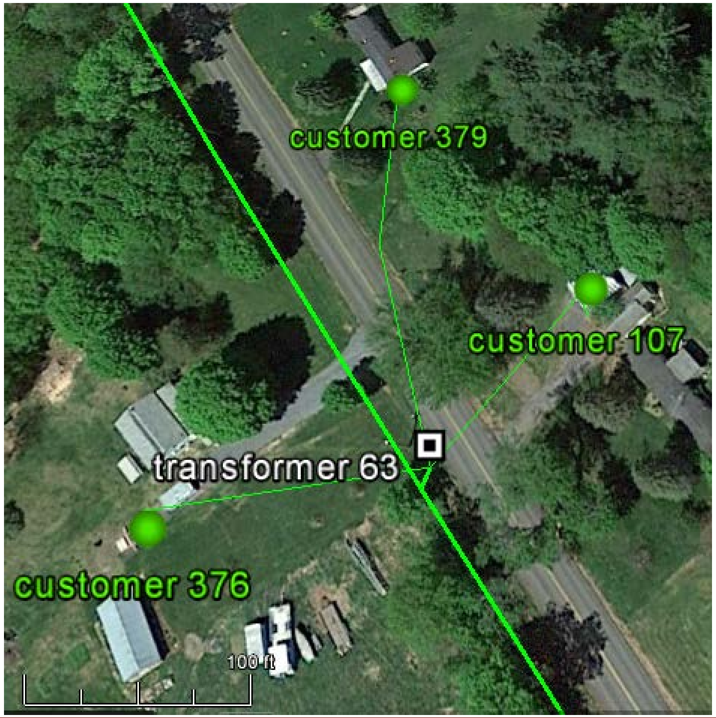


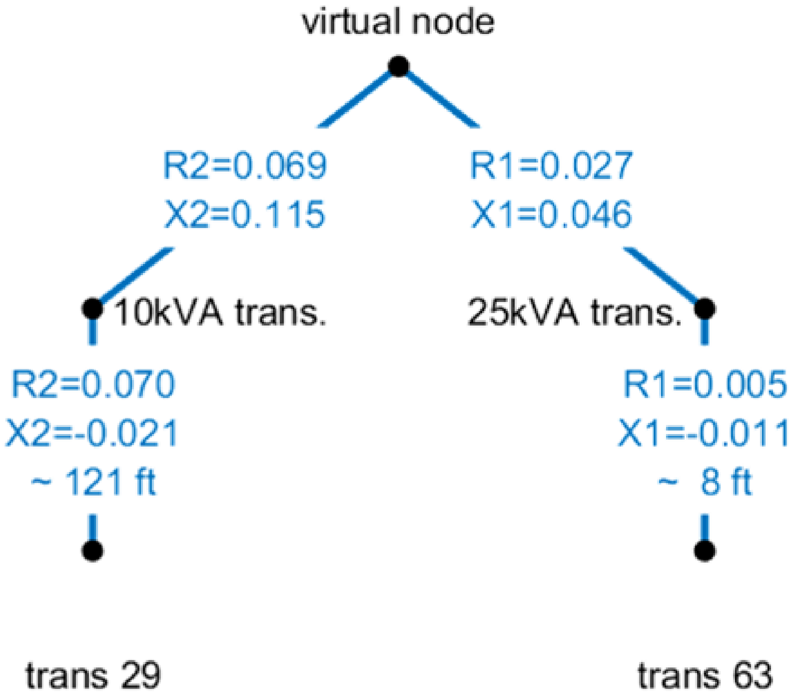
Step 3

- 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%

Transformer 29 on Feeder 1

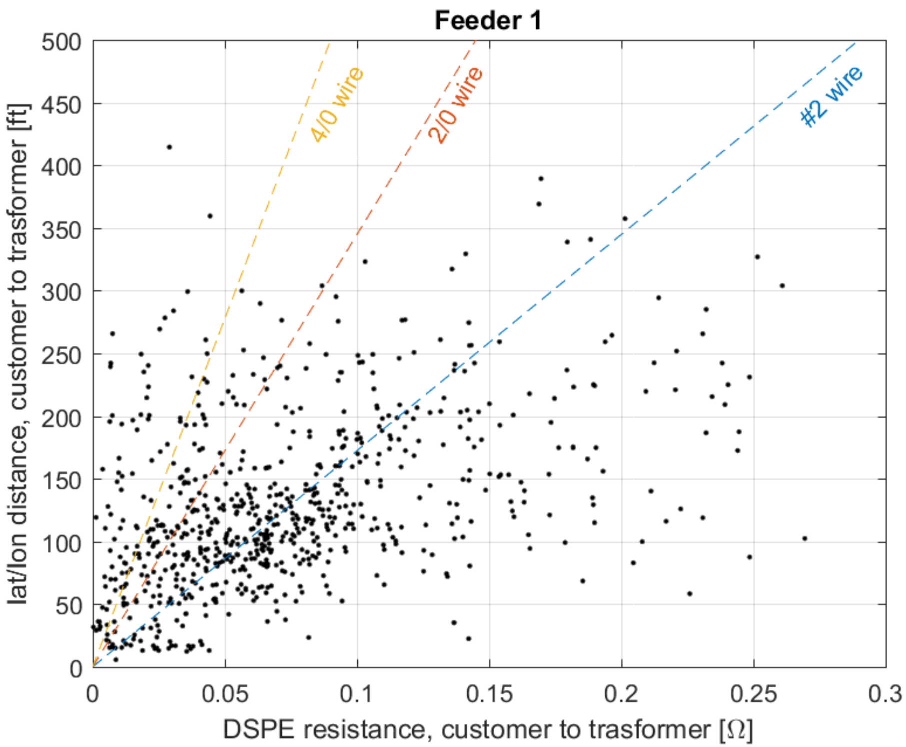




Results for Entire Feeders

- Ran all transformers with > 1 customer, all transformer pairs, and all single customer pairs for Feeders 1, 2, and 3
- Filtered out:
  - Customers with <1 week (4*24*7) of data
  - Customers with clearly errant voltage data (e.g., >>1 or <<1 p.u.)
- Compared resistance found to distances for a direct path based on latitude/longitude
  - Several reasons why lat/lon distances may disagree
    - Customer location is wrong in lat/lon
    - Customer meter is not at same location as customer
    - Circuitous wire route
    - Transformer -> customer mapping is incorrect

Feeder 1 Summary of Results



Reasons why PE > lat/lon (bottom right)

- Circuitous wire routing
- Lat/lon at wrong location (e.g., at transformer)
- Wire higher resistance than assumed 2/0

Reasons why PE < lat/lon (top left)

- Meter closer to transformer than house (e.g., before wire goes underground)
- Incorrect transformer – customer pair
- Wire lower resistance than assumed 2/0

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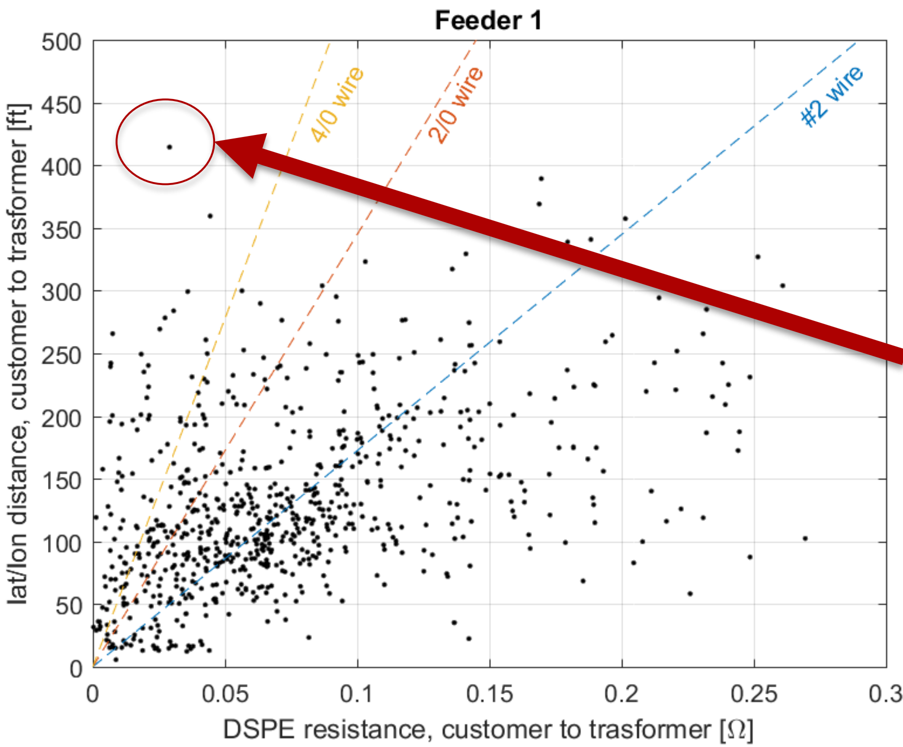
Feeder 1 Summary of Results



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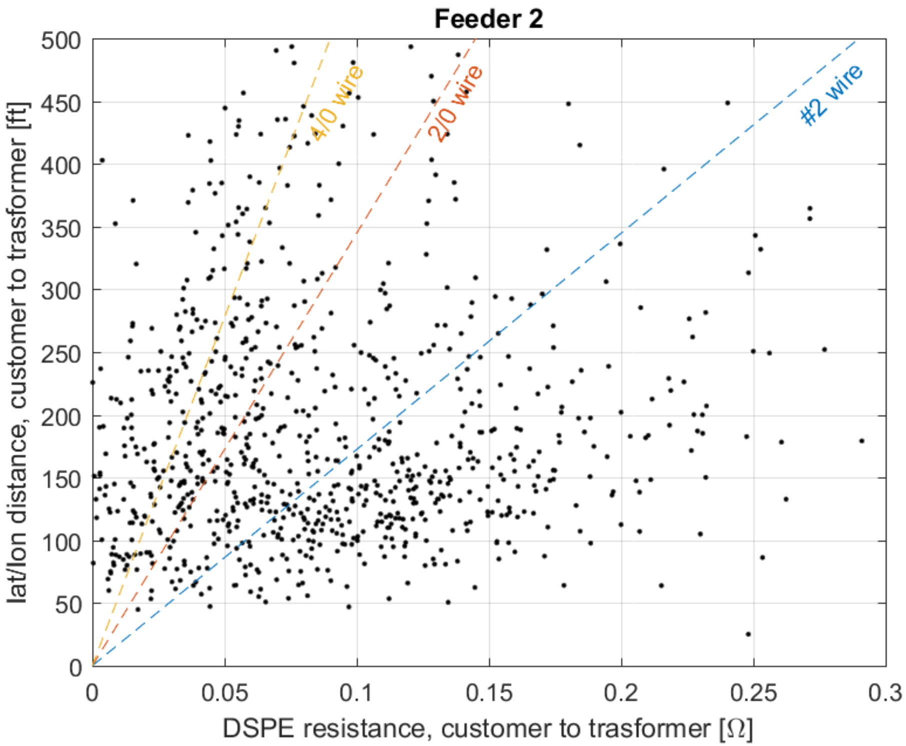
Feeder 2 Summary of Results



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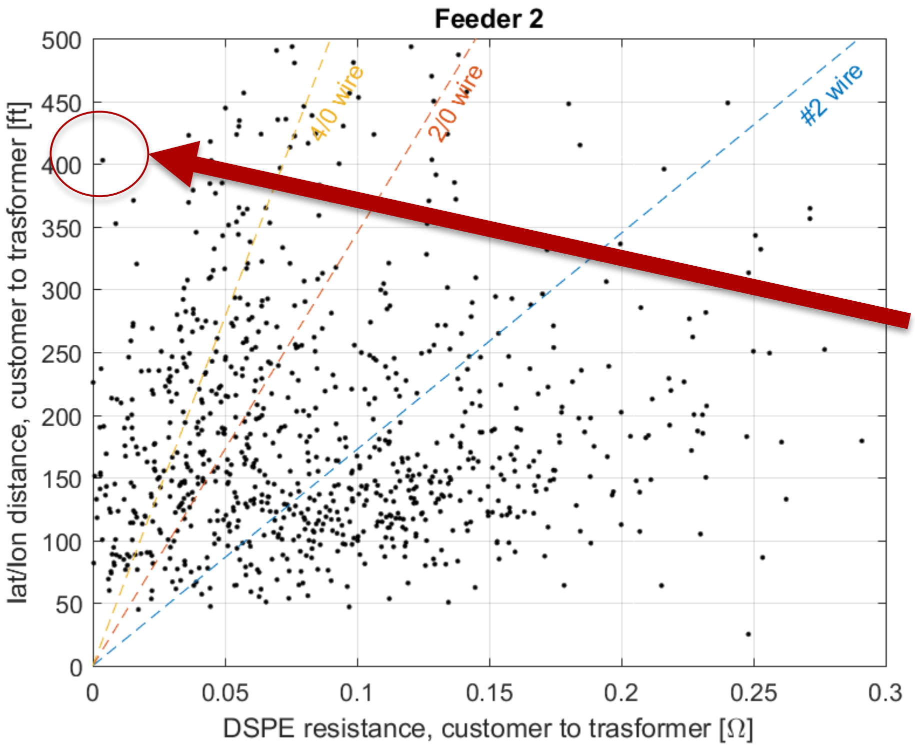

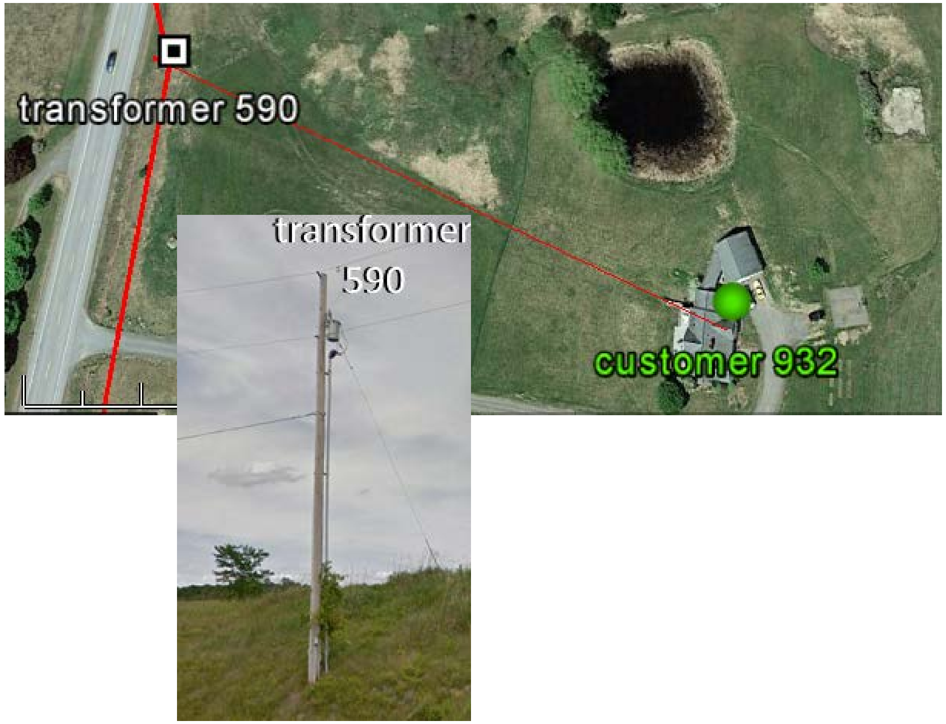

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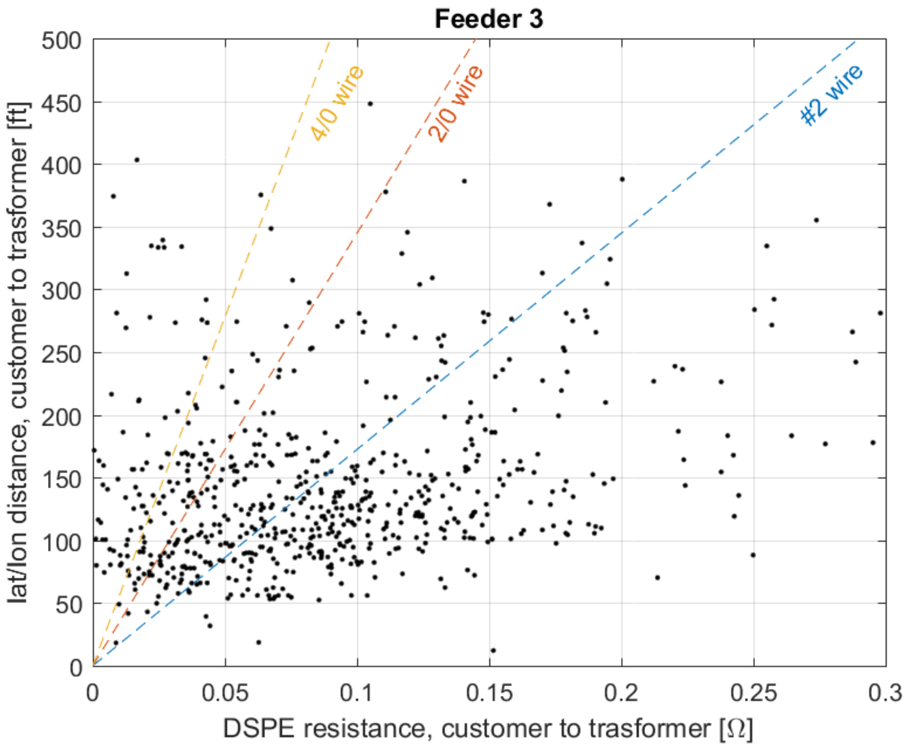
Feeder 3 Summary of Results



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- Circuitous wire routing
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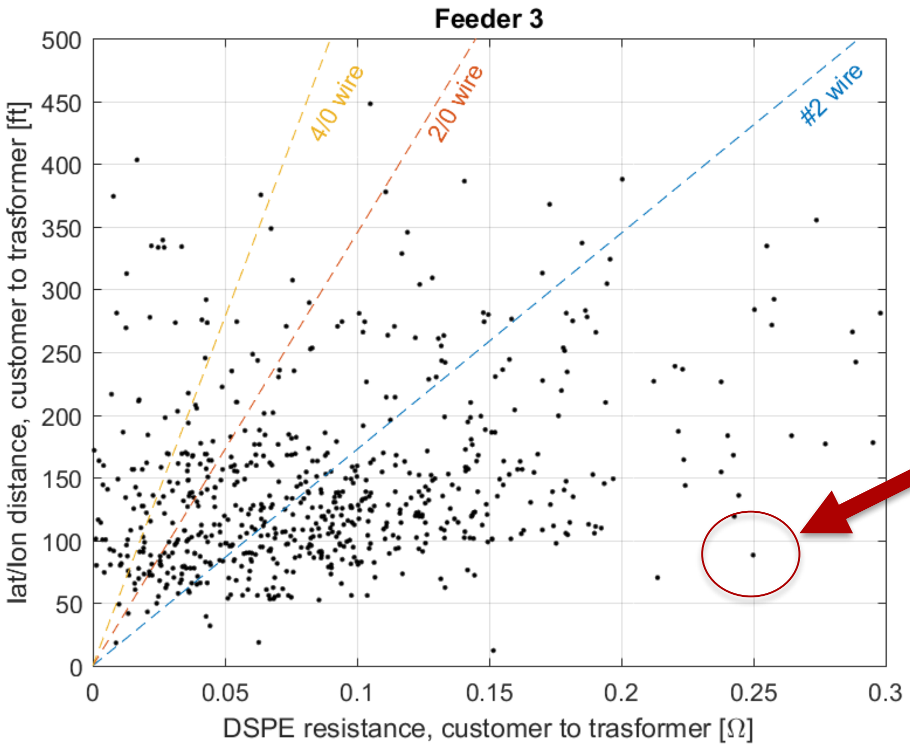
- Wire higher resistance than assumed 2/0

Reasons why PE < lat/lon (top left)

- Meter closer to transformer than house (e.g., before wire goes underground)
- Incorrect transformer – customer pair
- Wire lower resistance than assumed 2/0

Feeder 3 Summary of Results



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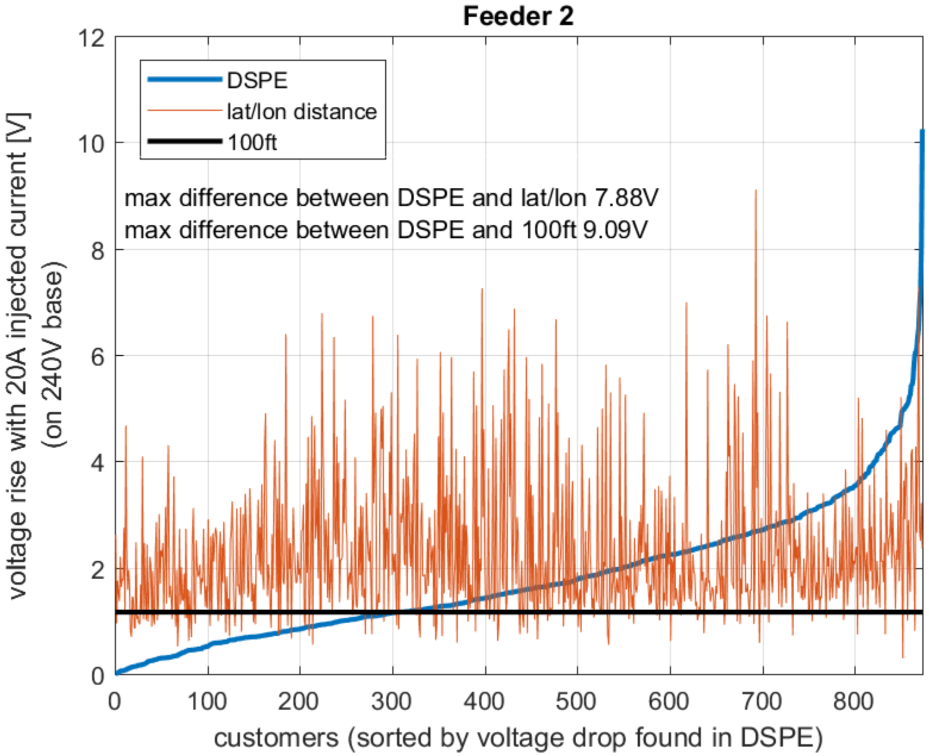
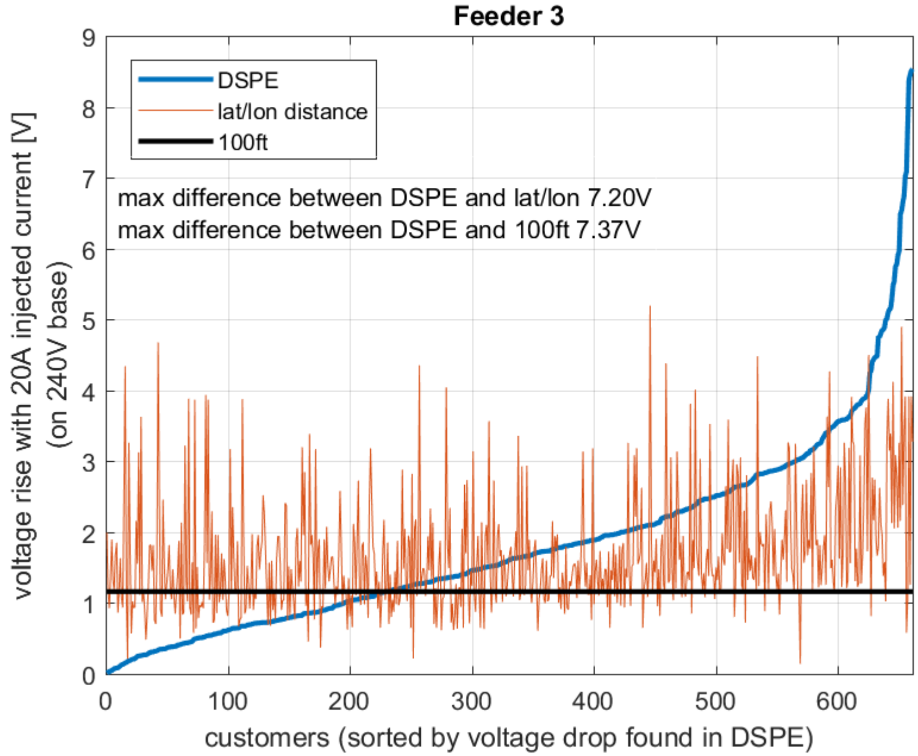
Impact on Voltage Estimates





Customer voltages vary between the methods

- Up to 7V differences in lat/lon or 100ft versus parameter estimation
  - Could result in voltage violation and/or unexpected advanced inverter behavior (e.g., if set to volt/var)
  - 100ft estimation often (>50% of the time) underestimates the voltage rise
  - Lat/lon distances often overestimated the voltage rise due to many meters on pole (then underground wiring to house)

Summary

- Parameter and topology method successful in creating an enhanced model of the low-voltage secondary system for three distinct feeders
- Results highlighted quickly 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 (extremely manually intensive – Google Street View)
  - Accurate transformer -> customer and transformer phase details
  - Further automation including implementation into feeder models