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Electricity costs for an electric vehicle fueling station with Level 3 charging

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HIGHLIGHTS

- The cost of supplying electricity to a Level 3 PEV refueling station is evaluated.
- Most PEVs used for shopping and work trips are not eligible for Level 3 refueling.
- Demand charges for the station exceed $1.00 per kW h when PEV use is low.
- Increasing PEV use and parking management can reduce demand charges.
- Increasing refueling rate raises demand charges, but not number of fueled PEVs.

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ABSTRACT

Three major perceived disadvantages of plug-in electric vehicles are limited driving range, slow recharge time, and availability of charging infrastructure. While increasing PEV range through larger and more efficient batteries may assuage concerns, public PEV charging infrastructure is required to increase the feasibility of widespread PEV adoption. In particular, Level 3 electric vehicle supply equipment (EVSE) can refuel a depleted PEV battery to 80% state of charge in half an hour. This work examines details of exact electric utility costs incurred by the operator of a public Level 3 EVSE used to refuel PEVs that perform two of the most common types of travel: driving to work and driving to shop. Both 44 kW and 120 kW EVSE refueling rates are considered. Utility rate models for Southern California are used to determine the cost of electricity. Cooperative game theory is then used to determine of the electrical demand charge incurred by each individual PEV that is charged. Results show that approximately 28–38% of typical travel results in a battery state of charge low enough to be eligible for Level 3 refueling. At low PEV total use, electric utility demand charges comprise an extremely high portion of electricity costs. Increasing PEV total use decreases demand charge contributions to the electricity costs, but must be coupled with parking management, such as valet parking, when dwell time at the destination is long (e.g., at work). Total energy costs to operate 44 kW Level 3 EVSE exceed $1 per kW h at low PEV use, but decrease as PEV use increases. The lowest costs occurred at the highest level of PEV use examined, resulting in a total energy cost of approximately $0.20 per kW h during the summer and $0.13 per kW h during the winter. Parking management may be avoided if multiple EVSE are installed, which is particularly effective in improving access for travel with a short dwell time (e.g., while shopping). Increasing EVSE refueling rate improves access to PEV refueling only if parking management is implemented, but always increases demand charges.

1. Introduction

Three major perceived disadvantages of plug-in electric vehicles (PEV) are limited range, slow recharging time [1], and availability of charging infrastructure [2,3] . Numerous research efforts have been made toward improving PEV range and charging infrastructure in an effort to overcome these perceived barriers to widespread PEV adoption [4]. Improvements to infrastructure have led to the installation of three types of electric vehicle supply equipment (EVSE) across the United States: the Level 1 (3.3 kW output), Level 2 (up to 14.4 kW output but typically 6.6 kW), and Level 3 EVSE (up to 240 kW output but typically 44–120 kW) [5]. Research focused on Level 1 and 2 type chargers has shown that

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while increasing battery size may assuage concerns regarding PEVs, some public EVSE capable of providing power beyond what is available from a typical electric socket (i.e., Level 3 charging) can increase the feasibility of widespread PEV adoption [6]. As a result, many aspects of Level 3 EVSE are currently being investigated.

The integration of EVSE with the electrical grid introduces new challenges to operating and maintaining the electrical grid [7]. Grid reliability must be considered when selecting locations for EVSE installation [8]. Once the EVSE is installed, electric grid reliability may be reduced for densely populated areas as PEV adoption increases [9,10] and voltage stability may also be reduced in areas of high PEV use [11]. In distribution circuits, losses are greater for secondary voltages than primary voltages [12]. However, other work has shown that charging plug-in hybrid vehicles within residential distribution circuits has little effect on residential transformer life unless drivers start charging as soon as they arrive at home with Level 2 EVSE [13]. Also, [14] showed that unscheduled PEV charging will only increase peak demand by 1% for some regions in the United States if moderate grid growth and improvement occurs.

The optimization of PEV charging is another area that has received significant research attention. Research based on the Ireland grid has shown that charging PEVs at night versus during the day can result in lower greenhouse gas emissions and cost [15]. When controlled properly, PEV charging can also be used to improve overall grid performance [16–19]. Electricity cost to charge PEVs can also be minimized [20–23], while also minimizing emissions [24] or grid losses [25] with smart PEV charging. Other work has looked at the possibility of utilizing PEVs connected to EVSE to help minimize building energy costs through peak shaving and load shifting [26].

The optimal siting of EVSE has also been explored in the current literature. This problem has been formulated as a mixed integer nonlinear program that minimizes initial investment cost and grid losses [8], and both investment and operational cost [27]. Several integer programs have been proposed that optimize EVSE placement such that total power losses in the grid are minimized [28], customer coverage is maximized [29,30], PEV refueling is maximized subject to an EVSE investment limit [31], and transportation distance to the EVSE is minimized [32]. Corresponding work has focused on evaluating the economics and feasibility of public EVSE. Research focused on plug-in hybrid vehicles found that making public EVSE ubiquitous increases the overall cost of PEV operation substantially [33]. However, some public EVSE is required to maintain high feasibility for PEVs [6]. Other work has focused on developing pricing methods for public EVSE to minimize cost of operation [34] while reducing congestion at individual charge points [35], or to recover investment cost while remaining cost-competitive with conventional gasoline vehicles [36].

As of 2015, approximately 70% of all public PEV charging outlets are Level 2, 21.5% are Level 1, and 8.5% are Level 3 [37]. Despite being the least adopted charger type, Level 3 EVSE are capable of charging a PEV battery up to 80% state of charge quickly [5]. Currently high investment cost and uncertainty associated with PEV adoption rates make investment in fast charging equipment risky [38]. If this risk can be reduced and the number of Level 3 EVSE increases, it is important to understand the costs associated with operating a Level 3 charger in addition to understanding optimal placement, charging strategy, grid impacts, and pricing methods.

The current analysis determines the cost of electricity to supply an individual PEV with electricity through a Level 3 charger. Other costs, such as investment and maintenance costs, also influence the decision to invest in and operate public Level 3 EVSE. However, these costs are straightforward to analyze. Thus, the current work conservatively analyze the more challenging to estimate cost of electricity of Level 3 EVSE operation. If these costs are too high then investment in this technology will not occur regardless of reductions in other costs. The US National Household Travel Survey (NHTS) was used to build a PEV travel model [39]. Charging scenarios that span most types of public EVSE operation were built and combined with the vehicle travel data to produce the electrical demand created by Level 3 charging. Models of PEV charging rates were then developed and used to determine the cost of meeting the total electrical demand. Finally, the individual cost to supply each PEV with electricity through Level 3 charging was determined using the Shapley value. Travel data and utility rates from California (with a focus on Southern California) are used. The goal of this work is to determine the cost to purchase electricity from a utility to supply electricity to a public Level 3 EVSE with careful consideration of existing electric utility rate structures, as well as the cost to refuel individual PEVs. Keep in mind that this analysis assumes that all PEVs that can be refueled using Level 3 EVSE are refueled if possible, conservatively presenting the most supportive case for using public Level 3 EVSE to power our most common types of trips.

2. Models

Models were developed to determine the monthly electrical demand and cost of electricity for a Level 3 fast charging station. These models consisted of a travel model, an electric utility cost model, and a Level 3 charging station model. Using these models, the cost of the total load supplied to all PEVs and the cost incurred by each individual PEV can be calculated. Fig. 1 shows a flowchart describing the simulation approach used in this study. Obround shapes represent model inputs using real data, squares represent built models or data selection processes, and diamonds represent model outputs.

2.1. Travel model

The purpose of the travel model is to determine the amount of electricity used by each PEV during travel. Since data on Level 3 charging stations was not readily available, the travel model was produced by generating vehicle travel profiles using probability density functions based upon PEV sales information and travel survey data. The PEV sales information was used to determine the model of PEV used for travel. The travel survey data was also used to determine day of travel, time of arrival, time spent at destination (or dwell time), and vehicle miles traveled. This information was then used to determine the battery state of charge.

2.1.1. Type of PEV

Four PEV models capable of fast charging that are available today are the Nissan Leaf, the Tesla Model S, the Chevy Spark, and the Mitsubishi i-MiEV. The battery size [40], vehicle range [41], and cumulative sales in the United States since 2010 [42] for these four vehicles are shown in Table 1.

It was assumed that any car utilizing a Level 3 charger would be one of these four cars, and that the chance of any of these cars using the station could be determined using the probability distribution created by the number of each model sold in the United States. Using PEV sales, a probability density function was created to determine what type of PEV arrived at a Level 3 charging station to be charged.

For a given number of total PEVs visiting the Level 3 charging station, the probability density function was then used to determine the model of each vehicle to be charged. Using the battery size and range information associated with each PEV, the trip