Charging Behaviour of Users Utilising Battery Electric Vehicles and Extended Range Electric Vehicles within the Scope of a Field Test

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Abstract—Electric vehicles (EVs) and their application raise new questions and demands. Accordingly, the charging process of electric vehicles is a novelty in everyday life when using such vehicles. This paper presents results of user charging behavior within a field test. In the field test, 500 people with above average yearly mileage took part in integrating the vehicles into their everyday lives. The differences in user behavior between purely electric (BEV) and extended range electric vehicles (EREV) are discussed. Additionally, the opportunities and limitations for vehicles with combined grid services appear from the results as well as the resulting grid load. The results indicate that the vehicles are parked close to a charging station the majority of the time. The results also show deviating user behavior for the BEVs and EREVs.

Keywords— battery electric vehicle, charging behaviour, energy consumption, extended range electric vehicle, field test, measurements, road vehicle

I. INTRODUCTION

Many studies show that the range of today’s electric vehicles (EVs) is still sufficient for most people in their everyday life without recharging during the day [1]. However, commuters with middle and long distances often cover distances of 100 km or even 200 km per day [2] and reach a yearly mileage of far more than 14200 km, representing the average value in Germany [3]. The same applies to vehicles in service companies. Accordingly these groups generate an above-average share of the greenhouse gas emissions in the transport and mobility sector. In metropolises or metropolitan areas, like the Ruhr-Area in Germany, with more than twenty cities (including nine cities each with more than 100,000 inhabitants) and a total number of 5.1 million inhabitants in an area of 4435 km², there are a lot of long distance commuters, as they live out of town but their work places are mainly in the city centers. In addition, a lot of people travel between cities every day. With the rise of renewable energies, a change from conventional cars with combustion engines to EVs by these commuters could help to prevent emissions.

Therefore in 2012 a project was initiated in the Ruhr-Area to examine the suitability of EVs for users with long daily distances. This project is presented in the following section, followed by the measuring concept and project results regarding charging behavior. A discussion from various points of view is presented, followed by the conclusion in the last section.

II. PROJECT DETAILS

A. Objectives

One of the major objectives of the project was to compare two of the main technologies to solve the range problems of EVs, the dc fast-charging option for pure Battery Electric Vehicles (BEVs) [4] and the range extender with combustion engine for Extended Range Electric Vehicles (EREVs) [5]. These vehicle technologies are compared in a field test and evaluated with regard to the main criteria, consumer acceptance and energy consumption. According to this one result is the users’ charging behavior [6] which will be presented in this paper.

B. Boundary conditions of the field test

The test fleet consists of nine EREVs (Opel Ampera) and ten BEVs with dc fast-charging capability (up to 50 kW, Mitsubishi i-MiEV, Peugeot iOn) (see Figure 1), on which the analysis is focused. Additionally, there are five BEVs with standard charging (2.2 – 11 kW AC, German E-Cars Stromos, Think City, Fiat 500 EV). All vehicles are equipped with measuring equipment.

Figure 1. Vehicles of the test fleet: Extended Range Electric Vehicle (Opel Ampera [7], left) and Battery Electric Vehicle with CHAdeMO [8], [9] fast charging capability (Mitsubishi i-MiEV [10], right)

The project “langstrecken-elektromobilität” (03EM0600 A-G) was funded by the German Federal Ministry of Transport and Digital Infrastructure.
Nine EVs were used by three service companies with different user profiles. Five EVs were used as long term rentals to private persons and also to companies. Ten EVs of the Ruhr-University Bochum were given to test persons with a focus on middle and long distance commuters with daily distances between 50 km and 150 km. Additional aspects for the choice of the users were social aspects such as age and profession as well as a balanced quota of women and men. The test periods lasted at least one week for every test person. A better part of the test persons exchanged the BEV for an EREV and vice versa after a week for a direct comparison of the two technologies. These vehicles are subject to the presented results to allow direct comparison of user behaviour in both BEV und EREV.

C. Key figures

The field test took place between November 2012 and December 2014. A total number of 500 test persons were reached with the proportion of women and men 50 % to 50 %.

The main region of the project was the Ruhr-Area in Germany including the surrounding areas. The locations where charging processes took place during the test period are shown in Figure 2. Due to an existent fast charging infrastructure between Cologne and Hamburg, trips from the Ruhr-Area to Hamburg were also executed. Some longer trips, including trips to other countries, were undertaken with the EREVs.

The total mileage of the 24 vehicles in the project was 785.000 km:
- EREVS: 404.000 km
- BEVS with dc fast-Charging: 256.000 km
- BEVS with standard charging 125.000 km

III. MEASUREMENT CONCEPT

All EVs are equipped with data loggers and measuring devices, measuring operating values of the following groups:
- GPS position, date and time
- Battery status
- Energy flow in the drive train and fuel consumption
- Charging energy flow and type
- Consumption of air conditioning and heating
- Consumption of auxiliary devices (12 V)
- Ambient conditions

All measurements are logged with either 10 Hz or 62.5 Hz, Allowing detailed analysis of all drive and charging stages.

One part of the measured data are the GPS details that allow precise time and date analysis as well as the analysis of the positioning with regard to vehicle velocity and altitude. In conjunction with battery details it allows connection between the profile or type of trip and the energy consumption. This is also supported by measurements regarding energy flows in the drive train.

During recharge the type of charging is detected as well as the current charge status and its power. Consequently, all electric details within the EVs are recorded and replicable [12], [13], [14].

IV. USER UTILISATION

Electric vehicles which receive their energy by electric recharging may be used as energy storage for the power grid. For this task electric vehicles need to be connected to the grid to allow energy storage and energy extraction. In this part, the occupation rate of the electric vehicles as used during the project is illustrated. Additionally the State of Charge with regards to the charging process is presented as well as the resulting grid load, resulting from the charging processes.

A. Occupation rate of the vehicles

The following graphs illustrate the vehicle usage for each day of the week. Each diagram shows to which rate the vehicles were charging, with either standard (dark blue) or dc fast-charging (black), were standing near a charging station (bright blue), were traveling electrically (green) or with fuel (red), or were just standing somewhere without reference to a charging station (white) (see Figure 3 and Figure 4). For each of the proportions the following circumstances apply:

Standard Charging: Charging with less than 3.5 kW with the integrated type 1 socket.

DC Fast-Charging: Charging with up to 50 kW using the CHAdeMO socket. (Only applicable for i-MiEV and iOn)

Standing near a Charging Station: Before or after the standing time at this point the EV was connected to a charger. The EV might have been moved to another parking spot nearby. The charger might have not been used by another vehicle while not charging.
Electric Trip: The trips taken into account are purely electrically driven.

Trips with Fuel Consumption: The trips taken into account utilized the combustion engine for the whole or any proportion of the trip. (Only applicable for Opel Ampera)

Standing Somewhere: The vehicle was not used during this period of time and was not connected to the charger while standing at this point. A charging station might have been available anyway.

As the testing period for the participants started and ended each Friday, the results of this day are influenced by management demands and therefore are not taken into account for any conclusion.

The illustrations in Figure 3 and Figure 4 indicate that the majority of the vehicles stood most of the day. At any time during the day more than 50% of the electric vehicles were either in charging progress or parked near a charging station (see Table 1). This proportion was established with the available infrastructure during the project time between the year 2012 and the year 2014. With the increasing amount of charging infrastructure this percentage has the potential to increase further. The minimal time of the day with up to 12%, the vehicles were actually driven.

With regards to the preferred charging time, the illustrations indicate that major charging times are, either during the day, starting in average at 8 a.m. and declining to a minimum at 5 p.m. either by a completed battery charge or interrupted charging due to returning from work. The second charging period starts at about 6 p.m. when the users come home and can connect the vehicle to the domestic power point. The latter represents the majority of charging processes as the vehicles often remain connected to the grid until the morning, however depending on the chargeable energy and the related time, the number of charging vehicles decreases past midnight.

The main utilization of the vehicles takes place with the general peak traffic between 7.30 a.m. and 9.30 a.m. as well as past 4 p.m. Even though the peak hour generally ends between 6 p.m. and 7 p.m. the vehicles were used well after that time. Those trips were often for leisure and shopping purposes.

Although Monday through to Thursday this commuter behavior is well represented, the weekend does not show a distinct utilization of the vehicles even though the charging behavior is more evenly distributed but postponed to the afternoon.

As both vehicles were used by the same user group and the same standard charging connections could be used it is noticeable that both vehicles were used slightly differently. With the ability of refueling the Opel Ampera the users did not have the need for recharging and therefore had more flexibility with finding a car park, even without a charging station. This also becomes noticeable with the higher amount (approximately 30% more) of trips in the afternoon (compared to the morning) that included the use of the combustion engine.

The utilization of the dc fast-charging in Figure 3 is almost not visible; this is due to the type of illustration. The dc fast-charging utilizes high power and high energy, but it does not take a lot of time. Therefore the dc fast-charging takes a minimum percentage in the daily use consistent with the demands of commuters and any other long distance traveler. This is in contrast to the standard charging processes which results in an average of 16% of the vehicles being connected to the charging station with an average number of 1.25 charging processes during weekdays (see Table I and Figure 6).
Slightly below 1, which indicates that the travelled distance on the weekend is below the workday commuting distance. The dc fast-charging was additionally used by the commuters to overcome long distances, especially if they did not have the chance of a second recharge, or had additional distances to travel. Unfortunately, the amount of dc fast-chargers is still limited so that only those testing people, who had the necessary infrastructure on their route could utilize the dc fast-charger. However the average number of dc fast-charging processes was above 20% of the charging processes which represents a very high amount according to the limited number of dc-quick chargers.

C. Re-Charging behaviour

As according to the different technologies the demands to recharge vary. This section focuses on the users charging behavior with regards to the State of Charge (SoC) level.

Using the EREV the driver can utilize the complete electric range down to zero without breaking down as the combustion engine allows continuation of the trip, offering the way to the next charging station. According to this and to the target group of long distance commuters, more than 50% of the charging processes start with an empty battery in an EREV (see Figure 7). 75% of the charging processes in an EREV are concluded with a fully charged battery (see Figure 8), which is representative of “overnight” as well as inter day charging during work time, as the vehicles generally remain connected to the charger for longer than the required charging time.
Figure 9 shows the distribution of the state of charge difference that occurred during each charging process. 35% of the charging processes in an EREV are complete charges starting with an empty battery and concluding with a fully charged battery. All other recharges are equally distributed with 5% to 10%.

The distribution of the SoC at the start of a charging process for a BEV (see Figure 10) is entirely different to the distribution in an EREV. The occurrences are more evenly distributed than with the EREV (see Figure 7). The highest occurrence with 15% is between 40% and 50% initial SoC of the charging process. This relates to the long driven distances, whereas the decreasing occurrences at lower SoC’s is distinct due to so called “range anxiety” as well as the strict limitation to the range at 0% SoC. Due to the current limitations of the availability of charging stations, the vehicles cannot be completely discharged before finding the next charging station, hence most of the users have to recharge the vehicle at a higher SoC level. The latter reason also leads to straight recharges, even at high SoC levels as a precaution.

Figure 11 shows the distribution of the SoC levels at the end of the charging processes. In contrast to the Opel Ampera there are about 40% of charging processes that finish with 70% to 90% SoC. This distribution is encouraged by the dc fast-charging processes that do not fully charge the battery due to power limitation at high SoC.

The distribution of the SoC difference is illustrated in Figure 12. The illustration indicates that the test people generally try to recharge the BEV whenever it is possible which leads to a high number of short recharges with a low change of the SoC level. Compared to the EREV, the level of encouragement to recharge the vehicle seems to be higher in the BEV. This is due to the combustion engine which offers a higher level of confidence and ambivalence of the SoC level.

Figure 8. Measured distribution of the SoC-level at the end of charging processes with the Opel Ampera

Figure 9. Measured distribution of the SoC-difference due to charging processes with the Opel Ampera

Figure 10. Measured distribution of the SoC-level at the beginning of charging processes with the Mitsubishi I-MiEV and Peugeot ION

Figure 11. Measured distribution of the SoC-level at the end of charging processes with the Mitsubishi I-MiEV and Peugeot ION

Figure 12. Measured distribution of the SoC-difference due to charging processes with the Mitsubishi I-MiEV and Peugeot ION
Figure 13 gives an overview of the average grid load curves caused by recharging the EVs during the project period [15]. The load during weekdays is clearly higher than at the weekend. This is according to the number of charges per day (see Figure 5 and Figure 6). The peak loads in the late afternoon and in the evening occur due to the rising number of vehicles being charged at this time of the day. During the night the load, due to charging, decreases to the daily minimum whilst the vehicles are still being connected. This offers potential for smart grid applications such as load shifting [16].

D. Charging, charging infrastructure

In an opinion survey of the test drivers after the respective test periods, it was identified that the public charging infrastructure is a major obstacle for the extensive application of EVs. Especially for people without (regular) charging possibilities at home or at the work place, a functional infrastructure is a mandatory requirement.

Several reasons for dissatisfaction were indicated. Problems with and unnecessary effort for the access of charging points caused by numerous registrations for various providers and various identification tools (APPs, RFID-Cards, ID, Keys, etc.) are one reason. Another problem is a restricted availability of charging stations due to other charging EVs, parked (conventional) vehicles, plug incompatibilities and sometimes also defects or vandalism. Another, mainly psychological barrier is the billing process. Firstly, often the actual costs for charging are not transparent due to included parking costs. Another, mainly psychological barrier is the billing process. Secondly, term-based billings with accumulated costs instead of case related billings can mistakenly provoke thoughts of expensive charging.

V. CONCLUSION AND SUSTAINABLE EFFECT OF THE PROJECT

The results indicate that EVs offer a good chance to be integrated into smart grid applications, as 50 % of the vehicles are already constantly standing in proximity to a charging station. This value may increase with growing infrastructure.

A distinct difference in the charging demands to the user as well as in the user’s charging behavior could be identified between the EREV and the EV. It is hardly possible to utilize the full capacity or range of the EV, however there are additional costs for the EREV. The better choice is dependent on the personal situation and the required range.

REFERENCES


