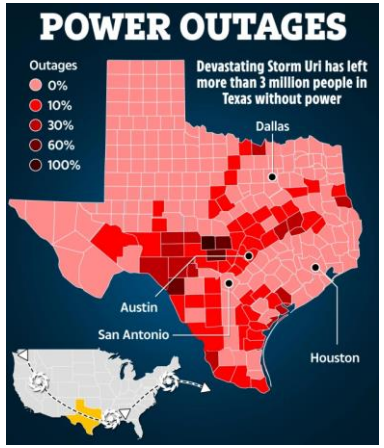
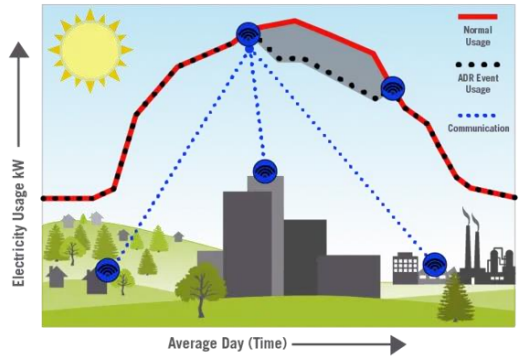
MOTIVATION

Aid public policy makers to deploy efficient plans for a decarbonized economy.



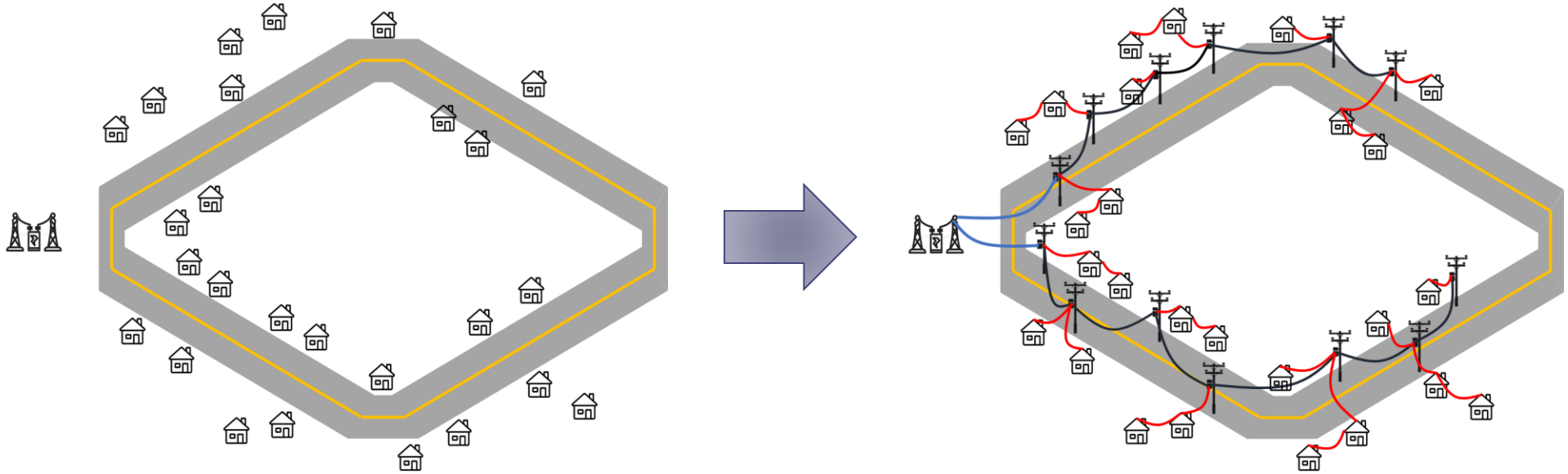


Utilities require emergency strategies to mitigate wide spread outages.

- Demand response program
- Direct load control

Extensive dataset of power distribution networks is necessary.

PROBLEM STATEMENT



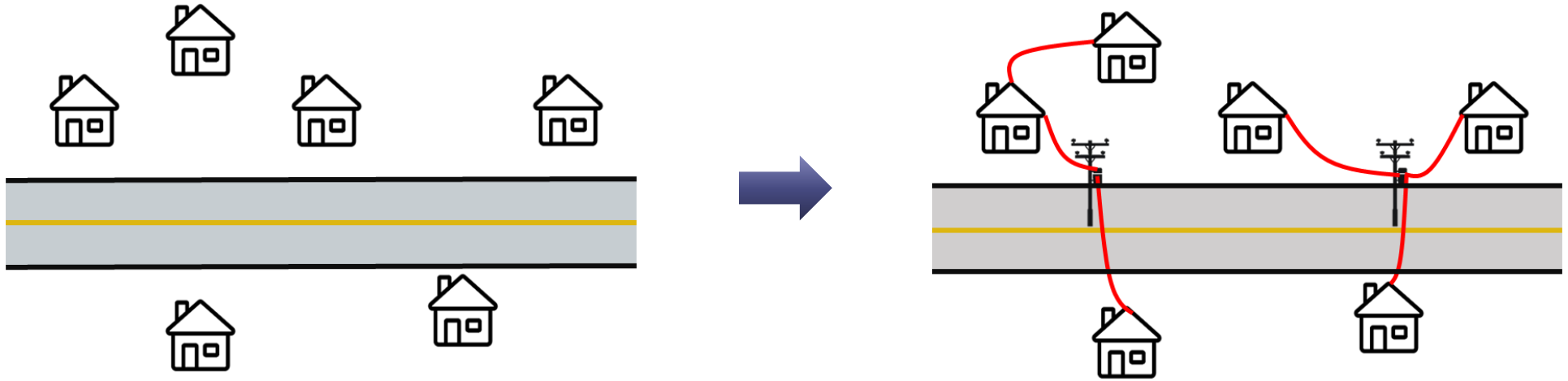
Problem: Given a set of residences and electric substations, construct a realistic power distribution network.

Assumption:
Distribution network follows road network.

Approach: two step bottom-up approach

- Construct secondary network.
- Construct primary network.

STEP 1: SECONDARY DISTRIBUTION NETWORK CREATION



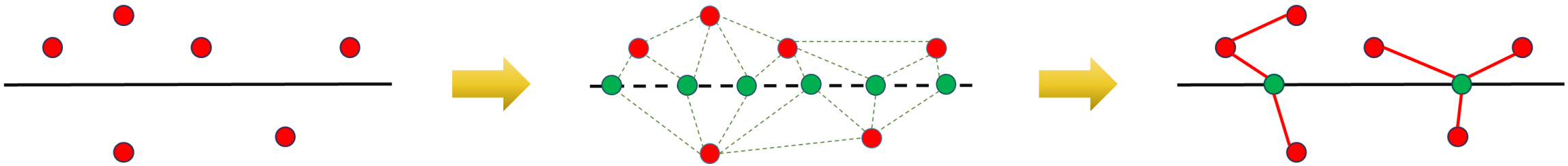
Given a road link and set of residences near it, construct the secondary distribution network.

- Network is a forest of trees.
- Root nodes are transformers.
- Root nodes are along road link.

STEP 1: SECONDARY DISTRIBUTION NETWORK CREATION

Creating candidate edge set.

- ❑ Interpolate transformer locations along road link.
- ❑ Get candidate set of edges.

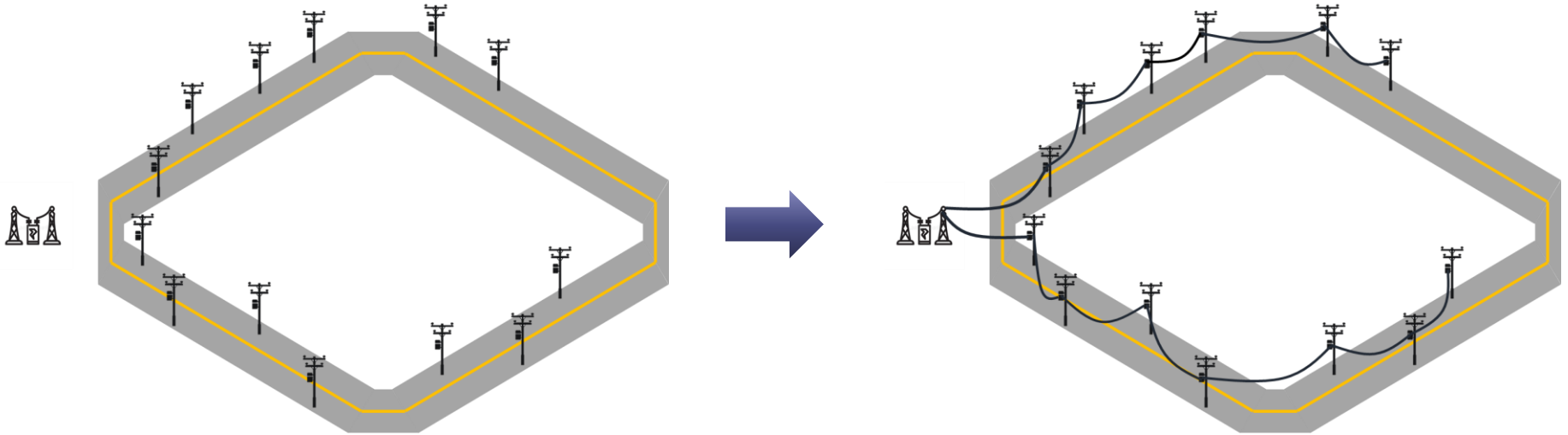


residence
transformer
road network
secondary network

Mixed Integer Linear Problem (MILP)

- ❑ Select optimal edges from the candidate set.
- ❑ Satisfy the structural constraints.
- ❑ Minimize the total length of network.

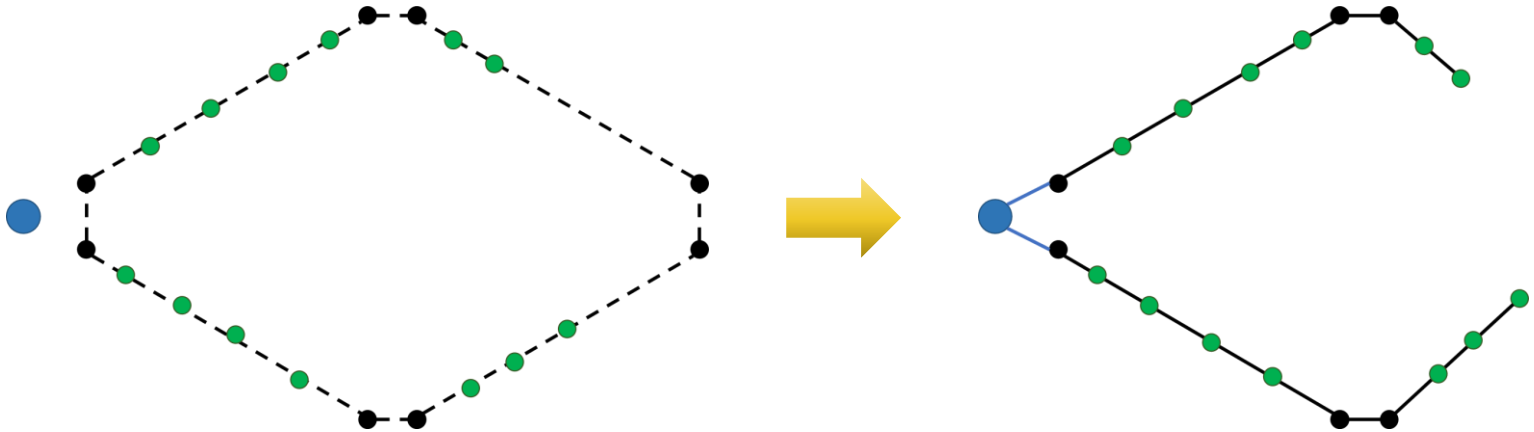
STEP 2: PRIMARY DISTRIBUTION NETWORK CREATION

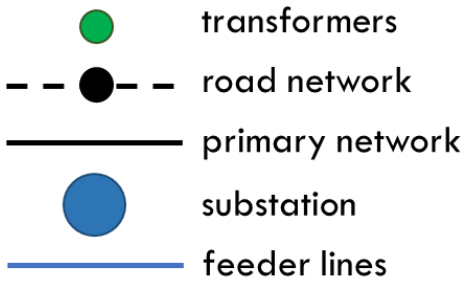


Given a set of transformers, substation and underlying road network, construct the primary distribution network.

- Network is a tree covering all transformers.
- The root node is the substation.
- Edges are chosen from the road network.

STEP 2: PRIMARY DISTRIBUTION NETWORK CREATION



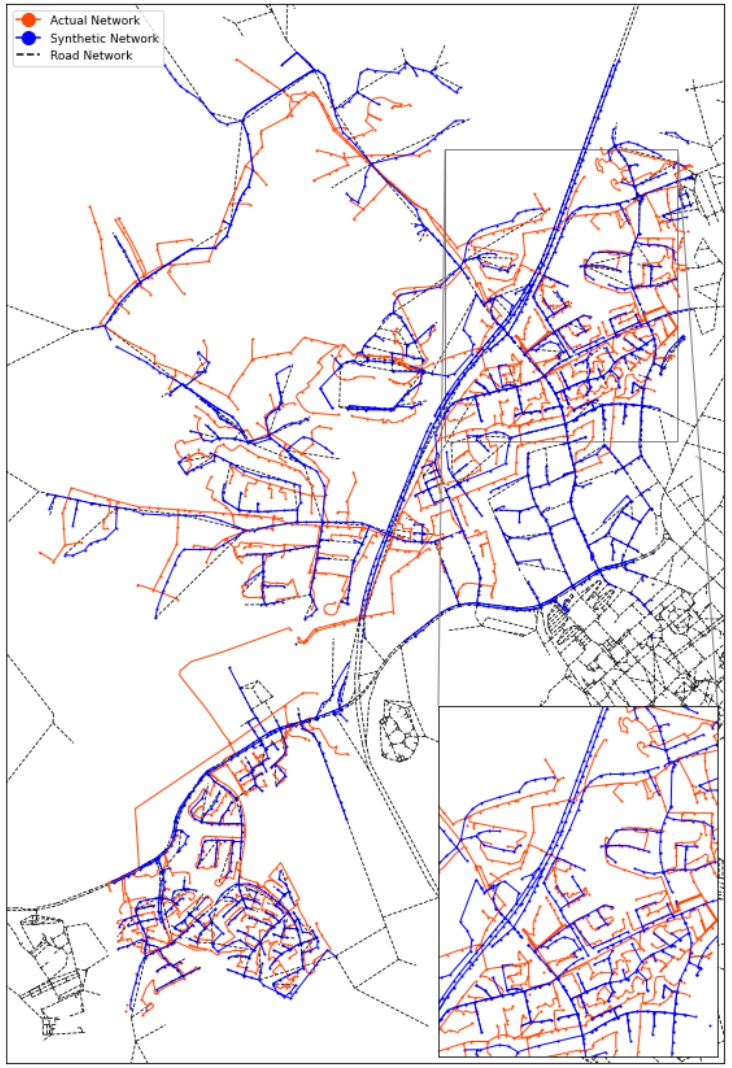


Mixed Integer Linear Problem (MILP)

- ❑ Select optimal edges from the road network edges.
- ❑ Satisfy the constraints.
  - Connect all transformers.
  - Output network is a tree rooted at substation.
  - Node voltages within ANSI limits (0.95-1.05 pu).
- ❑ Minimize the total length of network.

NETWORK VALIDATION

- We obtained actual power distribution networks of Blacksburg, Virginia.
  - Old dataset (before 2006).
  - Partial dataset of region from American Electric Power (AEP).
- Types of validation
  - Operational validation
  - Structural validation
  - Statistical validation

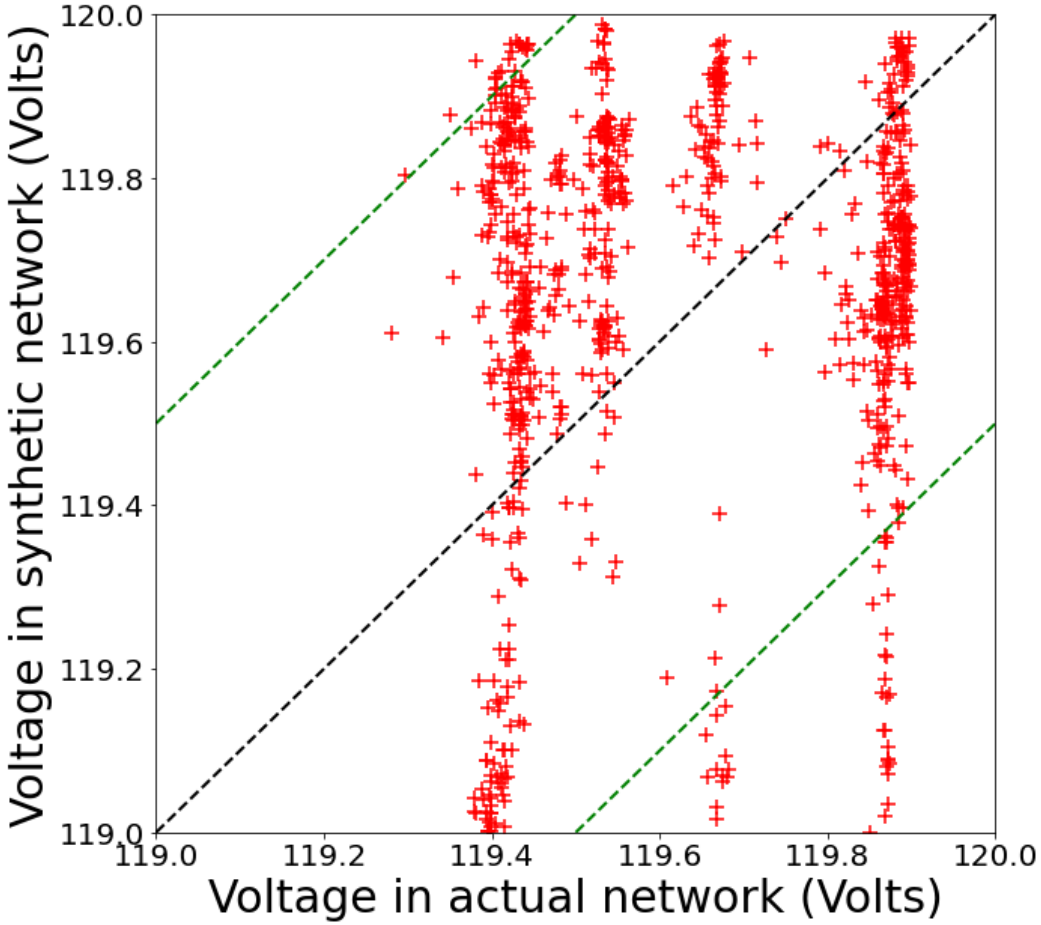


OPERATIONAL VALIDATION

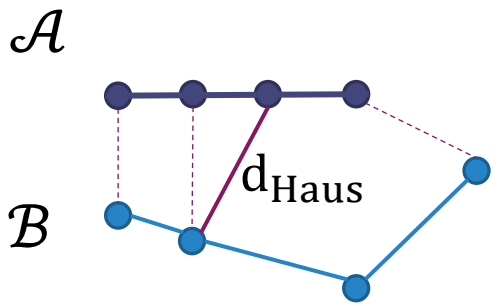
Compare voltage at residence nodes when

- They are connected to actual network.
- They are connected to synthetic network

Majority of residence voltages match within the ±0.5% tolerance margin.



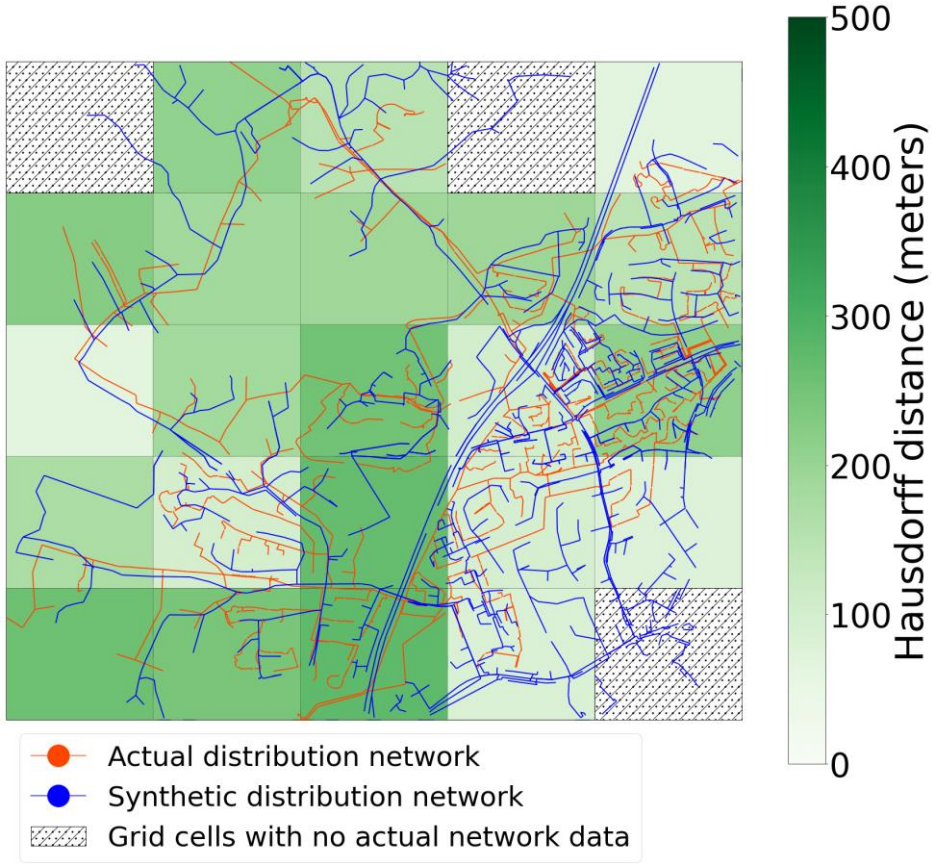
STRUCTURAL VALIDATION



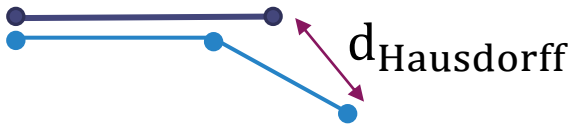
$$d_{Haus} = \max_{p \in \mathcal{A}} \min_{q \in \mathcal{B}} d(p, q)$$

Hausdorff distance

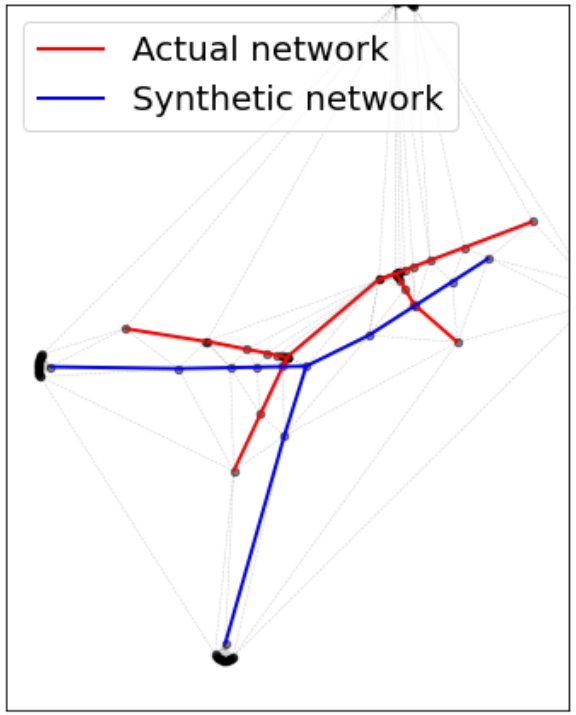
Maximum among all distances from point in $\mathcal{A}$ to closest point in $\mathcal{B}$

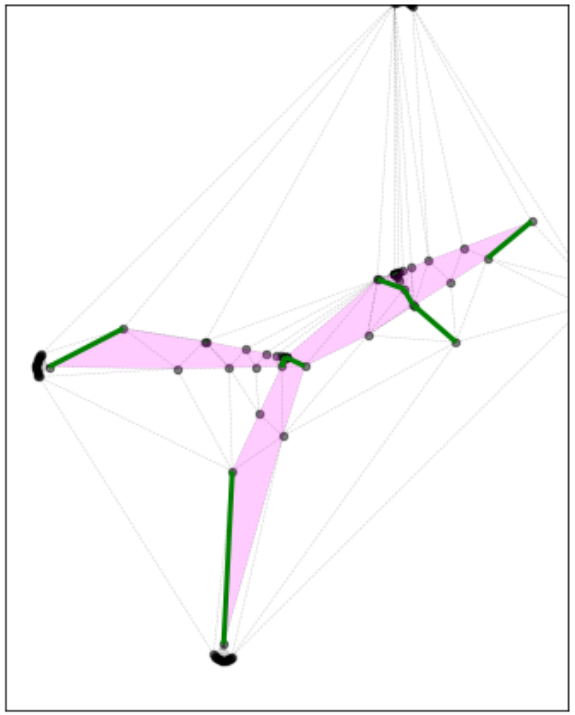


STRUCTURAL VALIDATION: USING SIMPLICIAL FLAT NORM



- Hausdorff distance only computes the maximum distance.
- We propose simplicial flat norm based distance metric which considers.
  - length deviation, and
  - area deviation.
- Good metric to compare planar graph structures or geometries.

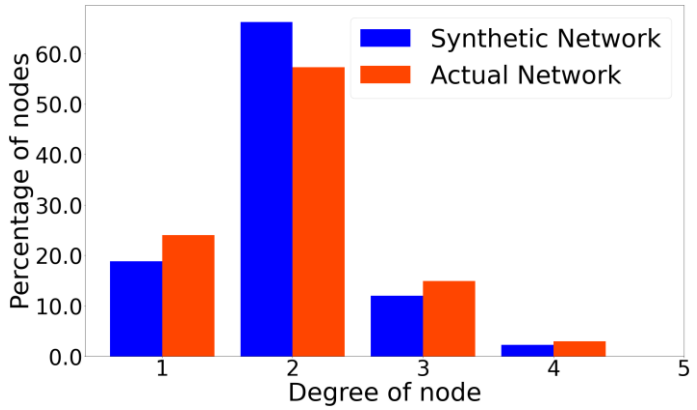




R. Meyur et al., "Structural Validation Of Synthetic Power Distribution Networks Using The Multiscale Flat Norm," 14th ACM/SPEC Conference on Performance Engineering, 2023 (submitted and under review).

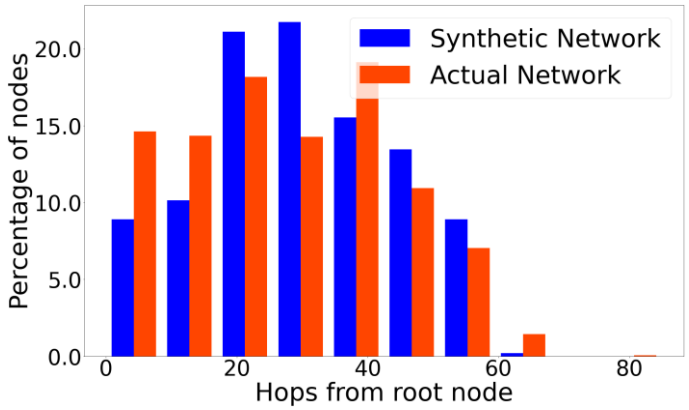
STATISTICAL VALIDATION

Degree distribution



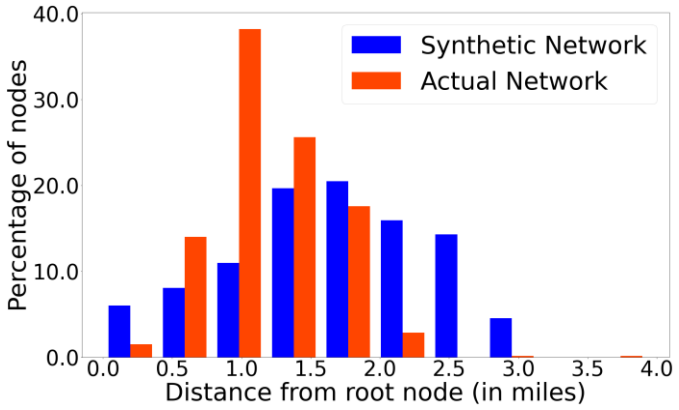
$\mathrm{KL}_{\mathrm{div}} = 0.0208$

Hop distribution



$\mathrm{KL}_{\mathrm{div}} = 0.0323$

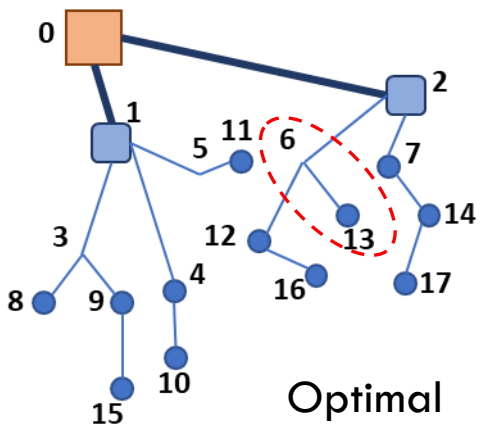
Reach distribution



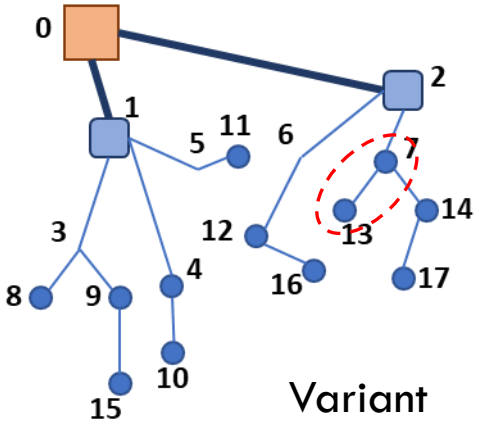
$\mathrm{KL}_{\mathrm{div}} = 0.0096$

ENSEMBLE OF NETWORKS

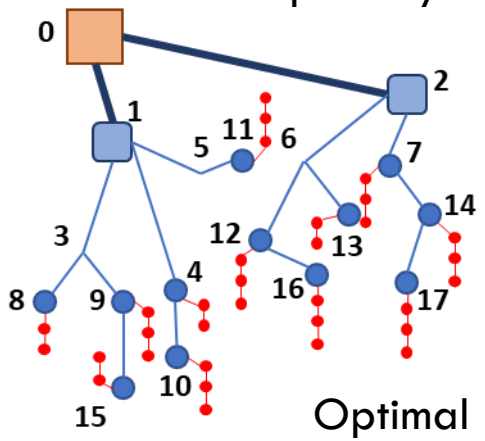
- Is the optimal network the actual physical network?
- Create multiple feasible networks connecting the same nodes.
- **Simplified problem:** create an ensemble of primary networks and keep the secondary network intact.



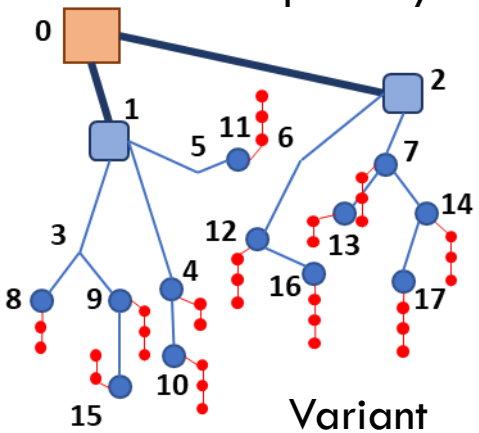
Optimal primary



Variant primary

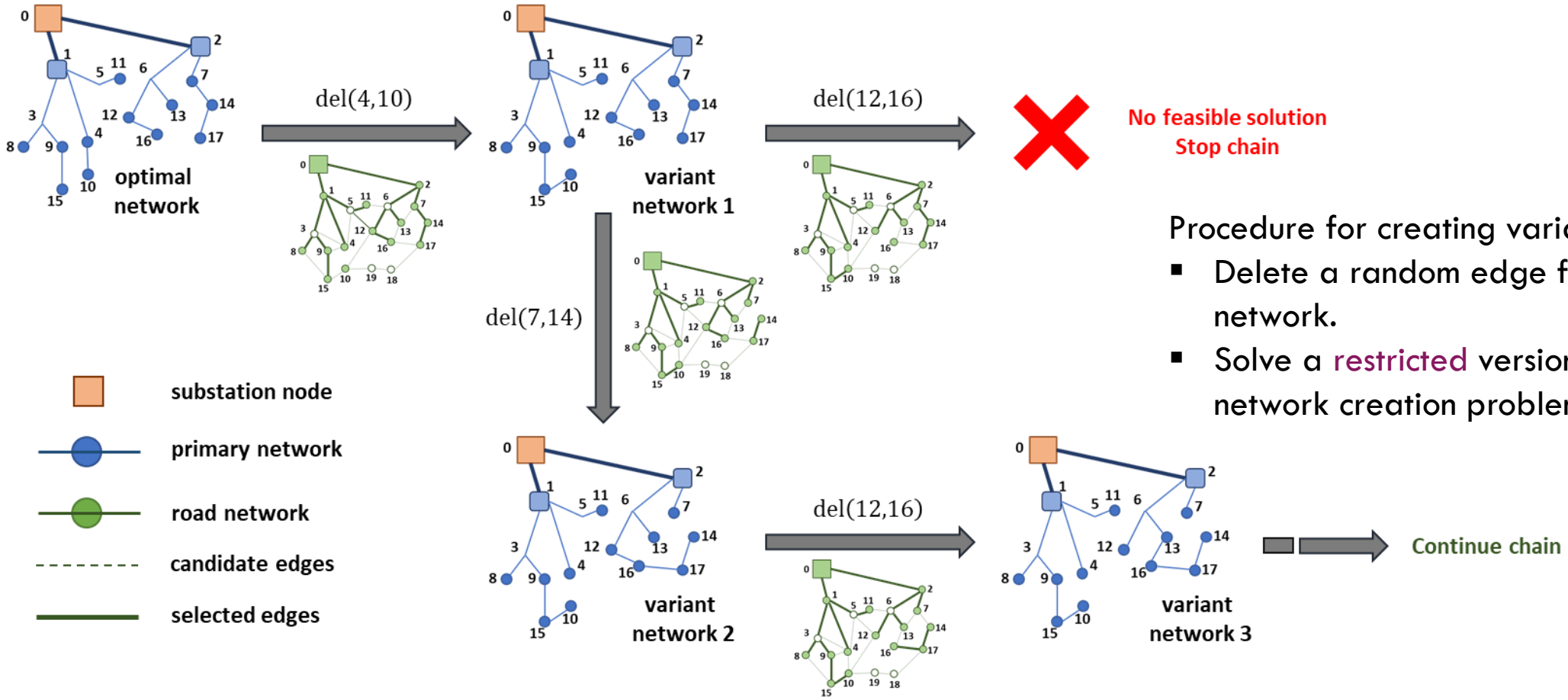


Optimal network



Variant network

CREATING AN ENSEMBLE OF PRIMARY NETWORKS



Procedure for creating variant network

- Delete a random edge from primary network.
- Solve a restricted version of primary network creation problem

USING SYNTHETIC NETWORKS TO ADDRESS PROBLEMS

- Effect of photovoltaic (PV) penetration.
- Reliability aware residential EV charging strategy.
- Optimal placement of electric vehicle (EV) charging stations.
- Address equity and fairness problems in different demand response strategies.