Virtual Power Plant Control of Heat Pump Water Heaters and EVs on Distribution Feeders with Thousands of Residential Loads

Steven Poore, *GSMIEEE,* and Dan M. Ionel, Ph.D., *FIEEE*

Stanley and Karen Pigman College of Engineering

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Problem Formulation

- With rising popularity in electric vehicles (EVs), infrastructure improvements may be needed to satisfy residential energy demand
- With increasing electrification of water heating and heating ventilation and air-conditioning (HVAC), further evaluation of coordination for high power appliances may be necessary.

EV Charging and Heat Pump Water Heater Operation

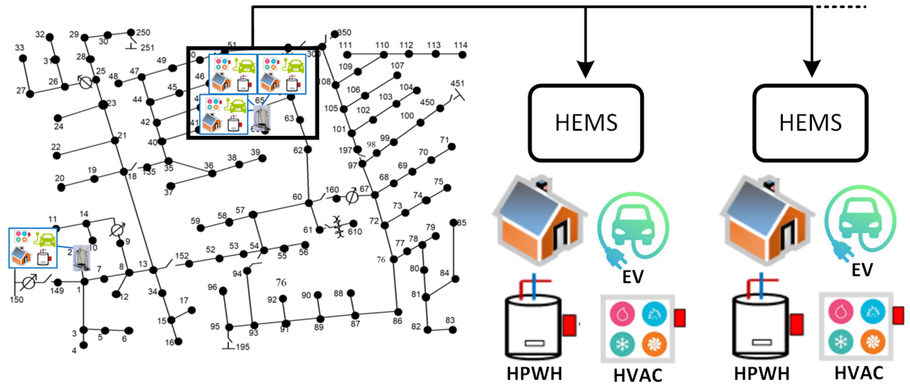
- To increase energy efficiency, resistive electric water heaters (EWHs) may be replaced with heat pump water heaters (HPWHs) long-term
- Two distinct loads for HPWH: a low power heat pump compressor, and a backup high power resistive boosting element that operates when tank temperature gets too low
- Overlap of EV charging and HPWH boosting element operation may cause overload of residential transformers, especially when multiple homes with EVs are serviced by the same residential transformer.

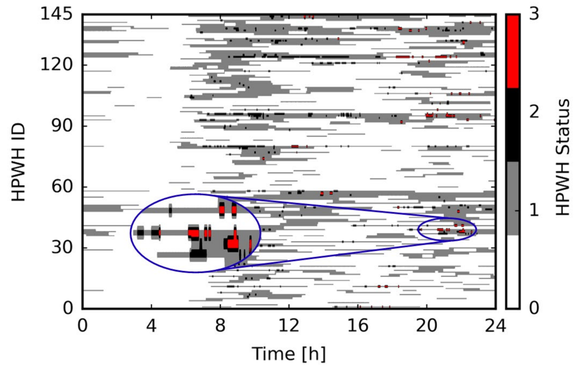
Synthetically-Generated HPWH and EV Profiles

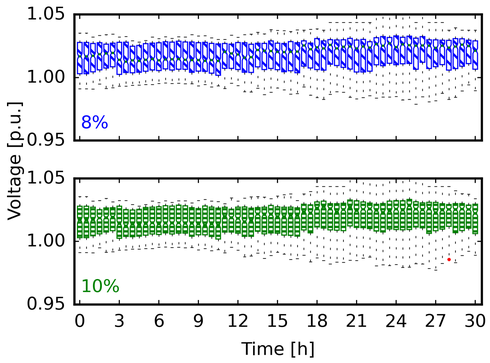
- A stratified node temperature model was employed to synthetically generate 145 unique and realistic HPWH power profiles using the 2019 and 2021 CBECC-Res hot water draw dataset
- Residential EV charging power profiles were generated using the California data from the 2017 National Household Travel Survey (NHTS)
- For the case study, EV charging times were determined based on vehicle arrival times and battery state-of-charge (SOC) upon arrival was calculated using distance traveled
- EV charging levels and battery capacities were assumed to be 10kW and 100kWh respectively.

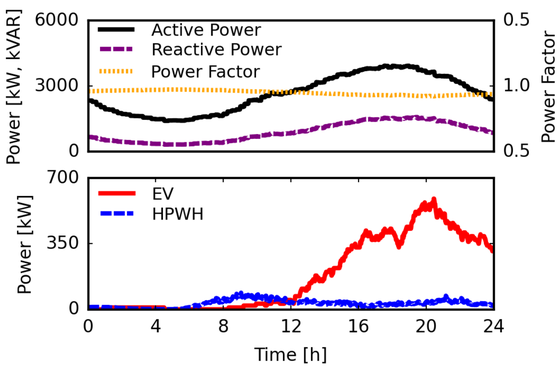
Proposed VPP Control Method

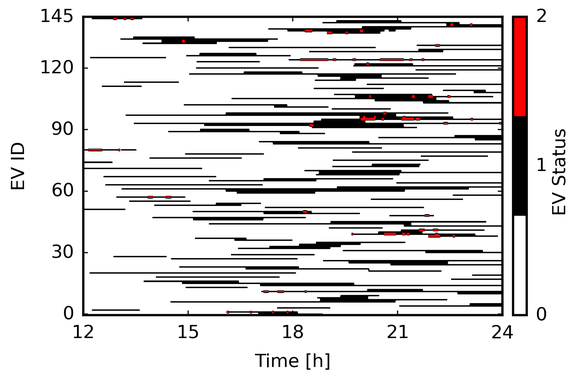
- From the perspective of virtual power plant (VPP), control of temperature setpoints for appliances such as HVAC and HPWHs should be avoided, if possible, to prioritize human comfort
- For this reason, EV comes first in the priority order for shed commands in the remaining case study.

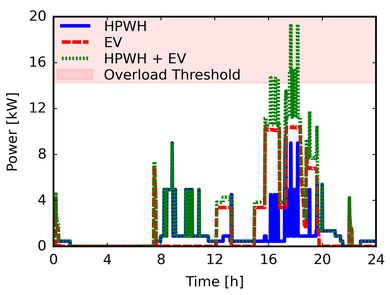


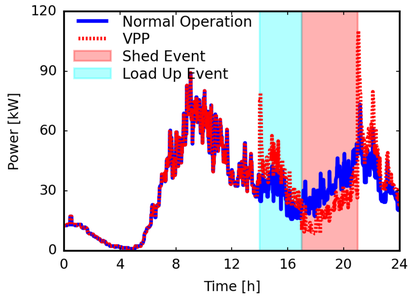












Case Study: Control of EVs to Ensure Continuous HPWH Operation

- A simulation of coordinated EV control was conducted on a modified IEEE 123-bus circuit populated with 1,765 home loads, including the 146 with CBECC-Res and NHTS-based HPWH and EV modules for a penetration rate of 8%, representing a transition case with low EV and smart appliance adoption
- The proposed VPP control method is implemented to temporarily suspend EV charging at a house if there would be simultaneous operation with its HPWH boosting element
- Residential transformers benefit more from this control method, especially during evening hours when residential demand is higher
- Most of the instances of paused EV charging happen during hours 18-24 in the day, and only for a short duration, as seen by the location and length of the red lines in the EV charging status figure.

System Voltage

- To investigate effect of EV charging on voltage, circuit simulations were implemented for different levels of EV penetration
- Voltage violations were present for penetrations of 15% and higher
- These results suggest control methods to prevent voltage violations may be necessary for distribution systems with higher EV penetration levels.

Conclusions

- Due to overlap with multiple EV charging loads with operation of high-power appliances, coordinated controls may be necessary to prevent transformer overload as EV penetration increases
- The new VPP control method was simulated on a modified IEEE 123-bus circuit populated with base home loads as well as synthetically-generated EV and HPWH loads. Impact of aggregated HPWH and EV charging load on the demand seen by the substation transformer was minimal for an 8% penetration.

Future and Ongoing Work

- Work in progress to include consideration of HVAC operation in control scheme
- Control methods to control system voltage at higher EV penetrations are in development.

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