QUANTIFICATION OF TRANSMITTED ENERGY AND POWER FOR SYSTEM SERVICES BY BATTERY ELECTRIC VEHICLES BASED ON REAL MOBILITY AND CHARGING PROFILES

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Abstract

This paper aims to separately quantify the application potential of electric vehicles for providing negative and positive system services. The data basis is the mobility and charging profiles of real battery electric vehicles. The vehicles only provide system services in the unused connection time with the charging infrastructure. The mobility offer for vehicle users is therefore not restricted. In addition, the power limitation by the energy grid as well as the efficiency losses through infrastructure and energy conversion depending on the energy direction are considered. The results show that battery electric vehicles can provide system service to a significant extent, especially in the period from late evening to the early morning hours.

1 Introduction

System services for stabilizing the energy grid have so far been provided primarily by conventional power plants. However, electric mobility and the resulting merging of the transport and energy sectors are opening up new fields of application for battery electric vehicles to be integrated into the energy network as decentralised storage units during the connection period with the charging infrastructure in order to provide system services. Possible applications for the integration of electric vehicles into the power grid were first presented in [1]. In publications based on this work, calculation models for the evaluation of vehicle-to-grid concepts were developed [2] and applied in various use cases [3]. The aim of this work is to quantify the power and energy that can be provided by battery electric vehicles for system services.

For this purpose, a simulation model was created in MATLAB. The simulation is based on the mobility and charging profiles of 40 BMW i3 vehicles in Germany. The data was collected using a data logging system over a period of 300 days from 19 January to 14 November 2015 for all vehicles. This means that the mobility and load profiles are available for over 80% of the year. The vehicles were the model 60Ah with a usable battery capacity of 18.8 kWh, a single-phase AC charging power of up to 7.4 kW and a DC charging power of up to 50 kW. 17 of the 40 vehicles were equipped with a range extender (REX). The simulation therefore took the vehicle-specific consumption values into account. The evaluation of the mobility behaviour was already the subject of the publications [4] and [5]. During this paper, the data were reprocessed and analysed in the context of the provision of system services.

2. Methodology

2.1 Charging behaviour of the vehicles

In total, more than 11000 charging events of all 40 vehicles were recorded in the simulation period of 300 days. Table 1 describes the charging behaviour of the vehicles separately for AC and DC charging processes.

Table 1 AC and DC charging behaviour of the vehicles

	AC charging	DC charging
Share	95%	5%
Average connection time	14 h	0.5 h
Median connection time	10 h	0.5 h

From the data it can be determined that the vehicles were connected to the charging infrastructure for an average of approx. 14 h and a median of approx. 10 h. However, an AC charging process with a nominal power of 7.4 kW takes only about 5 h for this vehicle model, considering the typical charging curve and efficiency losses. Even in the worst-case scenario in which the vehicle battery is fully charged with 18.8 kWh, only half of the available time is required for the charging process. In the other half, the vehicle battery could therefore provide system services to a significant extent without restricting the mobility offer for the owners.

Figure 1 shows the state of charge (SOC) of the vehicle battery during a charging process without and with system services. During a normal charging event the charging process is completed after approx. 5 h and the vehicle remains in a fully charged state at the charging infrastructure for the remaining time, waiting for the owner to call it up. During the charging event in which additional system services are provided, the vehicle battery is cyclically charged and discharged within a defined SOC area. In the simulation, the SOC range for the cycle is defined as 40 to 60%, as this SOC range represents a compromise between low ageing effects of the lithium-ion cells according to [6] and a mobility buffer of approx. 60 km after [7].

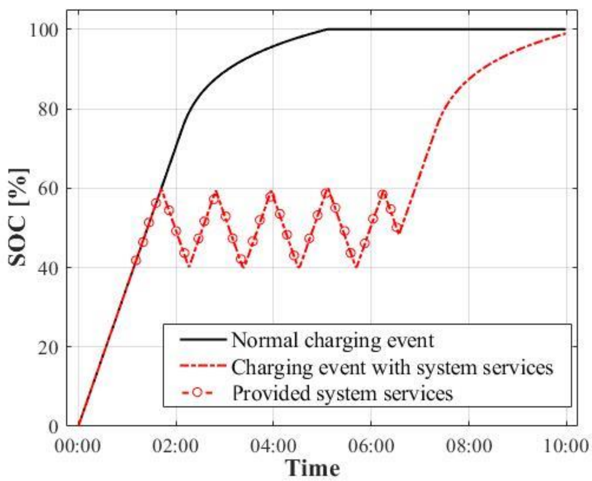

Figure 1 Characteristic charging events

The simulation assumes a nominal bidirectional AC charging power of 7.4 kW for each vehicle. Due to the low share of DC charging processes and the short connection time, it was also assumed that system service is only provided at AC and not at DC charging events. In the simulation, only the energy and power that is transferred into the defined SOC area by the cyclisation is evaluated as system service. The power and energy required to reach the lower SOC value of 40% or to complete the charging process to 100% is therefore not evaluated as system service. The typical charging curve of the IU charging process with decreasing charging power at high SOC values was considered in the simulation according to the formulas and parameters in [8]. The SOC value 75% was defined as the changeover point from I to U phase.

2.2 Power limitation by the energy grid

The transmission power is limited at the level of each individual vehicle by the available battery capacity and the AC and DC charging power. At the level of the vehicle fleet, the transmission power is additionally limited by the distribution network. For this purpose, an apartment building with 40 residential units and vehicle parking spaces was modelled as an example. For the simulation, it was assumed that all AC charging processes take place in this apartment building and that the charging points are thus connected to the energy grid via a common main line. The capacity limitation is achieved by a dynamic load management. A NYCWY 4x50/25 power cable, with 160 A rated current and a nominal transmission capacity of 110 kW was considered for the apartment building according to DIN 18015-1. In addition, after consultation with the local distribution network operator, the main line is only utilised to 90% permanently to compensate for asymmetrical loading of the three phases. This results in a maximum usable transmission power of about 99 kW. Figure 2 shows the average load curve of the apartment building in the simulation period.

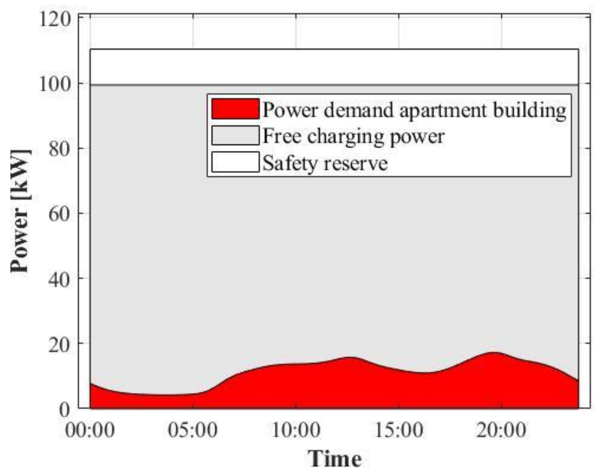

Figure 2 Load curve apartment building

The power demand by the building was modelled using the standard load profile h0 for private households. In Munich the average number of persons per household is 1.8 [9]. The annual electricity consumption per person was assumed to be 1400 kWh [10]. According to this, the annual electricity consumption per apartment unit is 2520 kWh or 100800 kWh for the entire building. The free power available for charging and discharging depends on the energy direction and is given in equation 1 for the negative and in equation 2 for the positive energy direction.

$$PBEVs_{nmax} = P_{MLmax} - P_{Building}$$

Equation 1: Maximum charging power for all electric vehicles

$$PBEVs_{pmax} = P_{MLmax} + P_{Building}$$

Equation 2: Maximum discharge power for all electric vehicles

The maximum charging power $PBEVs_{nmax}$ of electric vehicles is determined by the difference between the maximum transmission power of the main line P_{MLmax} and the power demand of the building $P_{Building}$. The calculated power is distributed to the individual vehicles by means of a dynamic load management system. The same logic is used to determine the maximum discharge power $PBEVs_{pmax}$. Here the assumption was made that the building does not supply power back into the energy network, e.g. through photovoltaic systems. Accordingly, the discharge capacity is not reduced by the building's power demand but increased.

2.3 Efficiency logic for system services

In the simulation efficiency losses are considered depending on the energy direction. Figure 3 shows the entire efficiency chain. In detail, efficiency losses due to energy conversion and storage in the BEV, power transmission in the charging point and in the building were considered.

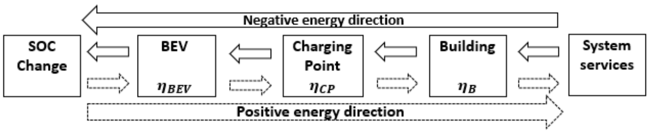

Figure 3 Efficiency logic for system services

The entire transmission chain in the simulation has an efficiency of 77% and is thus at the upper end of the defined efficiency range for vehicle-to-grid applications of 70-80% from [11]. If system services are provided by the vehicles, charging the vehicle battery (negative energy direction) with 1 kW results in a negative system service of 1.3 kW and discharging the vehicle battery (positive energy direction) with 1 kW results in a positive system service of 0.7 kW. The efficiencies thus increase the negative and reduce the positive power values for system services.

3. Results

In the results, the transmitted energy and power is quantified separately for positive and negative system service. Figure 4 shows the average negative system service of the 40 battery electric vehicles in the simulation period.

On average, 56 kW were provided. The simulation has a time resolution of 15 minutes. The 25% largest power values were provided in the period from late evening to early morning hours from 21:15 to 03:15. The time distribution of the highest values can be explained by the primary charging of the vehicles during the night. In total, more than 400 MWh of energy were transmitted for negative system services in the simulation period of 300 days.

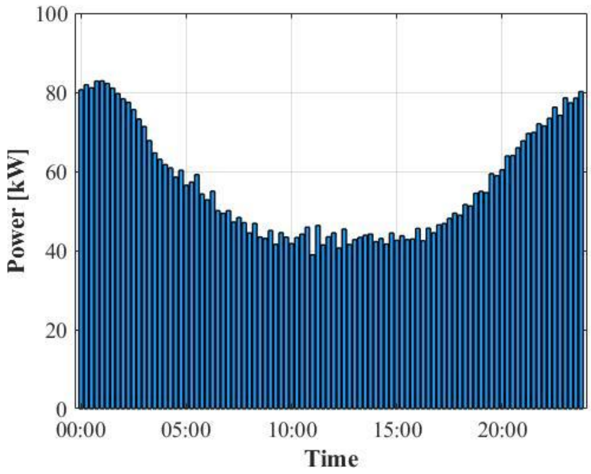

Figure 4 Power for negative system services

Figure 5 shows the positive system service provided by the simulated vehicles. On average, 35 kW of positive system service was provided by all 40 vehicles. The temporal distribution is like that for negative system service, but the values are about one third lower. The one-third lower value for positive system service can be explained mainly by the efficiency logic. In total, over 250 MWh were transmitted in the simulation period.

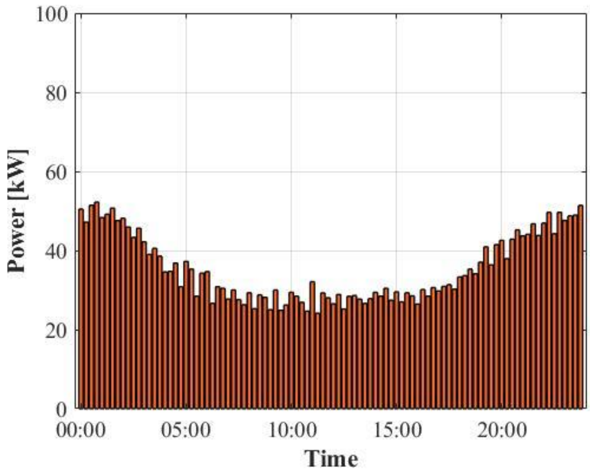

Figure 5 Power for positive system services

Figure 6 shows the distribution of power values for negative and positive system service in a box-plot diagram. The distributions were shown for the entire period and for the period with the highest power values from 21:15 to 03:15. The diagram shows that for all distributions the minimum value of 0 kW is present. In contrast to the other distributions, however, the extreme lower values for negative system service in the period from 21:15 to 03:15 are classified as outliers.

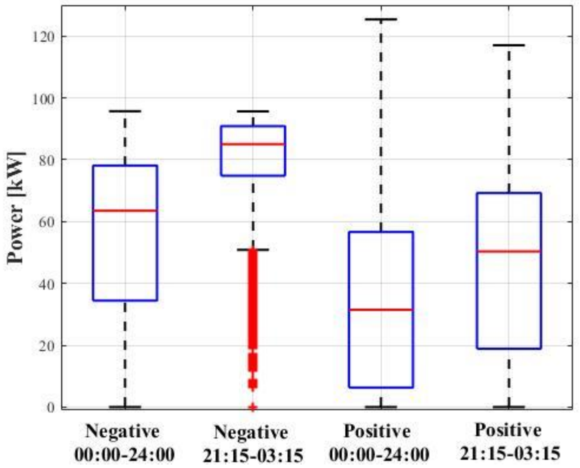

Figure 6 Box-Plot negative and positive power for system services

4 Conclusion

The results show that electric vehicles can provide system services to a considerable extent. In total, more than 650 MWh of energy were transferred for positive and negative system services. This corresponds to approximately three times the battery capacity for system services per vehicle and day. The high energy turnover can be explained by the long connection time to the charging infrastructure and the selected SOC range for system services below the charging changeover point. In accordance with the efficiency logic and the primary use of vehicles for mobility and the associated objective of a fully charged battery at the end of the charging process, the provision of negative system services for battery electric vehicles appears to be purposeful. The provision of positive system service with the associated additional ageing of the vehicle battery only appears sensible from an economic point of view if the resulting costs can be offset by revenues.

According to the data distribution, the period between 21:15 and 03:15 appears to be a suitable period for the provision of system services by electric vehicles. During these 6 hours about 33% of the energy for negative and positive system services was transferred without restricting the mobility behaviour of the vehicle users. The results also suggest that assured power values for negative system services can be expected for this period with a higher number of vehicles. It should be noted that the results are maximum values resulting from the cycling of the vehicle battery during the otherwise unused connection time with the AC charging points. However, the results quantify the application potential of electric vehicles for providing system services and determine the period with the highest availability.

6 References

[1] Kempton, W., Letendre, S. E.: ‘Electric vehicles as a new power source for electric utilities’, Transportation Research Part D: Transport and Environment, V. 2, No. 3, 1997, pp. 157–175.

[2] Kempton, W., Tomić, J.: ‘Vehicle-to-grid power fundamentals: Calculating capacity and net revenue’, Journal of Power Sources, V. 144, No. 1, 2005, pp. 268–279.

[3] Tomić, J., and Kempton, W., “Using fleets of electric-drive vehicles for grid support,” Journal of Power Sources, V. 168, No. 2, 2007, pp. 459–468.

[4] Kessler, L., Bogenberger, K.: 'Mobility patterns and charging behavior of BMW i3 customers', 2016 IEEE 19th International Conference, 2016, pp. 1994–1999

[5] Kessler, L., Bogenberger, K.: ‘Dynamic traffic information for electric vehicles as a basis for energy-efficient routing’, Transportation Research Procedia, V. 37, 2019, pp. 457–464.

[6] Trippe, A. E.: ‘Optimisation Model of Intelligent Charging Strategies for Battery Electric Vehicles Considering the Power System and Battery Ageing’, Munich, 2017

[7] Schleiffer, N., Proff, H., “Geschäftsmodelle für die Ladeinfrastruktur: Arbeitspaket 4.5 ColognE-mobil II, Duisburg, 2015

[8] Schuster, A., ‚Batterie- bzw. Wasserstoffspeicher bei elektrischen Fahrzeugen‘, Wien, 2008.

[9] Landeshauptstadt München - Referat für Stadtplanung und Bauordnung, ‚Bericht zur Wohnungssituation in München‘, 2016-2017,” München, 2018.

[10] Deutscher Mieterbund e.V., “Stromspiegel für Deutschland 2017: Verbrauchen Sie mehr Strom als ähnliche Haushalte?,” Berlin, 2017, https://www.mieterbund.de/presse/pressemeldung-detailansicht/article/34759-stromspiegel-fuer-deutschland-2017-verbrauchen-sie-mehr-strom-als-aehnliche-haushalte.html

[11] Noel, L., Zarazua de Rubens, G., Kester, J., Sovacool, K. B. Vehicle-to-Grid: A Sociotechnical Transition Beyond Electric Mobility, Springer International Publishing, Cham, 2019