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Community EV-based Large Energy Storage Capacity Assessment for VPP Services

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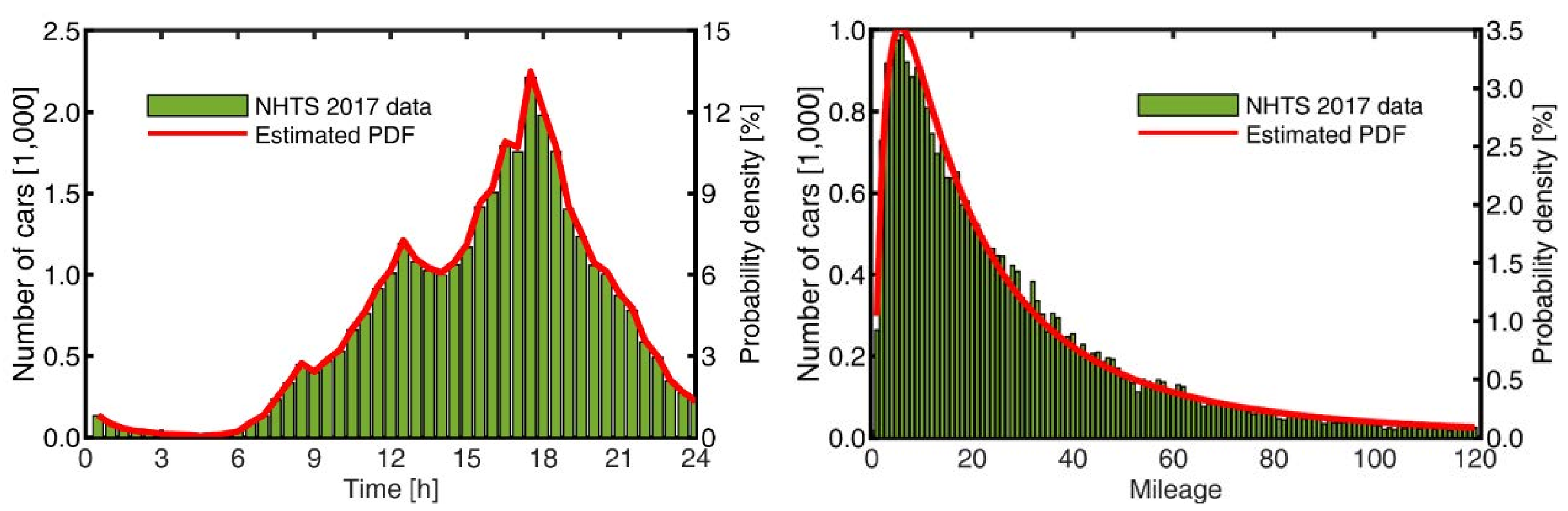
Problem Formulation

- By 2030 the goal in the US is that half of all new vehicles will be EVs and fifteen years from now, most homes will have energy storage capability higher than their typical daily energy use
- Benefits of growing distributed EV batteries include ancillary grid services such as peak power reduction, energy reserve assistance through vehicle-to-grid (V2G) connection, smoothing of renewable energy generation, increased resilience of microgrids, reactive power compensation
- Two community wide studies of over 300 homes, each with an EV, were completed to assess maximal grid benefit and the impact of EV batteries when operated as a VPP for short-term and long-term services through bi-directional chargers
- Use of collected National Household Travel Survey (NHTS) data for behavioral patterns of the EV's across the United States.

National Household Travel Survey (NHTS)

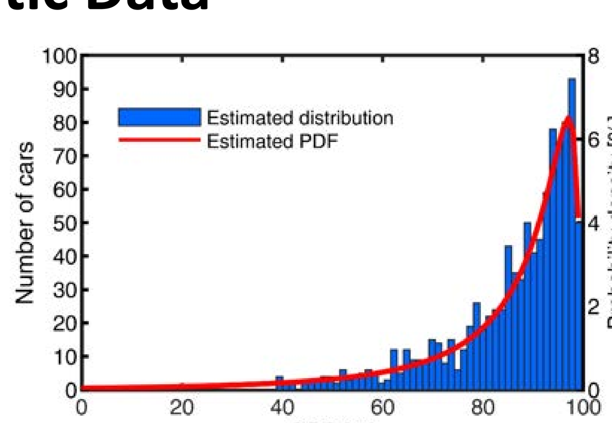


- NHTS is a large data source (60,000+ responses) provided from the Federal Highway Administration, and is the authoritative source on US public traffic behavior
- Available parameters per household income (2017):
  - Vehicles owned
  - Vehicle number of, purpose, and times of trips
  - Vehicle miles driven in a day
- Gaussian Kernel Density is used to create a synthetic EV community representative of national behavior habits.

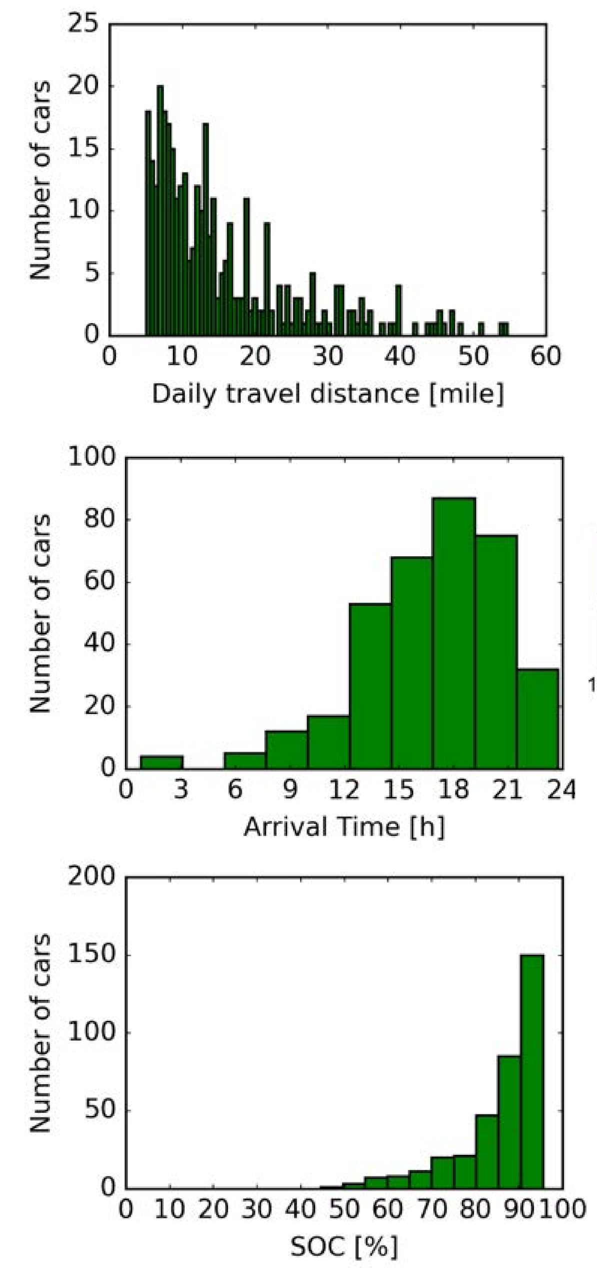
$$\widehat{f_G}(x;h) = \frac{1}{N}\sum_{i=1}^{N} K(x-x_i;h) \qquad K(x-x_i;h) = \frac{1}{\sqrt{2\pi}h} e^{\frac{(x-x_i)^2}{2h}}$$

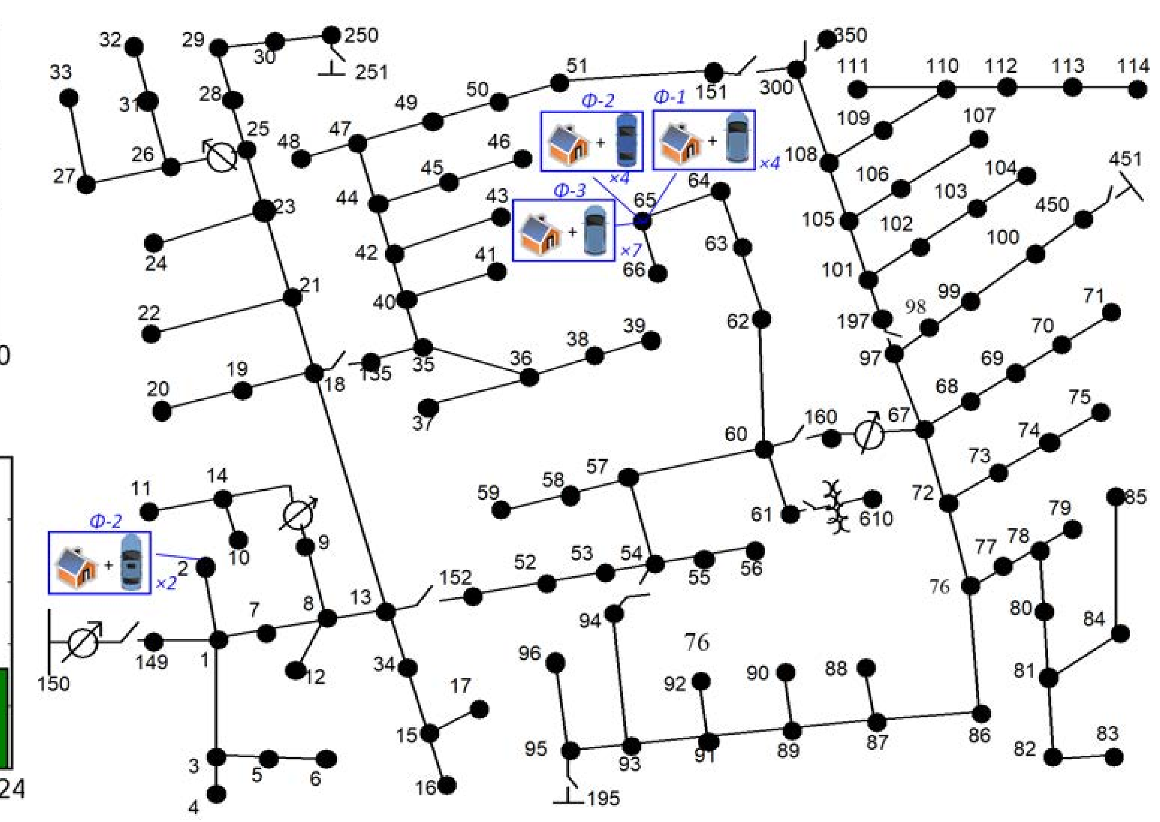
ML Model of HVAC load from Synthetic Data

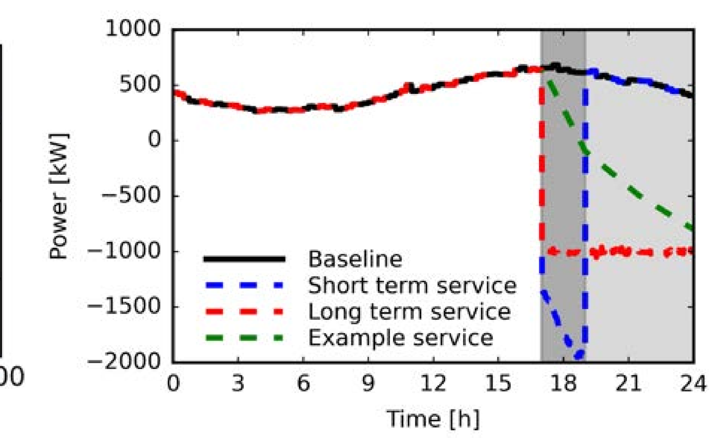
- SOC calculated as a function of the daily driving distance and the maximum driving distance for a battery capacity of 100 kWh
- Estimated distribution of EV SOC upon arriving home based on assumed speed of 202 Wh/km

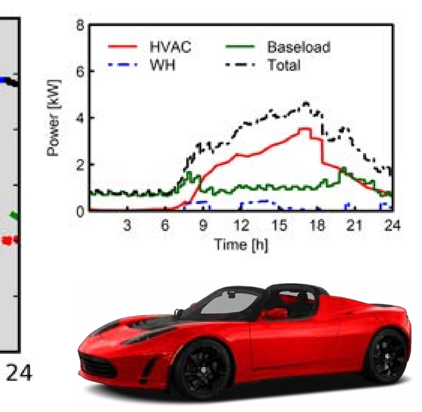


$$f(d) = \frac{1}{d\sigma\sqrt{2\pi}} exp\left[-\frac{(lnd-\mu)^2}{2\sigma^2}\right] \qquad f(SOC_{a,i}) = (1 - \frac{d}{d_M}) \times 100\%,$$



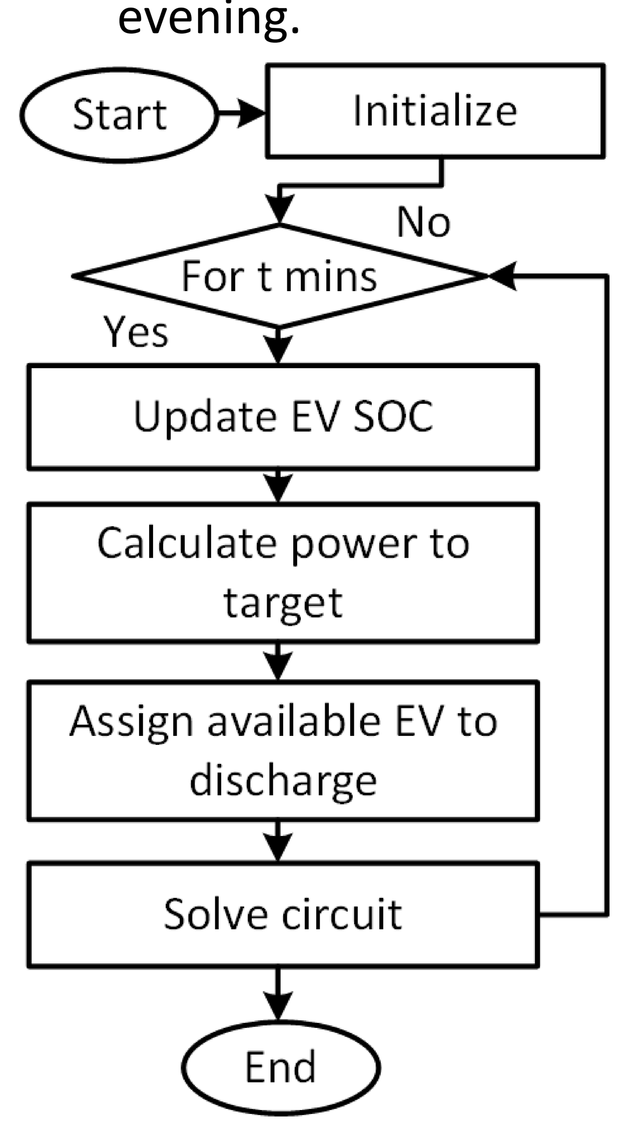






Synthetic Community of 353 Homes based on NHTS

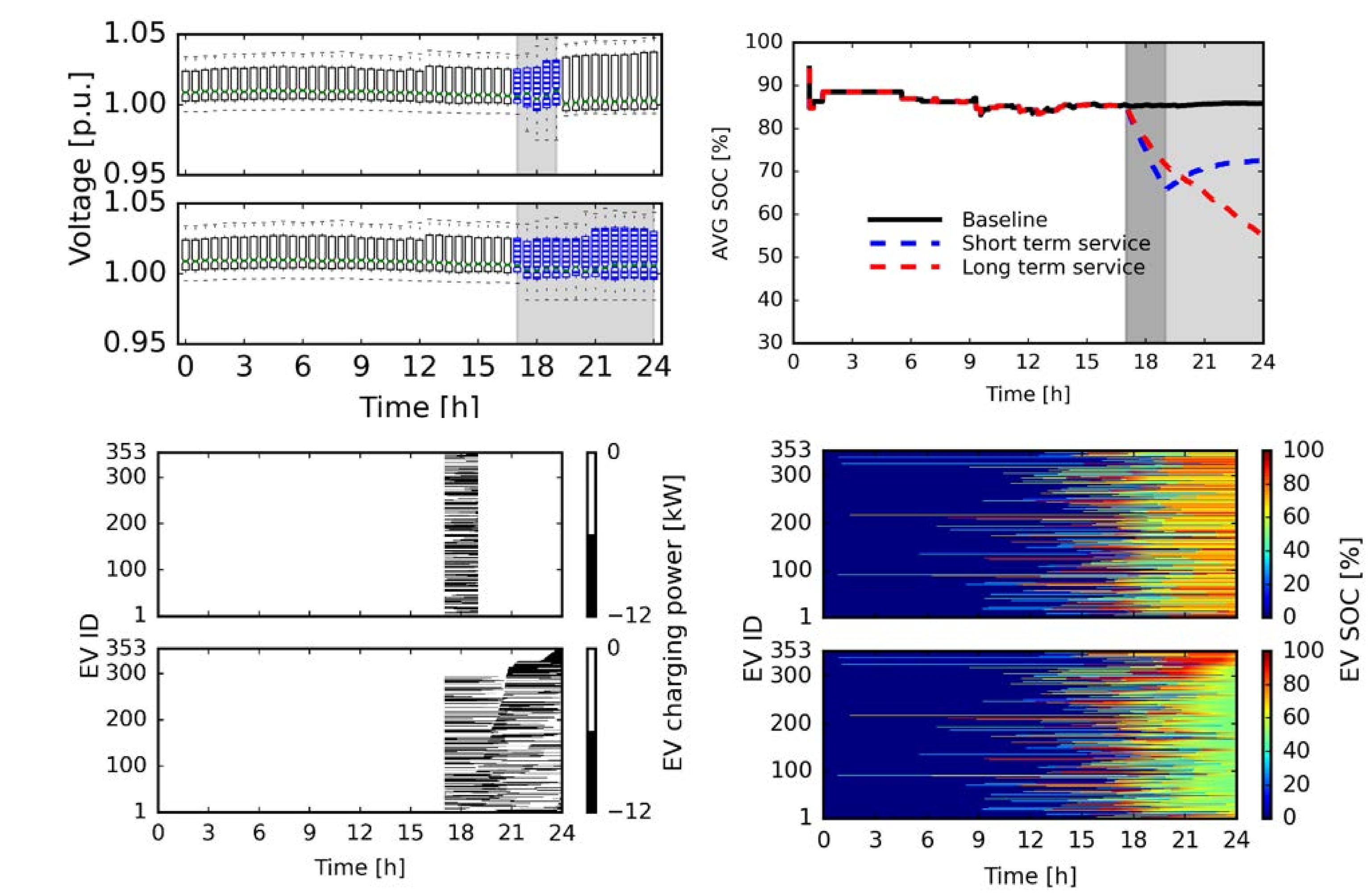
- Daily driving distance indicates most cars drive less than 20 miles a day and arrive home by 5pm
- Even after three days of driving most cars are almost fully charged, i.e. energy fully available for VPP through CTA-2045 commands
- Assumptions:
  - Each EV starts with 100% SOC and was allowed to drive for 3 days to drain the battery
  - Departure time was not considered as VPP control was used in the evening.



ITEC VPP Control Scheme

- Power system simulated using OpenDSS and the characteristic of each EV is stored and updated every minute
- Developed algorithm to calculate the number of EV's to discharge to meet target profile at the main feeder head
- Assumed discharging at 12 kW for maximal impact study
- Available EV's have higher than 50% SOC, are home, and have not been previously active in the VPP for that day.

Virtual Power Plant (VPP) with Extreme Controls



- Short term DR program/event (5-7 pm) for all cars with SOC >50% parked at home after 5pm
- Long term DR program (5pm-midnight) only cars selected with SOC >50% parked at home after 5pm to meet VPP target profile of -1000 kW at circuit feeder header
- Substantial reverse power flow for residential VPP with no voltage violations found in simulation.

Conclusions

- V2G case studies of a power distribution system for an example community with high EV penetration were performed
- EVs provided community long time VPP support for constant aggregated net power, in this case, through the entire night
- The assessed example energy capacity of EVs was extremely large, substantially exceeding the typical residential load of the community
- Under the extreme studies:
  - Voltage regulation was not a major issue as no violation were observed in simulation
  - Transformers identified as the equipment most affected by VPP EV discharging and charging.

Future and Ongoing Work

- Incorporate efficiency of EV battery discharging along with nominal rate of 10 kW
- Optimization of EV discharging to reduce cost to the utility and allow customer bidding.

Acknowledgement

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