ENSEMBLES OF REALISTIC POWER DISTRIBUTION NETWORKS

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Power Distribution Network

- Connects substation to individual residences.
- Voltage level less than 33kV.
  - Primary distribution network: medium voltage (MV) 11 kV.
  - Secondary distribution network: low voltage (LV) 120 V.
- Transformers in network.
  - HV/MV transformer at substations.
  - MV/LV pole top transformers near residences.
- The operational part of a distribution network has a radial or tree structure to facilitate protection coordination.

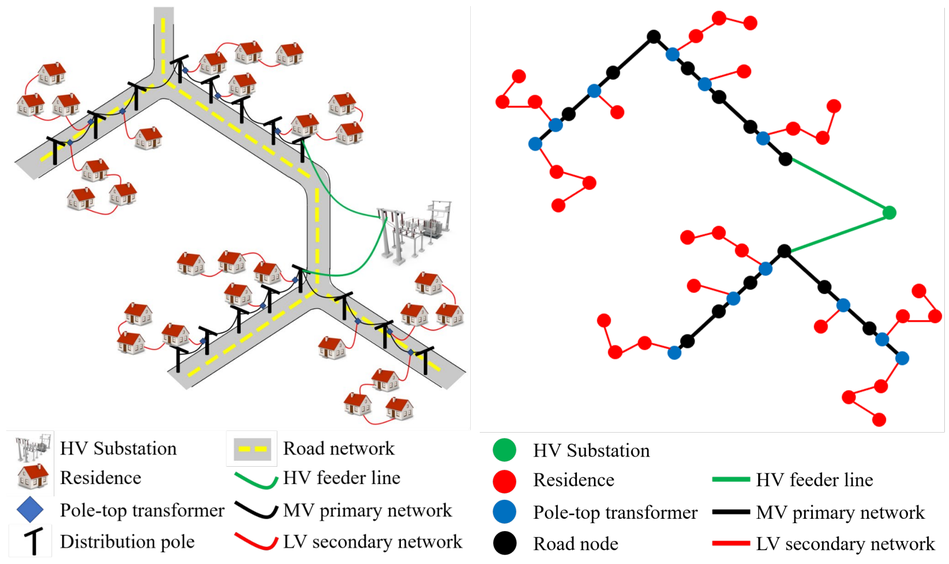


Figure 1. Schematic of power distribution network

Motivation

- Lack of realistic distribution network test scenarios to validate state-of-the-art algorithms.
  - Standard IEEE test systems (IEEE-123 bus system, IEEE-39 bus system) are very small in size.
  - No geographical attributes associated with available networks.
- Lack of network models which consider role of human behavior and interactions.

Existing Datasets Used

- Electric high voltage (HV) transmission network published by EIA [1].
- Electronic navigable maps published by Open Street Maps [2].
- Synthetic residential locations and load demand [3].

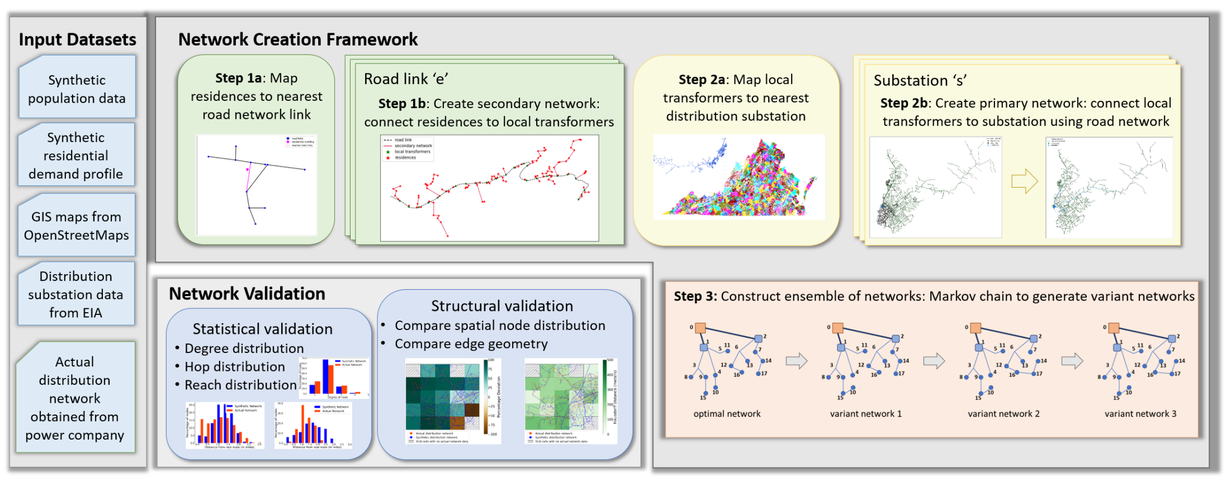


Figure 2. Framework to create realistic ensembles of distribution networks

Method Step 1: Create Secondary Network

- Goal: Connect residences to local pole top transformers.
  - Construct a forest of trees network.
  - Transformers are root nodes placed along road links.
  - Residences are connected using a chain structure.
- Solve an optimization problem which minimizes overall length

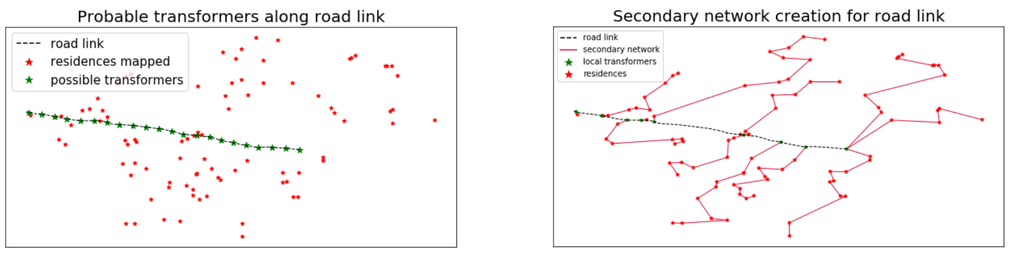


Figure 3. Secondary network creation for a road link (Step 1)

Method Step 2: Create Primary Network

- Goal: Connect local transformers to substations.
  - Construct tree network with substation as root node.
  - Use road network as proxy.
  - Acceptable voltages at nodes.
- Solve an optimization problem which minimizes overall length

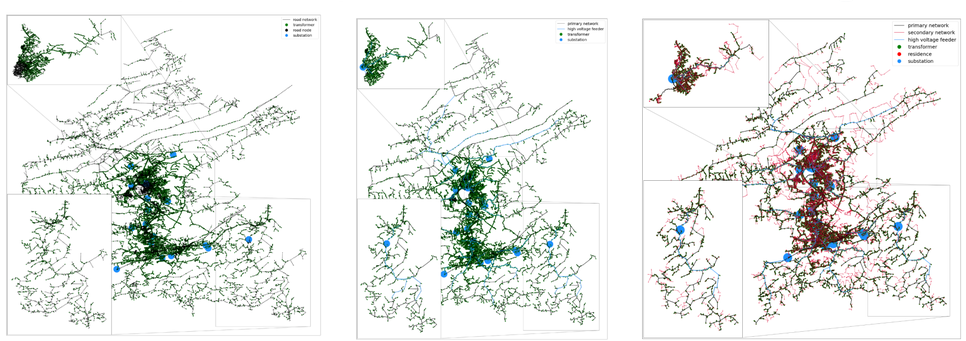


Figure 4. Primary network creation using road network (Step 2)

Method Step 3: Create Ensemble of Networks

- Goal: Develop a framework which creates multiple network realizations with the same residences and substations.
- Construct a Markov chain with each state as a network realization.
- Perform transition in the Markov chain as:
  - Perform random edge deletion in primary network.
  - Solve a restricted primary network creation problem.

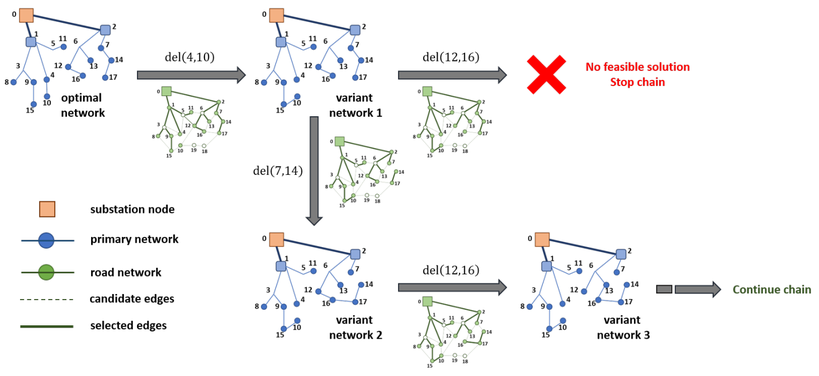


Figure 5. Markov chain to create ensemble of networks (Step 3)

Results

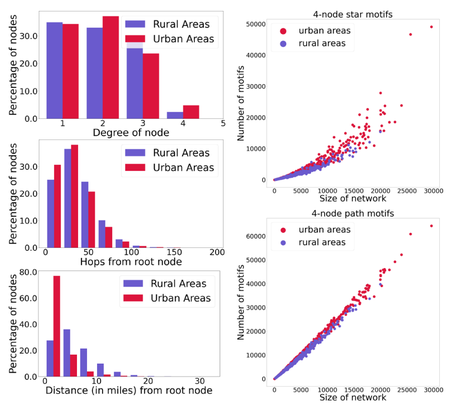


Figure 6. Structural attributes

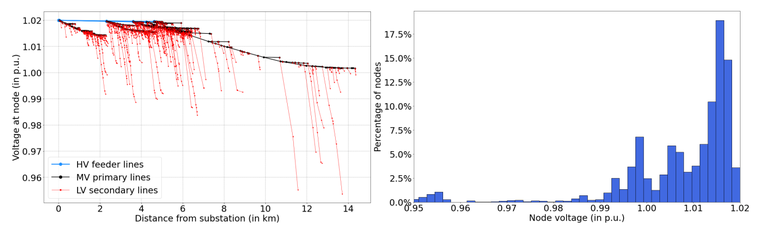


Figure 7. Operational attributes: node voltages in network

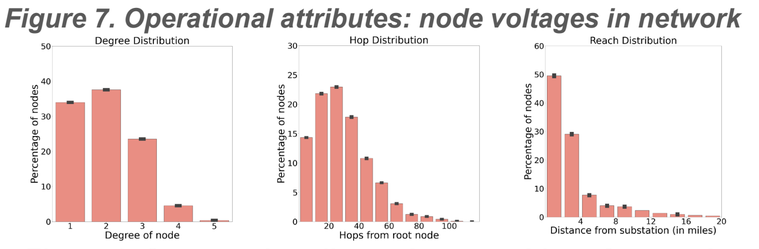
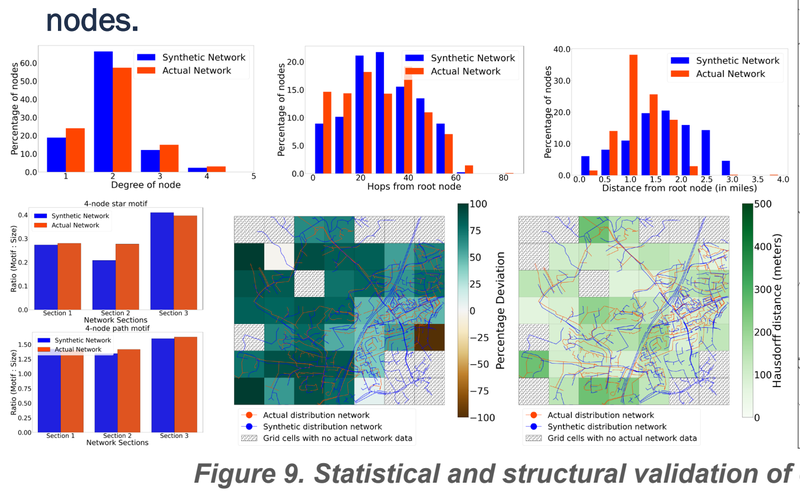


Figure 8. Structural attributes in ensembles of networks

Validation

- Statistical validation: compare degree, hop, reach and motif distribution.
- Structural validation: compare Hausdorff distance between network geometries, spatial distribution of nodes.



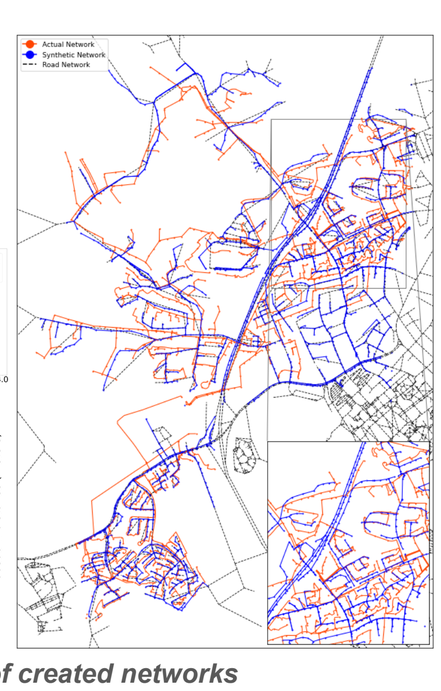


Figure 9. Statistical and structural validation of created networks

Using Synthetic Networks

- Analyze impact of photovoltaic (PV) penetration
  - Rural networks are susceptible to overvoltage issues
  - MV level penetration of photovoltaics is likely to cause overvoltage problems.

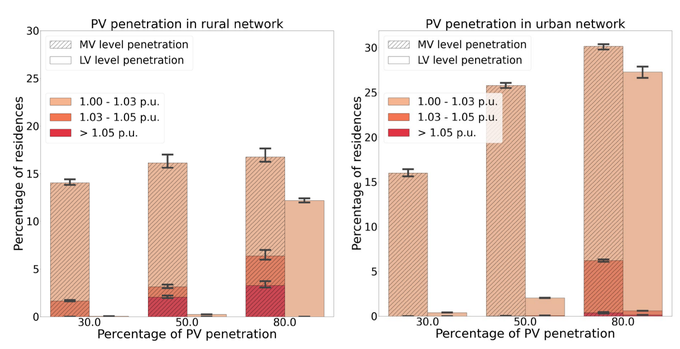


Figure 10. Impact of PV penetration in rural and urban networks

References

1. U.S. Department of Homeland Security, "Electric Substations," https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-substations, 2019.
2. Open Street Maps 2021, last accessed 13 April 2022. [Online]. Available: www.openstreetmap.org
3. S. Thorve, S. Swarup, A. Marathe, Y. Chungbaek, E. K. Nordberg, and M. V. Marathe, "Simulating Residential Energy Demand in Urban and Rural Areas," in 2018 Winter Simulation Conference (WSC), Dec 2018.