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Fast charging infrastructure for electric vehicles: Today's situation and future needs

Till Gnann[a,*], Simon Funke[a], Niklas Jakobsson[b], Patrick Plötz[a], Frances Sprei[b], Anders Bennehag[c]

[a] Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Strasse 48, 76139 Karlsruhe, Germany
[b] Chalmers University of Technology, Energy and Environment, 412 96 Gothenburg, Sweden
[c] Exigal Technologies AB, Strandlyckås väg 28, 459 93 Ljungskile, Sweden

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ABSTRACT

Potential users of plug-in electric vehicles often ask for public charging facilities before buying vehicles. Furthermore, the speed of public charging is often expected to be similar to conventional refueling. For this reason, research on and political interest in public charging focus more and more on fast charging options with higher power rates, yet estimates for future needs are rare. This paper tries to fill this gap by analyzing current charging behavior from a large charging data set from Sweden and Norway and take the findings to calibrate a queuing model for future fast charging infrastructure needs. We find that the ratio of battery electric vehicles to public fast charging points can be similar to other alternative fuels in the future (close to one fast charging point per 1000 vehicles for high power rates of 150 kW). In addition, the surplus on the electricity prices for payoff is only 0.05–0.15 €/kWh per charging point. However, charging infrastructure needs highly depend on battery sizes and power rates that are both likely to increase in the future.

1. Introduction

Battery electric vehicles (BEV) can reduce greenhouse gas (GHG) emissions if powered with renewable energy (Nordelöf et al., 2014). A barrier to the market diffusion of BEVs is the limited range with current batteries. Though it is possible to find user groups who can fulfill their driving needs and for whom a BEV is economical without public charging (see e.g. Jakobsson et al., 2016), a broader introduction of BEVs would require an improvement of battery technology or a more extensive charging infrastructure setup. This is also postulated by potential vehicle buyers (Dütschke et al., 2011) and policy makers (D'Appolonia et al., 2016, NPE, 2015). On the other hand, fast charging stations imply a large investment (Schroeder and Traber 2012) which warrants the question of how many fast charging stations are actually needed. Here, we define fast charging if power rates are above 22 kW (BMWi, 2015) while a charging site may contain multiple charging stations with even more charging points (= outlets).

The European Commission suggested national targets for public charging points in 2013, which favored 150,000 public charging points in Germany and 14,000 public charging points in Sweden (EC, 2013). The later suggested German national action plan suggested 43,000 public points (of which 7000 should be fast) (BMWi, 2015). Although both numbers contain slow and fast charging options, they differ largely. The first calculations for these estimates were made based on small batteries and low charging power, but recent developments in charging points and vehicles put more relevance on the necessary number of fast chargers. By the end of

* Corresponding author.
E-mail address: till.gnann@isi.fraunhofer.de (T. Gnann).

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2016, there were 1403 fast chargers in Germany, 523 fast chargers in Sweden and 1052 fast chargers in Norway.[1] In Sweden, the ratio of BEV in stock per fast charger is the lowest (15.3), compared to Germany (29.6) and Norway (78.9).[2] Norway has reached a BEV share of about 6% of the total vehicle stock.[3] These numbers show different market situations which are expected to change even more in the future. Still, today's ratio for Norway is a magnitude larger than the suggestion from the European Commission. This discrepancy is important to address since the initial public charging infrastructure might have to be largely subsidized by governmental bodies (Gnann, 2015).

In the literature, there are no estimates on the required number of fast charging points for large geographical areas (with the exception for some highway corridors) based on real-world driving data and existing charging data, even if the planning and placement of charging stations for electric vehicles has been the subject of various studies. The studies vary in methods and approaches. Shahraki et al. (2015) optimize the vehicle miles traveled. They use actual vehicle travel demand as input, but only from taxis and not private vehicles. Their study focuses on Beijing. For a review of optimization methods related to charging parameters see (Rahman et al., 2016). Xi et al. (2013) combine simulation and optimization to study the location of chargers. However, they only look at level-1 and level-2 chargers. Actual charging behavior in Ireland is studied in Morrissey et al. (2016). They find that fast charging infrastructure is most likely to become commercially viable in the short- to medium-term based on current charging frequency.

Different perspectives are also taken into account. Guo et al. (2016), e.g., look at the business perspective and the investment planning for charging station providers. Their model is theoretical with no real life case study. Similarly, Sadeghi-Barzani et al. (2014) look at how to minimize the total cost of charging station investment. They have a real life case: the city of Teheran. Still, they do not take into consideration driving patterns or the actual need for charging, instead they presume a predefined number of vehicles that charge per day. Wang et al. (2013), similarly to Liu et al. (2013), look at the distribution system with the objective to minimize power losses and voltage deviations. Both these studies are not based on actual data. Another common objective is to maximize the amount of electric miles traveled or to reduce the number of unfulfilled trips if all vehicles would be BEVs. Dong et al. (2014) base their analysis on GPS data from the greater Seattle metropolitan area and simulate travel and charging behavior based on this data. They assume a 100-mile battery range for the whole fleet. Alhazmi et al. (2017) use the US national household travel survey to generate virtual travel distances using a Monte Carlo simulation. Their main focus is the location of charging stations.

As described above, some studies use actual driving data, see e.g. (Dong et al., 2014, Shahraki et al., 2015, Yang et al., 2017), but these are limited to a specific city or larger metropolitan area. Sathaye and Kelley (2013) look at highway corridors in Texas and base their calculations on existing traffic volumes. Jochem et al. (2016a, 2016b) calculate the number of fast charging points needed along the German autobahn based on Origin-Destination data. With increased penetration of BEV, queueing at charging station will be an issue. Explicit queueing models have been implemented and analyzed in (Yang et al., 2017). Their data consists of taxi movements and is limited to one city. The objective of their study is to minimize the infrastructure investment.

We aim at contributing to this policy relevant field of research by determining the necessary number of fast charging points per BEV in a queuing model as well as the potential supplement per kilowatt-hour need to economize. Our research is based on large empirical data sets for driving and charging behavior and is thus a new approach for the field. We focus on public fast charging points (with at least 50 kW power), since calculations on slow charging points showed no effect on BEV market diffusion and no business models for slow chargers (Dong et al., 2014, Gnann, 2015). In the model, we analyze the effects of charging behavior, different vehicle ranges, and increasing charging power. A further novelty of our study is the usage of real-world charging data from Swedish and Norwegian fast chargers to calibrate some of the model parameters.

For the sake of clarity, we refer to a charging point as a device suited for charging a BEV that only charges one BEV at a time. For the analysis on charging data, the number of charging sites is important while for all model calculations, we focus on charging points. Accordingly, we will only refer to charging sites and charging points from now on. Furthermore, we will only analyze the demand for fast charging of BEVs since plug-in hybrid electric vehicles can also be refueled with the existing conventional fueling infrastructure.

In the following section, we present both the charging and driving data as well as the methods applied. In Section 3, the results are presented starting with the empirical analysis of fast charging usage in Norway and Sweden, followed by the model development and results from the queuing model. We end with a discussion and conclusions.

2. Data and methods

For the estimation of the specific charging infrastructure need per BEV, we calibrate a queuing model with real world charging and driving data. We use empirical charging data from Norway and Sweden to analyze the variation of charging behavior throughout the day and between different BEV users. Since current charging behavior might not reflect future conditions of charging - due to increased charging power and vehicle ranges – we use driving data of conventional vehicles from Germany and Sweden as a second input to the queuing model to simulate charging behavior under today's and expected future conditions. Finally, we compare our model results against today’s charging behavior as identified before. The structure of our approach is summarized in Fig. 1.

[1] Fast charging options of the company CHAdeMO with 50 kW, the Combined Charging System (CCS) with 50 kW, and Tesla Superchargers with 90–125 kW. Data from http://www.eafo.eu/electric-vehicle-charging-infrastructure, last accessed: 22.11.2017.

[2] Data of vehicle stock as sum of BEV registrations until 2016 from http://www.eafo.eu/countries, last accessed: 30.11.2017.

[3] https://elbil.no/english/norwegian-eV-market, last accessed: 22.11.2017.