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DEALING WITH LOCAL NETWORK PEAKS DUE TO SIMULTANEOUS EV CHARGING: VOLUMETRIC OR CAPACITY NETWORK TARIFFS?

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Overview

Decarbonizing the transportation sector will require rapid electrification of the light duty vehicle fleet [1]. Most electric vehicle (EV) owners prefer charging at home [2]. Yet under the flat network retail tariffs in place in most of the US, there is a risk that unmitigated residential charging will cause significant increases in peak demand on the distribution grid, necessitating costly capacity upgrades [3]. Flat network tariffs also provide no opportunity for EV owners to reduce their charging cost by shifting demand towards hours when there is excess network capacity [4]. While there is broad consensus that flat network tariffs are ineffective, we see a range of approaches by different regulatory commissions in designing alternatives. In this paper, we calibrate a realistic case study to investigate whether (time-varying) volumetric or capacity based network tariffs deal best with the problem of increasing network costs due to EV charging. Besides network costs, we examine two other important criteria: levelized cost of EV charging and cost shifts between EV owners and non-EV owners.

Methods

We employ a mixed-integer linear program to evaluate 4 network tariff designs under different EV adoption levels: flat (FLAT), 2-part volumetric time-of-use (TOU), annual capacity charge (DC), and a hybrid rate including both volumetric time-of-use and capacity charge components (TOU+DC). We simulate 400 homes over a full calendar year to approximate a typical residential distribution feeder. For each tariff, we set the price at the equilibrium point such that the full revenue requirement is collected (based on the annual peak demand) and the consumer response does not deviate. Household (inelastic non-EV) demand is modeled using end use profiles from the US National Renewable Energy Laboratory's ResStock database [5]. Vehicle driving patterns are constructed via random sampling using responses in the US National Household Transportation Survey [6]. We make the following assumptions: all EVs charge exclusively at home, the energy supply charge is flat and all other bill items are either fixed or flat, charging can be programmed to follow price signals (i.e. is perfectly elastic), and all customers are required to enroll on the tariff.

Results

We evaluate each tariff on three metrics: annual aggregate peak demand, levelized charging cost for EV owners, and levelized electricity cost for non-EV owners. We compare annual peak demand to a "central planner" scenario where peak demand is minimized across the entire feeder, which provides a baseline for the theoretical optimum. The TOU tariff yields the highest annual peak among the 4 designs at all EV adoption levels beyond 10%; this is due to correlated charging at the beginning of the "off-peak" period, illustrated in Figure 1. TOU+DC performs slightly better, but beyond 30% adoption the annual peak exceeds that of the FLAT tariff. Surprisingly, the FLAT tariff produces only a modest increase in annual peak due to the heterogeneity of vehicle arrival times but performs worst for levelized charging cost and offers no protection against unexpected correlated charging events. A sensitivity analysis in which vehicle arrival times are highly correlated yields a peak demand similar to the TOU tariff with heterogeneous arrival times. We find that the DC tariff performs best for annual peak & levelized charging cost but worst in levelized cost for non-EV owners, especially for homes with high peak demand and low annual consumption as indicated in Figure 2. This creates a cost shift from non-EV owners to EV owners. Due to long overnight dwell times and low daily driving distances, over 95% of homes pay no additional cost to charge their EVs under the DC tariff. If EV owners are incentivized to delay charging until the morning hours immediately before vehicle departure, we find nearly identical annual peak demand under the DC tariff as the central planner scenario (1.6% increase, compared to 22.3% increase if charging begins as soon as possible within the window in which the car is plugged in). This indicates the potential value of incentivizing "delayed" charging.

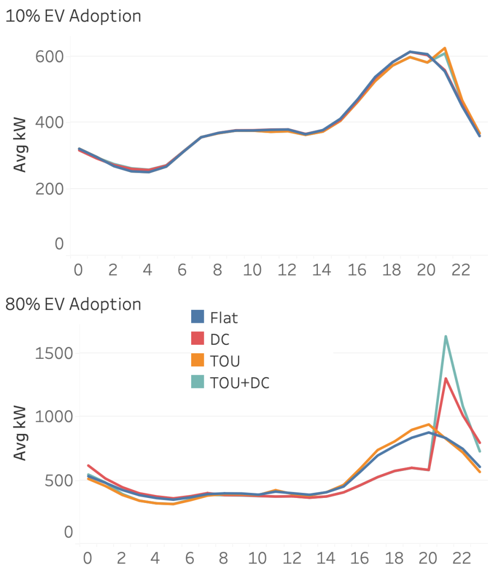

Figure 1: Hourly aggregate demand at 10% and 80% EV adoption levels

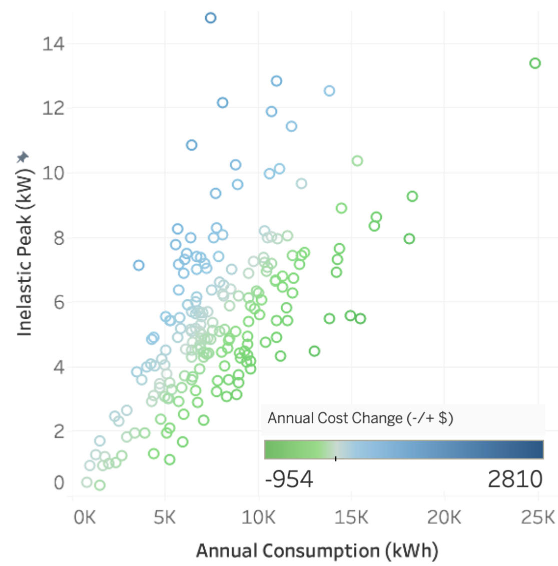

Figure 2: Annual cost change for non-EV owners at 50% EV adoption

Conclusions

We see a range of approaches undertaken by regulatory commissions in their design of network tariffs motivated by increasing electrification. For example, California has opted for volumetric rates, while Belgium recently adopted a capacity charge to collect the majority of distribution costs. Our results indicate a tradeoff between reducing costs for EV owners (through capacity-based tariffs) and non-EV owners (through volumetric tariffs). To balance these tradeoffs, we recommend a hybrid network tariff that includes an annual capacity charge that reflects long-run marginal costs and a non-distortive fixed charge to collect embedded network costs. Based on our modeling results, this proposal would 1) nearly eliminate the need for local capacity upgrades, 2) remain effective at high EV adoption levels, and 3) provide low levelized charging costs for EV owners, a key motivator for EV adoption. This is an important finding due to the prevalence of TOU rates promoted by US utilities to EV owners today, which will yield suboptimal results beyond low adoption levels.

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