Quantifying the Energy-Storage Benefits of Controlled Plug-in Electric Vehicle Charging

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Abstract

Flexibility in plug-in electric vehicle (PEV) charging can reduce PEV charging costs. Moreover, controlled PEV charging can be viewed as a limited form of energy storage, insomuch as charging loads are shifted from high-cost periods to lower-cost ones. Energy storage that is used for generation shifting is used in much the same manner. In this paper, we study these benefits of PEV charging, demonstrating that controlled PEV charging can reduce generation costs. We also determine how much energy storage would be needed to provide the same cost-reduction benefits that the PEV fleet does.

Keywords: **Plug-in electric vehicle, controlled charging, energy storage**

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1. Introduction

Concerns surrounding growing energy demand, climate change, and finite fossil fuel supplies have increased interest in the use of electrified transportation recently. Transportation accounted for close to 20%

2. Materials and Methods

Our analysis is based on a combined economic dispatch and PEV charging model [17]. Our analysis assumes perfectly controlled charging, meaning that a single entity co-optimizes PEV charging with generator fleet dispatch. Although our model is agnostic to who this entity is, we refer to it as the SO throughout. Although the SO can control the timing and rate of charging while PEVs are parked, it cannot change PEV driving patterns. Moreover, the SO is required to fully recharge each PEV before it departs its charging station.

The following subsections detail the SO model formulation, the method used to quantify the benefits

The SO's model is then formulated as:

$$\min \sum_{t=1}^{T} \sum_{i \in I} F_i(q_{t,i}); \tag{8}$$

$$\text{s.t.} \sum_{i \in I} q_{t,i} = L_t + \sum_{\gamma \in \Gamma} b_{t,\gamma} + c_t - d_t; \qquad \forall\, t = 1, \ldots, T; \tag{9}$$

$$P_i^- \leq q_{t,i} \leq P_i^+; \qquad \forall\, t = 1, \ldots, T; i \in I; \tag{10}$$

$$R_i^- \leq q_{t,i} - q_{t-1,i} \leq R_i^+; \qquad \forall\, t = 1, \ldots, T; i \in I; \tag{11}$$

$$e_t = e_{t-1} + c_t \cdot \eta^c - d_t/\eta^d; \qquad \forall\, t = 1, \ldots, T; \tag{12}$$

$$0 \leq e_t \leq \overline{e}; \qquad \forall\, t = 1, \ldots, T; \tag{13}$$

$$0 \leq c_t, d_t \leq R^e; \qquad \forall t = 1, \ldots, T; \tag{14}$$

where the values of $b_{t,\gamma}$ are fixed according to equation (7), since we are modeling a case with uncontrolled PEV charging.

This model has the same objective as in the original model and constraint sets (10) and (11) are the same technical generator limits as before. Load-balance constraint set (9) forces the total generation to equal the sum of non-PEV and PEV load and net energy stored in each hour. Constraint set (12) defines the ending hour-t energy level of storage in terms of its hour-($t-1$) storage level and any hour-t charging or discharging. Constraint sets (13) and (14) are storage energy and power limits, respectively.

3. Case Study

We study performance of a test system, which is based on the ERCOT system in 2005, over a one-month period. We include all of the thermal and hydroelectric generators that were installed in the ERCOT system in 2005. We combine stepped heat rate data obtained from V cases in which the storage device has between half an hour and 20 hours of energy capacity. This means that if fully charged, the device can be discharged at its rated power capacity for between 30 minutes and 20 hours. This range of energy capacities encompasses a number of grid-scale energy storage technologies. Battery and compressed-air energy storage systems can have energy capacities that are less than four hours, whereas PHS systems with 20 hours of energy capacity are currently in operation.

We formulate the SO's models as a non-linear optimization problem using version 12.1.0 of the AMPL mathematical programming software package and solve it using CPLEX 12.5.1.0.

4. Results and Discussion

Table 1

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