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Day ahead optimization of an electric vehicle fleet providing ancillary services in the Los Angeles Air Force Base vehicle-to-grid demonstration

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HIGHLIGHTS

- We present an overview of an ongoing EV vehicle-to-grid demonstration project.
- We discuss practical issues of bidding EV capacity in frequency regulation markets.
- We formulate a MILP optimization model to plan EV charging and day-ahead bidding.
- We analyze the model sensitivity and bidding strategy to variation of key inputs.
- Model behavior is highly sensitive to predicted resource utilization and prices.

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ABSTRACT

The Los Angeles Air Force Base Electric Vehicle Demonstration is a currently ongoing vehicle-to-grid demonstration project with the objective of minimizing the cost of operation of a fleet of approximately 30 electric vehicles (EVs) through participation in the California Independent System Operator (CAISO) frequency regulation market. To accomplish this, a hierarchical control system has been developed to optimize, plan, and control the charging, market bidding, and response to grid system operator control of the EVs. This paper presents an overview of the day-ahead optimization model component of the hierarchy. The model is a mixed integer linear program that optimizes daily EV charging and regulation capacity bids strategies in order to minimize operation costs and maximize ancillary service revenue. A deterministic approach is used due to several practical concerns of the demonstration project, including model complexity and the availability and uncertainty of input data in day-ahead decision making, and the limited size of the fleet. The model includes additional user-defined parameters to tune model behavior to better match real-world conditions and minimize the risks of uncertainty.

The paper conducts scenario analysis to explore the impact of these parameters on high level model behavior and resulting bid strategy. The parameters explored include hourly regulation prices, local load conditions leading to retail demand charges, forced symmetry constraints for regulation bids, SOC penalty values to reserve higher states-of-charge in vehicles, and expected regulation resource utilization while providing reserves. These analyses show significant sensitivity in the frequency regulation bidding strategy to the regulation utilization, as well as large differences in the regulation prices between regulation up (discharging capacity) and regulation down (charging capacity). Results also suggest enforcing symmetry in regulation appears to have significant impacts in regulation revenue when there is large relative disparities between prices in the up and down direction. Finally, imposing a small cost on low SOC values significantly impacts the fleet-wide average SOC, making the system more resilient to uncertainty in the mobility demands gathered at the time of making day ahead decisions.

1. Introduction

1.1. Motivation

Electric vehicles (EVs) have been touted as a panacea for our carbon-hungry, energy importing transportation sector. Their ability to shift the energy production burden away from

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Nomenclature

$\mathcal{B}_i$	energy capacity of EV i
$b_i^{av}(k)$	binary availability for EV i
$b_i^{ch}(k)$	binary variable indicating charging or discharging
$\mathcal{C}_e$	total cost of energy
$\mathcal{C}_d$	total demand charges (power)
$\mathcal{C}_{SOC}$	SOC Penalty cost total
$c_e(k)$	price of electricity at interval k
$c_D(h),\ c_U(h)$	hourly regulation prices down, up
c_{I_j}	demand charge for each demand period
c_{SOC}	SOC penalty value [$/%-h]
Δt	duration of interval, in t k, in this case 5 min
Δt_h	duration of bid interval h, in this case 1 h
$\Delta t_{\mathcal{K}}$	duration of demand interval $\mathcal{K}$, in this case 15 min
$E_{flt}(\mathcal{K})$	energy consumed by fleet in interval $\mathcal{K}$
$E_{base}(\mathcal{K})$	energy consumed by base in interval $\mathcal{K}$
$E_i(k)$	energy stored in EV i at interval k
$E_{max,mo}(I_j)$	maximum observed energy consumption in each demand period
$f_D(h),\ f_U(h)$	AGC utilization factors down, up
η_i^{ch}	charging efficiency for EV i
η_i^{dis}	discharging efficiency for EV i
h	hourly time interval
I_j	time interval of demand charge j
J	optimization objective
$\mathcal{K}$	time interval for demand charges
k	time interval
$P_i(k)$	charging power for EV i and interval k
$P_i^{reg}(k)$	AGC charging power for EV i and interval k
$P_{flt}(k)$	net charging of full fleet
P_i^{min}	maximum discharge rate for EV i
P_i^{max}	maximum charge rate for EV i
$R_D(h),\ R_U(h)$	hourly regulation bids down, up
$R_D(k),\ R_U(k)$	regulation capacity down, up available at interval k
$R_D^{min},\ R_U^{min}$	minimum allowable regulation bid down, up
$\mathcal{R}_{reg}$	total regulation revenue
SOC_i^{min}	minimum state-of-charge of EV i
SOC_i^{max}	maximum state-of-charge of EV i
T	time horizon of optimization

distributed, inefficient internal combustion engines to the electricity sector supports national priorities in energy security and public health, and opens up opportunities for decarbonization of personal mobility [1,2]. Further, their commercial renaissance corresponds with significant introduction of intermittent, renewable energy resources into the electricity grid. As renewable generation becomes more prominent, some electricity system decision-makers are looking to increase storage capacity [3], and EVs appear to be a promising, low-cost energy storage resource for the grid. However, the interaction of individual EVs with electricity grid and market operators can be far too onerous from such a small resource to warrant electric vehicle participation directly. This creates a niche for an entity that aggregates a population of electric vehicles to present them to the market operator in a size that is useful for grid operations.

The EV aggregator will play a number of important roles in vehicle-to-grid (V2G) services offered into markets. They will need to understand the availability of the EVs that they represent, take positions and assume the financial risks associated with providing the services in a market, manage their resources in a way to meet any capacity and energy obligations made (e.g. ensure that there is adequate energy stored prior to a service provision period), and finally to determine which vehicles will provide the requested grid service in real-time. All of these must be accomplished while ensuring that the mobility needs of vehicle owners are met, and the cost of EV ownership is reduced. For consumers and fleet operators, the deployment of EVs also creates opportunities for operational cost reduction (e.g. from demand side management) and revenue from new and existing markets, by employing novel planning and control strategies to leverage idle EV capacity.

In the present paper, we focus on a real-world demonstration of one such aggregation at the Los Angeles Air Force Base Electric Vehicle Demonstration (LAAFB EVD). The LAAFB EVD integrates a mixed fleet of roughly 30 electric vehicles capable of bi-directional charging into the wholesale frequency regulation market run by the California Independent System Operator (CAISO) to minimize the net cost of operating the fleet [4]. The demonstration is the first of its kind to take an operational vehicle fleet, replace it with electric vehicles, and participate as a full market resource (subject to all rules and financial obligations) in a frequency regulation market in the US. The hierarchical control system that enables many EV aggregator functions in the LAAFB EVD project is composed of a fleet scheduling tool to gather input data, day-ahead and hour-ahead charging and market participation optimization models based on LBNL's Distributed Energy Resources – Customer Adoption Model (DERCAM) [5,6], and a real-time myopic optimal controller for charging instructions described in [7]. Of particular interest to this discussion is the formulation and design choices made in the development of the day-ahead market participation optimization model.

1.2. Market opportunities and context

The costs of owning and operating an electric vehicle can be reduced through offering vehicle-to-grid services.[1] Service opportunities in current markets are found either in the management of retail electricity purchases, or in wholesale electricity market participation. Retail bill management falls into two major categories: (1) taking advantage of time-varying electricity tariffs by charging/discharging to minimize retail electricity costs; and (2) managing peak electricity demand charges, set by the highest consuming 15-min interval in a month, which can account for nearly 50% of retail electricity bills for commercial account customers. While savings on retail electricity can be a significant opportunity for vehicle-to-grid capable EVs, wholesale market revenue opportunities are more varied.

Grid services in wholesale markets include offering planning capacity, energy, and operational reserves. Planning capacity is an offer to participate in the wholesale energy market during a period of performance in the planning horizon (months to years). In contrast, wholesale energy and operational reserves are offered day-ahead or hour-ahead. Energy offers are simply for buying or selling a quantity of electricity, and the market matches buyers and sellers to determine the price and quantity of electricity each is awarded. Energy markets offer the opportunity for EV owners to charge when the cost of electricity is lowest and even arbitrage energy purchases between high and low priced periods.

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[1] Vehicle-to-grid services potentially introduce additional costs. Key among these is battery degradation costs. A full accounting of all additional costs in not considered in this analysis.

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