Combined Experimental and Synthetic Data with Example Simulations on Large-scale Distribution Test Feeders for Power Quality Analysis

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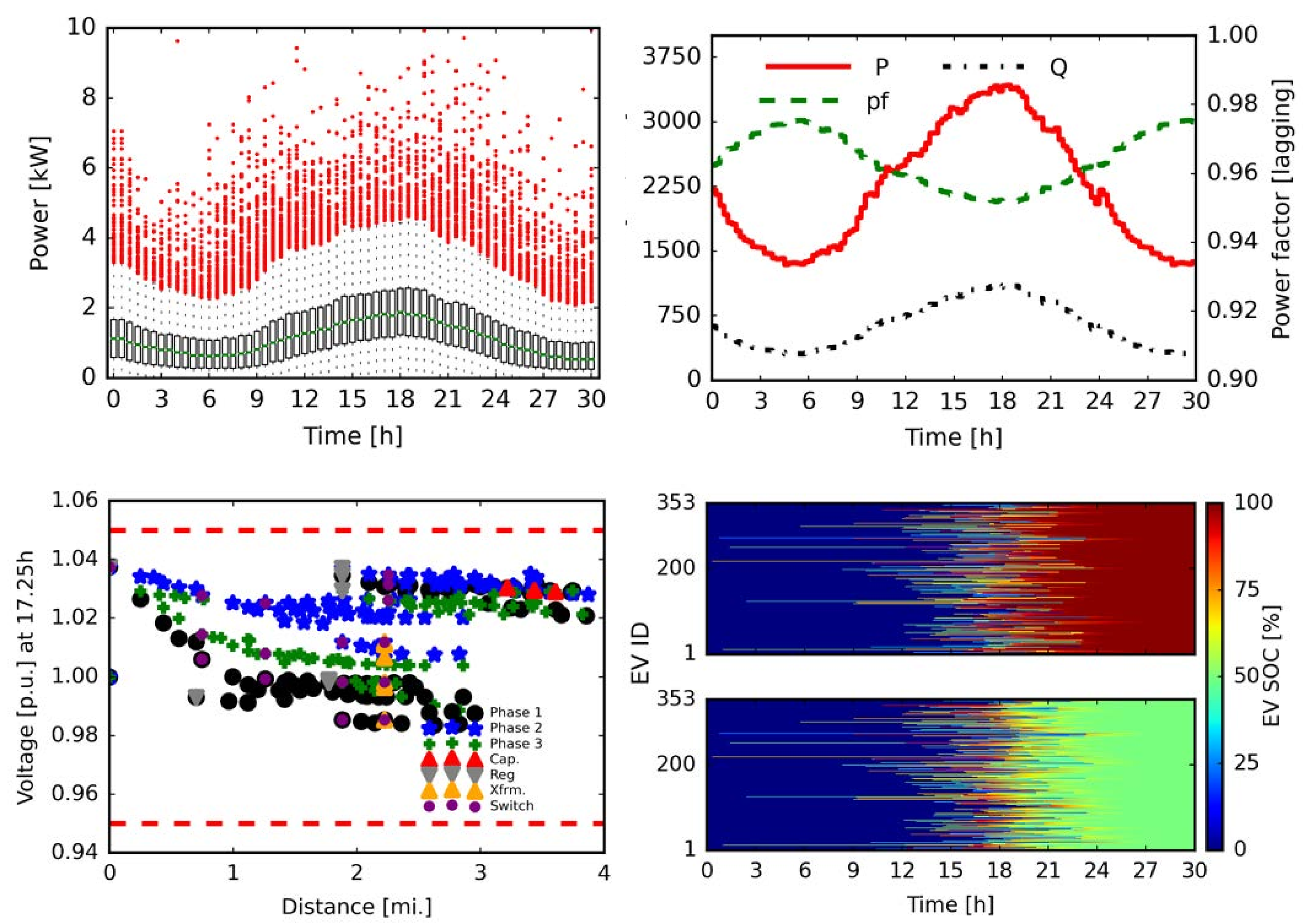
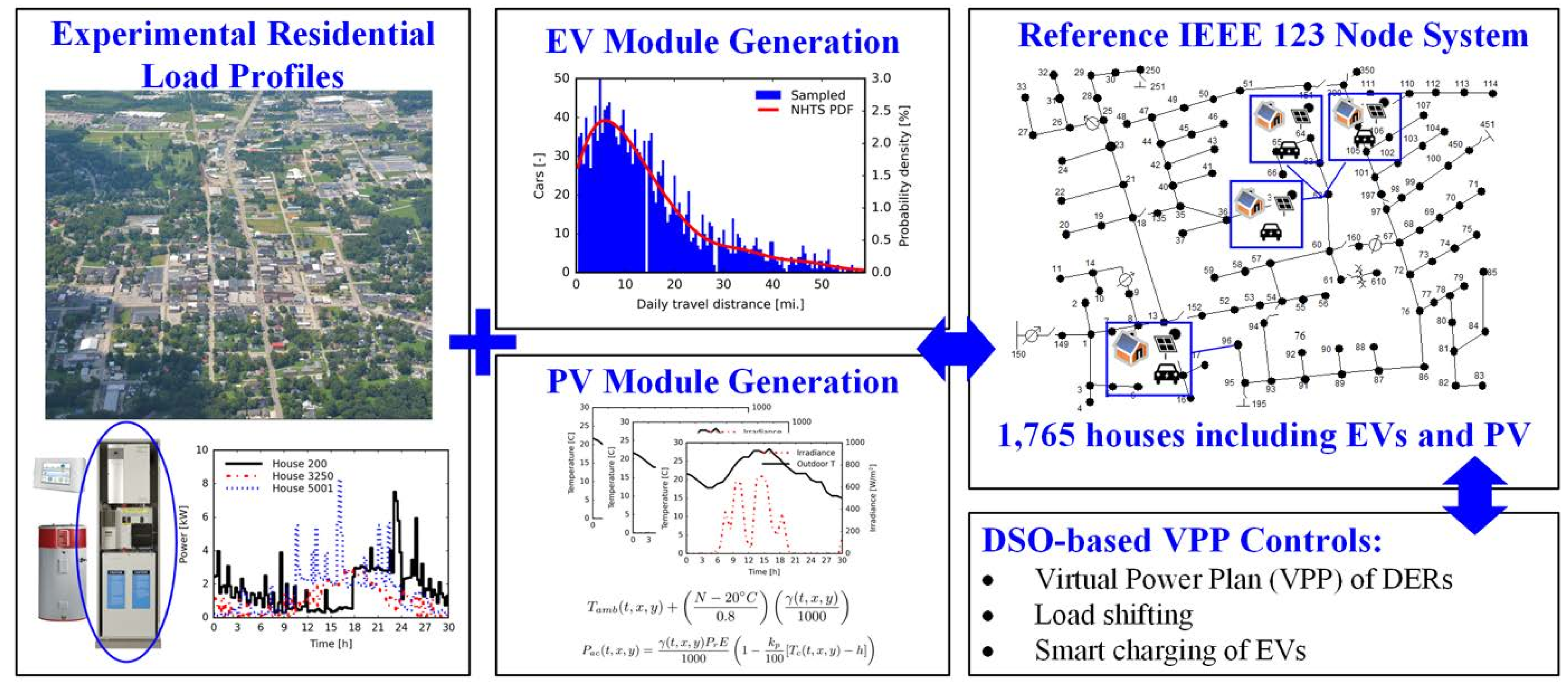
Introduction and Major Contributions

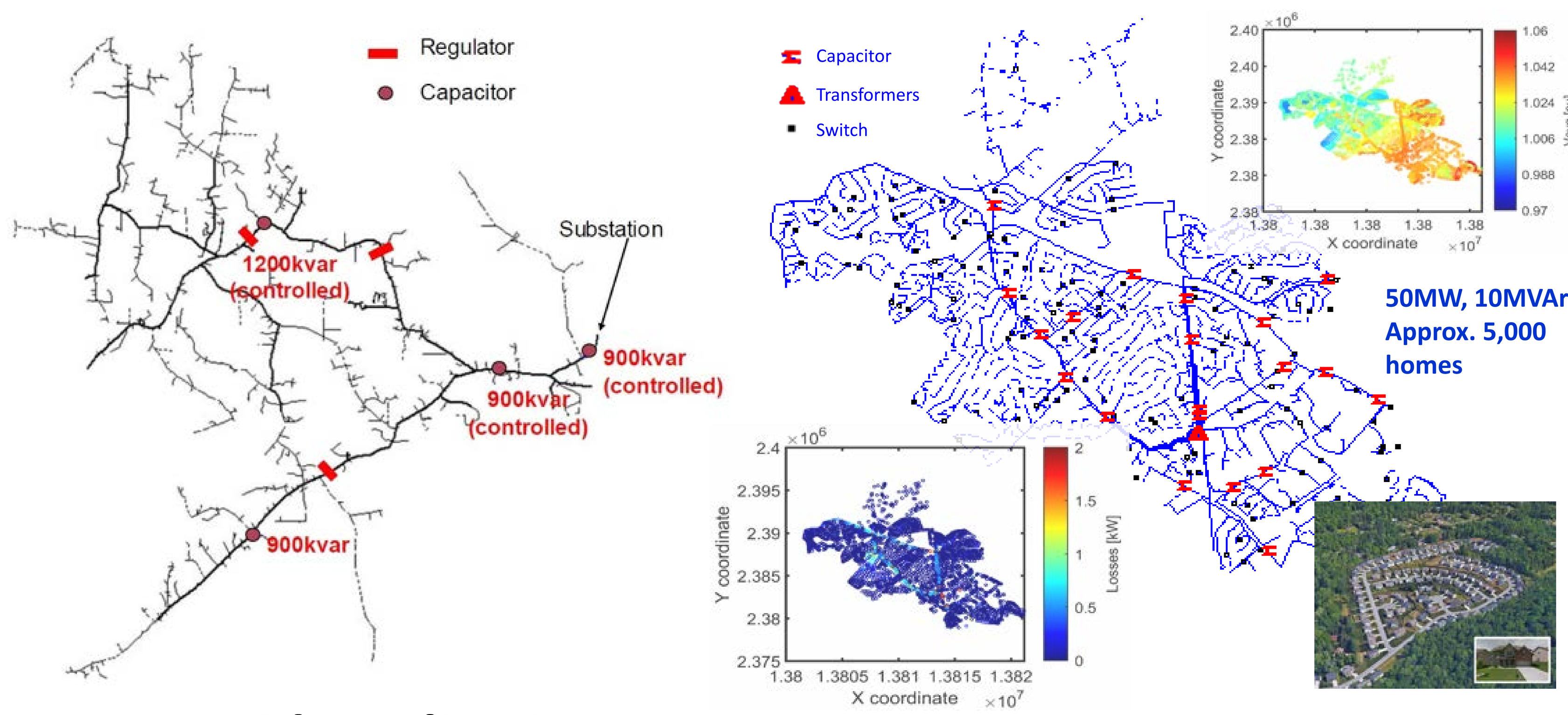
- Changes to electric power distribution equipment may be needed to adapt to distributed energy resources (DERs) such as solar photovoltaic (PV) generation and electric vehicle (EV) batteries.
- A methodology is proposed for synthetic neighborhood modeling from big data using open-source steady state power flow software
- An IEEE benchmark distribution system, the 123 node test feeder, is modified and modeled with 1,765 experimental residential profiles at typical, high resolution of 15min from smart meters
- Co-simulation framework enables large-scale virtual power plant (VPP) studies for development of centralized controls.



Distribution System with Residential Load, EV, and PV

- Example IEEE 123 Node distribution system:
  - 4.16kV system with a 5000 kVA transformer
  - Two and three phase loads with residential transformers and lines assumed sufficient
- Modified to include:
  - Experimental smart meter profiles from the SET project, one of the largest rural data sets with 5,000+ homes, in Glasgow, KY
  - Synthetic modules for solar PV generation from weather data
  - EV modules including battery state of charge (SOC) based on the National Household Travel Survey (NHTS)
- Power quality analysis including main substation power factor and peak load to determine the number of houses, i.e. 1 profile/ 2.5kW of original loading
- Simulated in OpenDSS through the python API at 1min resolution, the main substation aggregate power matches the original load of 3.6MW at peak time, and the 0.93-0.98 lagging pf was considered acceptable for a substation transformer on a hot summer day.



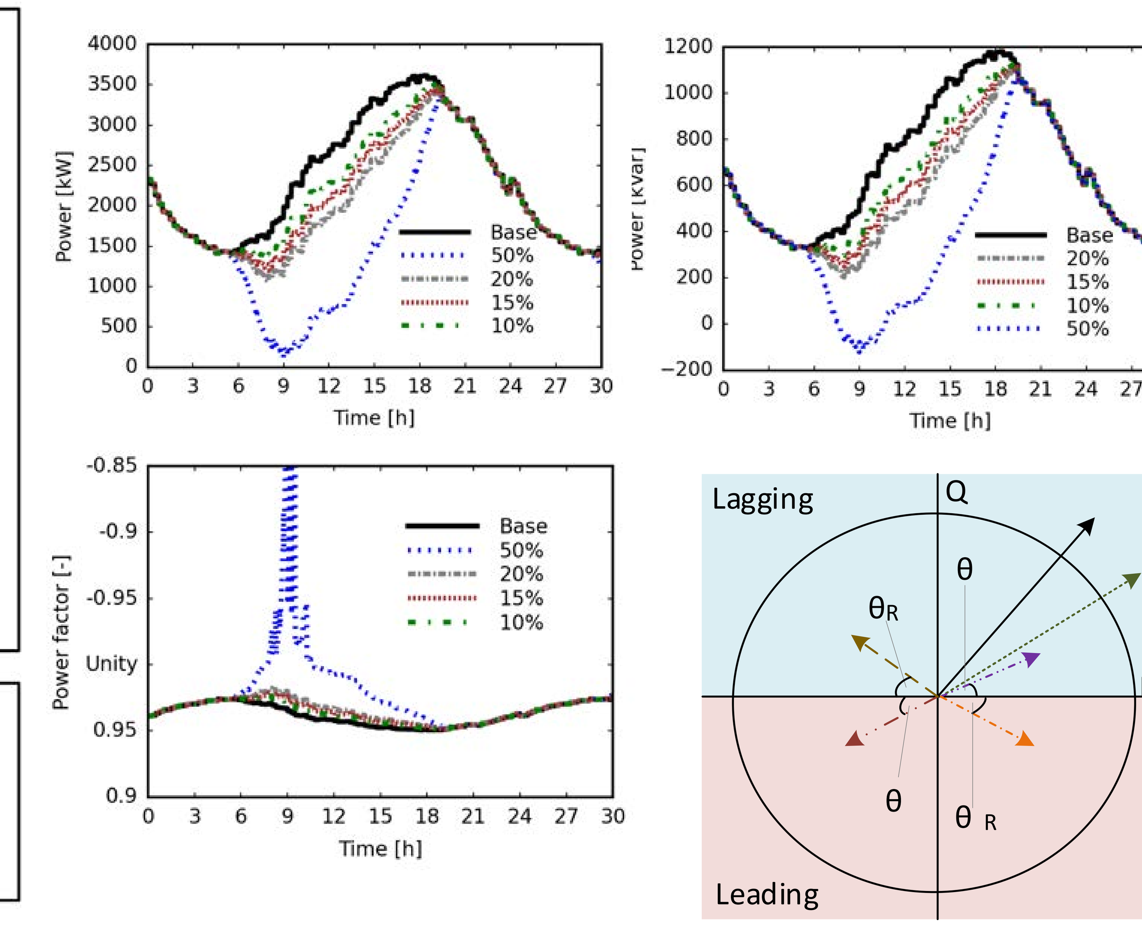


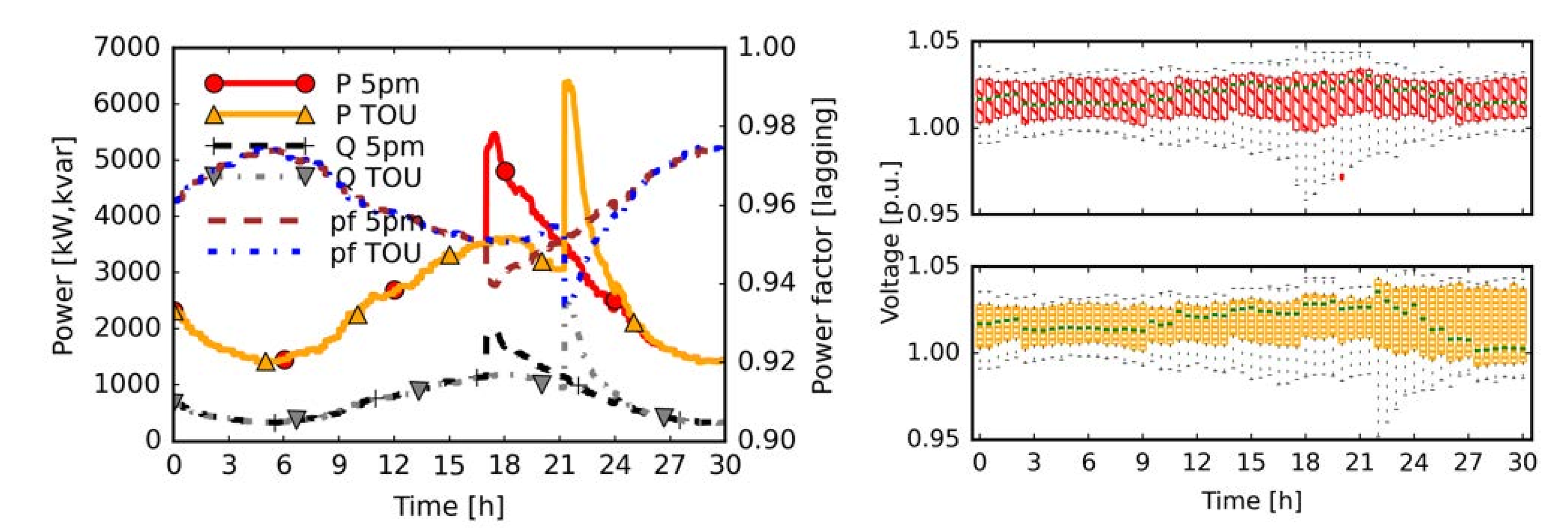
Smart Grid Applications

- Big-data based case studies with power flow models provide basis for development and testing of controls
- Use cases of this framework include:
  - Grid hosting capacity studies for EVs and solar PV
  - Reactive power support for voltage regulation
  - Load change studies with electrification of high-power appliances for space and water heating and cooling
  - Load shifting through centralized energy management system
  - Equipment installation and controls, such as switch capacitors
- Previous conventions to size fixed distribution system capacitors based on historical light load magnitude do not account for very low load or reverse radial power flow
- Investigations of machine learning models for HVAC, HPWH, and other appliances may be incorporated.

Example Solar PV and EV Charging Study

- Two case studies were performed: solar PV generation hosting and EV charging considering time of use (TOU) pricing
- Bi-directional EV chargers at 10kW with battery characteristics based on National Household Travel Survey (NHTS) daily driving distance and home arrival time data for local regions





- Solar PV improves the main feeder and transformer power factor (pf) initially and causes leading pf at high penetration, e.g. 50%
- Aggregate load may be dropped by DERs to below the installed fixed capacitors, originally intended to improve voltage at night
- Case study with 15% of the homes, 265 EVs, charging at the same time after work caused voltage violations with significant drop of substation power factor
- Further development of centralized EV charging and reactive power support through phase angle controls.

Conclusions

- A large-scale IEEE benchmark system was deployed with 1,765 experimental residential smart meter profiles and hundreds of solar PV and EV modules
- Potential for V2G and G2V controls and SOC availability was simulated based on human behavior for daily driving distance and home arrival time
- Future work will include use of the additional distribution systems such as the IEEE 8500 and utility owned example.

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