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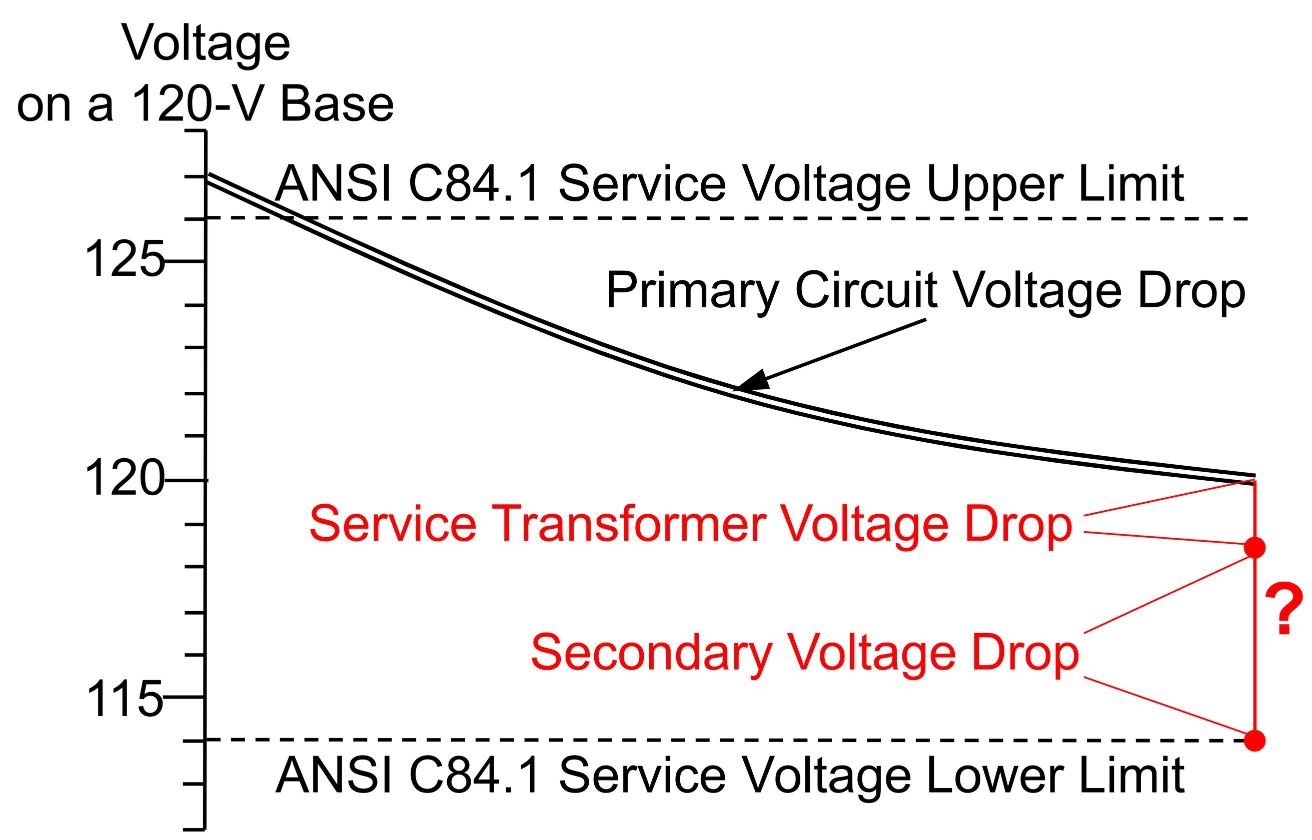
Distribution System Low-Voltage Circuit Topology Estimation using Smart Metering Data

Jouni Peppanen[1], Matthew J. Reno[2], Robert J. Broderick[2], Santiago Grijalva[1]
[1]Georgia Institute of Technology, Atlanta, GA, USA
[2]Sandia National Laboratories, Albuquerque, NM, USA

Motivation

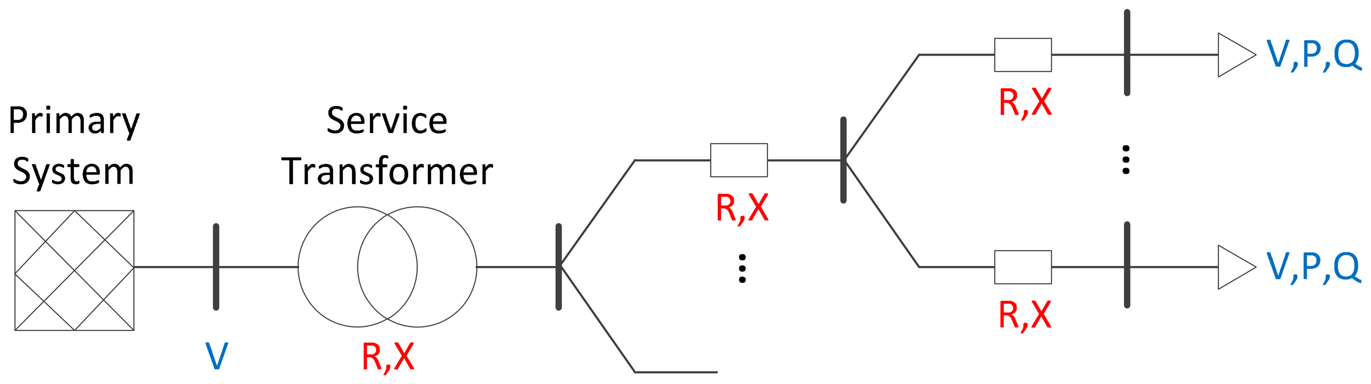
Operating distribution systems with a growing number of distributed energy resources (DERs) requires accurate feeder models down to the point of interconnection.

Many DERs are located in the secondary low-voltage distribution circuits that typically are not modeled or modeled with low level of detail.



Topology Estimation Objective

Identify secondary circuit topology and series impedance parameters (below in red) using the measurements from smart meters and DER (below in blue).



Infeasibility of Exhaustive Search

It would be a computationally demanding task to evaluate all the alternative topologies even with 5 to 7 meters.

# Leafs	1	2	3	4	5
# Trees	1	3	22	262	4,336
# Leafs	6	7	8	9	10
# Trees	91,984	2.38e6	72.8e6	2.57e9	1.03e11

Topology Estimation Algorithm

The algorithm is based on the widely used linearized voltage drop approximation

$$V_{drop} = V_1 - V_2 \approx (RP + XQ)/V_2 = RI_R + XI_X$$

Build linear regression models for each meter pair

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

For the series meter connection (below on the left)

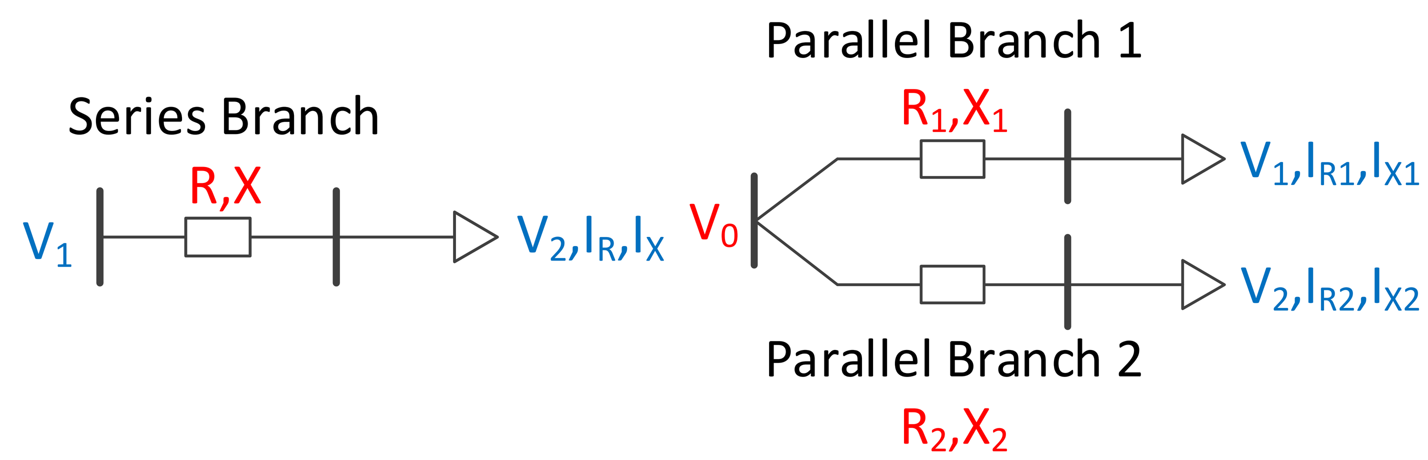
$$\boldsymbol{V}_1 - \boldsymbol{V}_2 = \boldsymbol{I}_R R + \boldsymbol{I}_X X + \boldsymbol{\epsilon}$$

And for the parallel meter connection (below on the right)

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

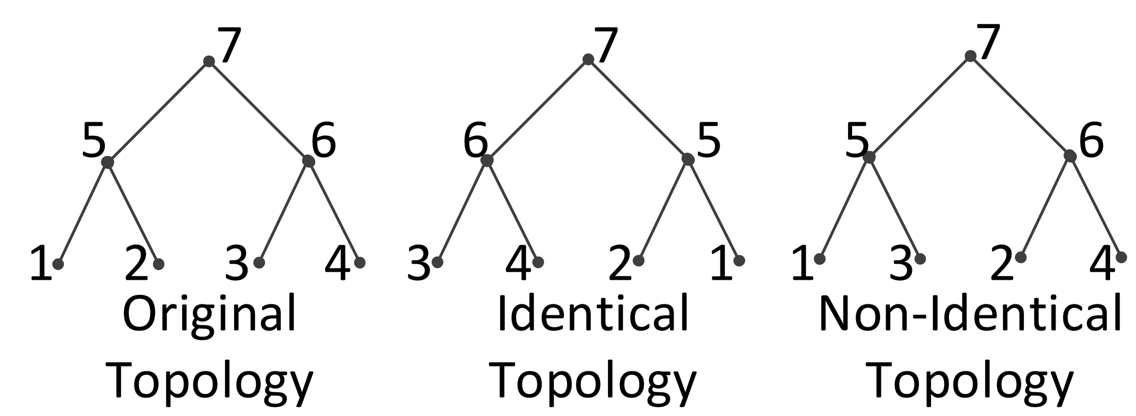
At each iteration, select the meter pair and the circuit type with the best regression fit.

Stop with an estimated secondary circuit (topology and R,X parameters) that includes all the meters.

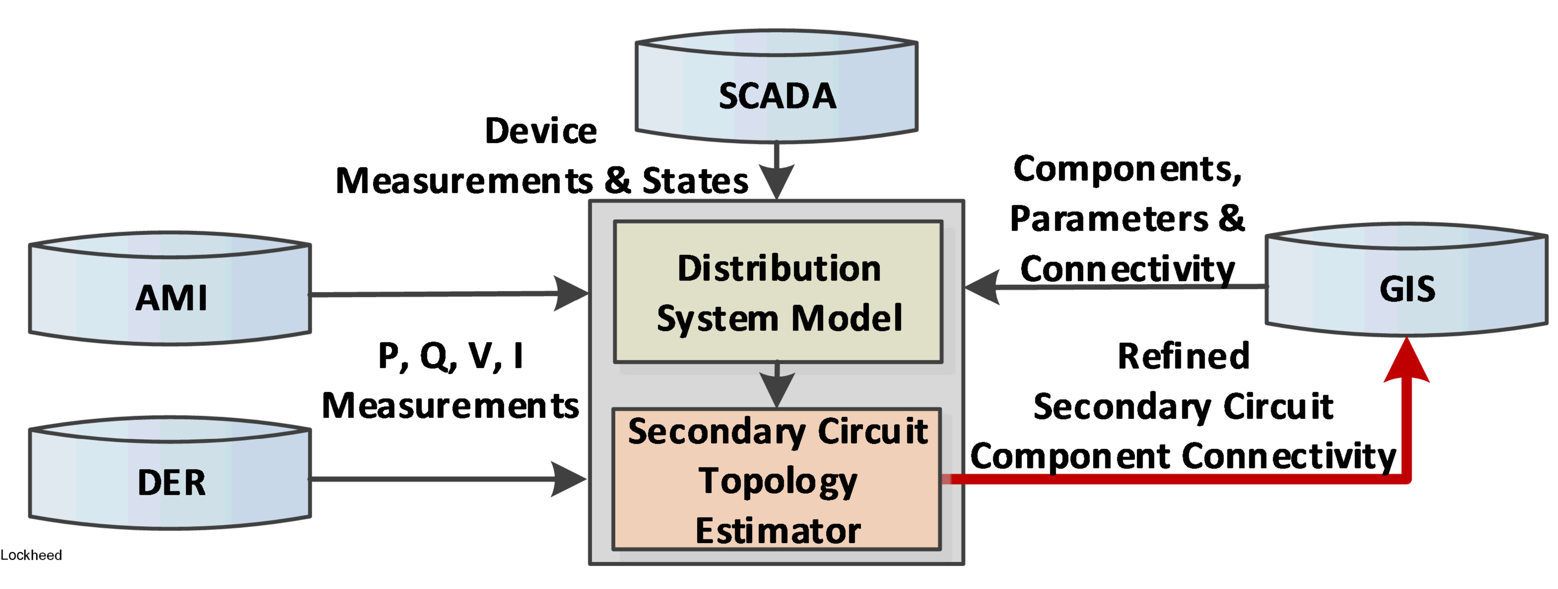


Topology Comparison Algorithm

The paper shows an efficient algorithm for comparing an estimated topology with a known secondary topology.



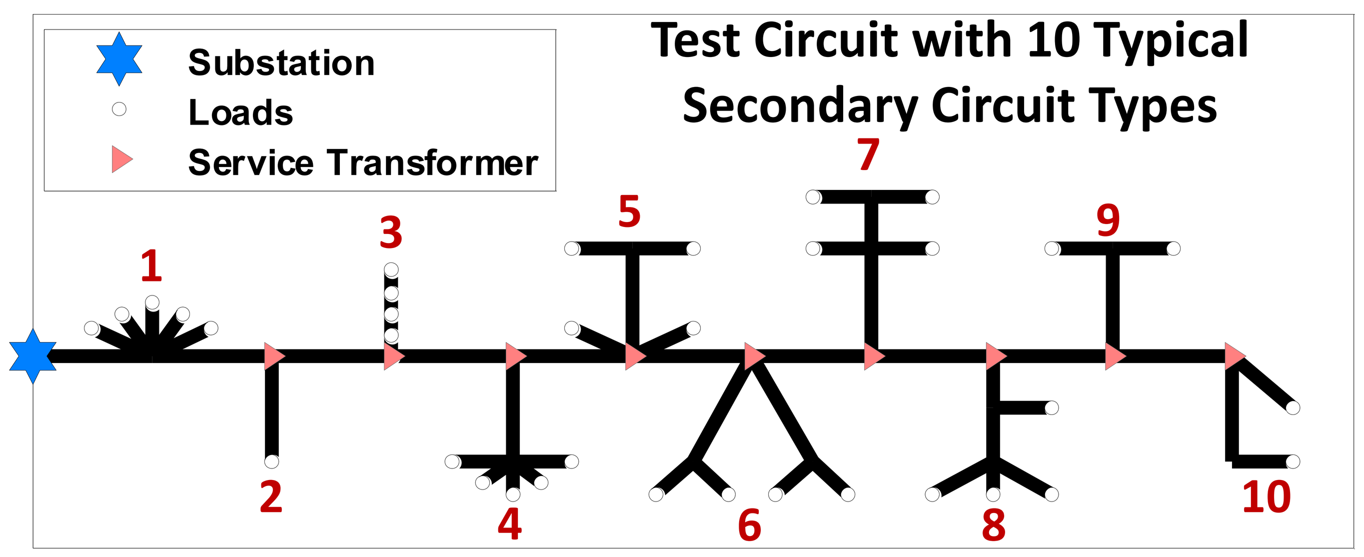
Practical Implementation



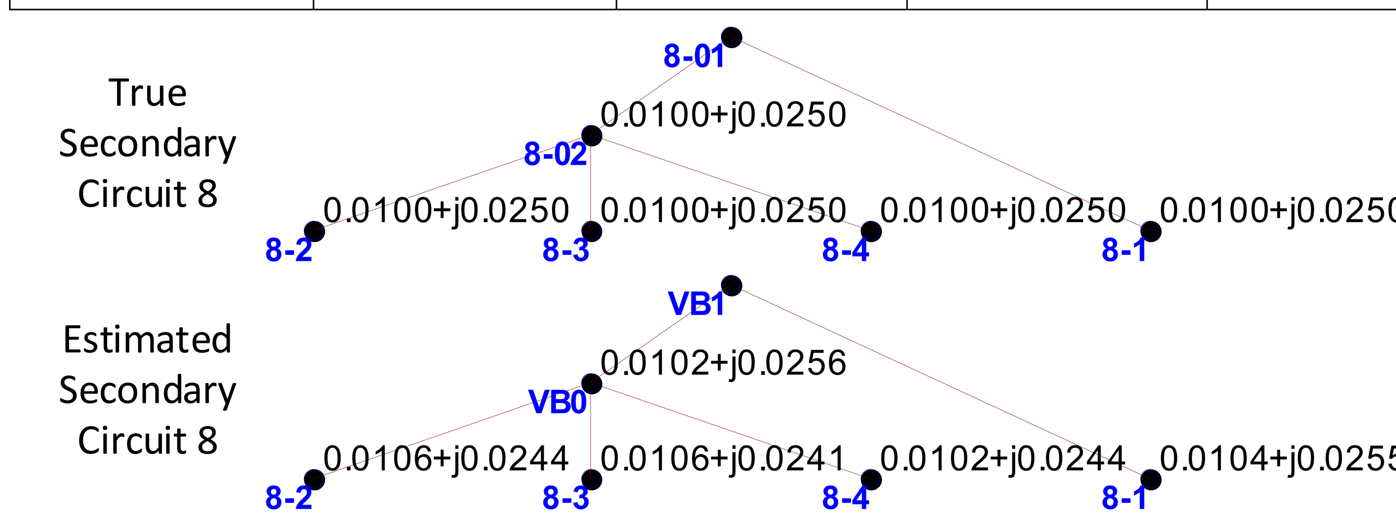
Topology Estimation Results

The topology estimation algorithm correctly estimates all the secondary circuit topologies of test circuit (figure below). The algorithm also accurately estimates the parameters (table below).

The algorithm also correctly estimates the topologies of most of the secondary circuits of a Georgia Tech feeder.



Meas. Error?	$R_{err,avg}$ [%]	$X_{err,avg}$ [%]	$R_{err,max}$ [%]	$X_{err,max}$ [%]
No	0.45	0.36	2.80	1.44
Yes	3.31	3.84	17.57	11.66



Conclusions

This paper shows:

- The infeasibility of exhaustive topology search
- Algorithm to compare whether two topologies are identical
- Computationally efficient and accurate greedy-type joint topology and parameter estimation algorithm.

The algorithm creates secondary models using only AMI/DER data (no additional information is required).

The algorithm is executed offline without the need of modifying any existing information systems.

The algorithm is executed within seconds for each secondary circuit even when thousands of measurement samples are used to counteract the accuracy, granularity, and time synchronization issues related to AMI and DER measurements

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