Creating Realistic Synthetic Power Distribution Networks based on Interdependent Road Infrastructure

In order to study coupled infrastructures such as power and transportation network, a central challenge is the lack of realistic data sets. Such datasets should have detailed representations of each network as well as the interactions across infrastructures and the interactions with the human population. This work proposes a methodology to generate realistic synthetic distribution networks for a geographical location using open source information. We further aim to generate a network which follows structural (radial configuration) and operational constraints (voltage and power flows within limits) of a real distribution system.

| Aspect               | Previous Works                                                                 | Present Work                                                                 |
|----------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| network type         | synthetic transmission networks with generators and aggregated loads          | synthetic distribution networks connecting high voltage substations to individual customers. |
| realism of generated networks | statistical distribution of network attributes to generate synthetic power grids | Realistic distribution networks comprising of primary and secondary levels are generated for a given geographical location. The generated network resembles an optimal network designed by power distribution companies. It follows the usual structural and power flow constraints of a typical distribution system. |
| size of network      | small sized networks such as standard IEEE test systems                        | Optimal radial network is identified for unknown number of root nodes (feeders) and for large sized networks with more than 20000 nodes. |
| radiality of network | radially is ensured by avoided isolated cycles or considering single commodity flow model. | Power balance constraint is proved to be sufficient condition to ensure radiality of generated network. |

A comparative analysis of the work with other related works is presented in the above table. The contribution of this paper can be summed up through the following aspects: (i) proposes a methodology to create realistic synthetic distribution network using information from other infrastructures such as transportation networks, residential data etc., (ii) creates an optimal network by minimizing the overall length of distribution lines which is a principal consideration of power companies while planning distribution networks, (iii) generates a distribution network which is particular to the geographical location of interest and hence provides a realistic representation of the actual network.

The goal of this work is to generate a realistic synthetic distribution network to connect the substations to all residential building locations. Therefore, the problem of synthesizing such networks is a tree-task problem: (i) evaluate a mapping between sets of residential buildings and road network links such that each residence is mapped to the nearest road link. Additionally, identify probable locations of local distribution transformers along these road network links, (ii) connect the local distribution transformers to mapped residences in a radial configuration to resemble a typical secondary distribution network, (iii) identify subset of road network links which connects distribution substation transformers to the local pole-top/pad-mounted transformers in the form of a radial.
feeder network. The proposed methodology is used to generate synthetic distribution networks connecting substations to individual residences in Montgomery county of southwest Virginia, USA. Fig.1 shows the creation of secondary distribution network for a set of residences mapped to a road link. The blue points along the road link indicate the probable locations of local transformers along the link and the red points are the residences which are required to be connected. The optimal secondary network is shown in the bottom figure which covers all the residences mapped to the road link and rooted at the local transformer nodes. The secondary network is generated for all road links mapped to at least one residence. The final task is to generate the primary distribution network which connects these local transformers to the substations. The optimal primary network originating from one substation is shown in Fig.2. The first figure shows road network consisting of possible edges and the local transformers which are to be connected. The second figure shows the generated optimal primary network. Fig.3 shows the entire synthetic distribution network (primary and secondary) generated for the same substation. The generated network is validated for the structural and operational constraints. The network has a radial structure with no loops and the operating voltage at different points in the network is shown in the second figure. The operating voltages are calculated when the residential customers are consuming average load. It is observed that the voltage profile is within acceptable limits of 0.95 to 1.0 pu. The voltage profile can be further improved by optimally placing capacitors along the network.

Fig.1: Secondary distribution network connecting residential homes along a road link to local transformers placed along the link.

Fig.2: Creating synthetic primary distribution network from edges in the existing road network while maintaining a radial structure.

Fig.3: Verification of generated synthetic distribution system network based on its structural and operational constraints.