Community Charging Hubs: A model for cost-competitive charge scheduling of heavy-duty electric vehicles

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Abstract

The adoption of heavy-duty battery electric trucks and buses in Europe is progressing. To scale up and achieve the European carbon emission targets, it is critical to develop a heavy-duty charging infrastructure, where most charging is expected to take place at private depots. However, building depot charging infrastructure is capital intensive, and exclusive private use does not typically result in sufficient utilization rates. Despite existing research into private depot charge scheduling, the question of how a variety of locally proximate commercial users could share their charging infrastructure to improve utilization and reduce charging costs remains unanswered.

This study proposes semi-public Community Charging Hubs as a novel model to optimize the charging schedules of electric trucks and buses belonging to various commercial and municipal users. We explore how each additional vehicle can improve charger utilization and lower the break-even charging price. Our approach starts with a deterministic mixed-integer program, which we then extend into a real-time approximate dynamic program. In collaboration with logistics operators, public bus companies, grid operators and the municipality in a pilot city in Switzerland, we demonstrate that Community Charging Hubs can reduce charging prices and grid load by up to 50 percent, while accelerating municipal decarbonization efforts.

Introduction and Motivation

Due to current range limitations, heavy-duty electric vehicles are mainly used for regional operations, making depots and cross-docks primary charging sites. However, the capital costs associated with the installation of private charging infrastructure can reach up to four million euros, depending on the number of charge points and necessary grid upgrades, yet average utilization remains low at typically 5 to 10 percent. As logistics operators are often clustered within commercial zones, semi-public Community Charging Hubs can serve as shared charging points in their neighborhood, enabled by a charging-as-a-service model. An increased utilization helps reduce infrastructure providers' total cost of ownership and enables competitive charging costs for users, making better use of idle charging capacity during daytime loading, unloading, and breaks.

Applied Method

We first formulate and solve a mixed-integer linear program to determine a deterministic charge schedule that maximizes charging profit for a mixed fleet of 30 electric vehicles, including heavy-duty trucks, buses and municipal vehicles serving a given set of routes. For a three-day horizon, the model accounts for dynamic time-of-use electricity rates, local PV generation, and peak-based grid fees. To allow for real-time decision-making under stochastic vehicle arrivals at the charging hub, we then develop an approximate dynamic program, incorporating user-specific charging priorities, charging demand, and parking durations. To address the high-dimensional, time-varying state and action space of deciding which vehicle to charge, at what power level, and at which slow or fast charger, we leverage the mixed-integer program results and apply multivariable fractional polynomials to construct a linear basis function approximator that effectively values each system state.

Results

Through numerical simulations with real-world data from a pilot commercial zone in Switzerland, we derive a break-even charging price frontier as a function of the number of vehicles and demonstrate reductions of up to 50 percent in both user charging prices per kWh and overall grid load. Additionally, we show that our tailored state value function approximation provides explanatory power and is required for a convergence of the approximate dynamic program and for achieving the expected price and grid load benefits.

Conclusions

The objective of this study is to develop and solve a charge scheduling model to evaluate the potential of Community Charging Hubs with a diverse set of users and derive managerial insights through simulations. Our model integrates dynamic electricity and PV generation rates and extends existing literature by considering trucks and buses and their respective stochastic arrival times simultaneously. For a concrete pilot case, we demonstrate that Community Charging Hubs lead to highly competitive charging prices while reducing grid loads, thereby serving as a key enabler for heavy-duty electrification.

References

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