Synthetic Charging Profiles Development of Battery-Electric Trucks for Probabilistic Grid Planning

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Abstract

The electrification of freight transport can help reducing greenhouse gas emissions and achieving climate protection goals in the transport sector. Truck manufacturers are progressively releasing modern battery-electric models onto the market. Charging the batteries of those trucks will create additional burdens to the power grid, nevertheless research in grid planning has so far focused mainly on the charging of electric passenger cars. However, due to different driving behavior in terms of distances and downtimes, the charging profile of electric trucks can differ significantly from that of electric cars. As the availability of measurement data is still scarce in the field of truck charging, synthetic charging profiles offer an opportunity to consider them in grid planning. This paper proposes a methodology to produce synthetic charging profiles of electric trucks using trip chain generation based on real historic mobility data of conventional vehicles. The obtained synthetic profiles can be used in grid planning, not only in the development of new industrial areas, but also for further development of motorway service areas. The proposed approach is exemplified in a real logistics center, showing the necessary charging powers to ensure the correct logistics operation, giving an insight of the expected energetic consumption increase.

1. Introduction

Electric mobility is becoming increasingly important to achieve climate protection goals and to reduce greenhouse gas emissions in the transport sector. However, charging infrastructure integration leads to new challenges for the power grid. Charging behavior and charging profiles of electric vehicles (EVs) have to be known to consider them in grid planning. Since EV charging is highly time-variant, time-series based probabilistic grid planning offers a starting point for taking their behavior into account. Therefore, time-series of charging processes are required as input data.

Previous research in the field of grid planning considering EVs has mainly been focused on the grid integration of electric cars (e.g. [1]-[4]). However, the importance of electric trucks is increasing worldwide. More and more manufacturers are launching models on the market. Their charging behavior can differ significantly from that of electric cars due to shorter downtimes, higher charging powers and longer driving distances. Due to the lack of enforcement, experience on the grid impact of battery-electric truck charging is scarce. Investigations in the area of electric trucks are divided into many sub areas as fuel cell vehicles [5] or dynamic charging on motorways [6], but an investigation of grid effects, considering realistically simulated charging behavior, is not covered much.

In the FELSeN research project, the requirements for integrating electric trucks into the operation of a logistics center are investigated. The research takes basis on the operation of a real logistics center in south-west Germany, an industrialized region with a highly developed logistics sector. This paper proposes the use of a methodology based on trip chain generation to simulate the charging behavior of electric trucks at the logistics center. The trip chain generation concept can be used to determine EV charging profiles based on historical journey data of conventional vehicles [1]. In order to generate a new synthetic annual driving profile of a vehicle, random trips are drawn from a historical dataset for each day. Using the consumption data of battery-electric vehicles, charging profiles can then be determined from these data [4]. This makes it possible to simulate the driving behavior of EVs, if there are not enough measurement data available. Up to now, the method has mainly been used in modelling electric cars.

In this paper, mobility data obtained from [7] is used, which was additionally complemented with real data provided by the logistics center operator. This allows to determine the additional power required to charge electrical trucks, as well as necessary alterations in the supply chain, parking space occupancy and the impact in the surrounding power grid. First, the proposed method to generate synthetic charging profiles of electrical trucks is presented. Then, the application of the method in a case study including the logistics center is described, showing how the electrical consumption patterns can be affected through the penetration of electrical trucks and its impact in the grid.

2. Charging Profile Generation Approach

This chapter describes the generation of charging profiles for battery-electric trucks, based on mobility data. First, the underlying vehicle and mobility data sources are presented. Then, the trip chain generation approach is described before the conversion of the trip chains into charging profiles is discussed.

2.1. Truck Model Data

Based on a market analysis of existing and to be released trucks models in Germany, a total of 35 different battery-electric vehicle models could be identified. Figure 1 shows battery capacity and range of the models investigated, categorized according to their weight class.

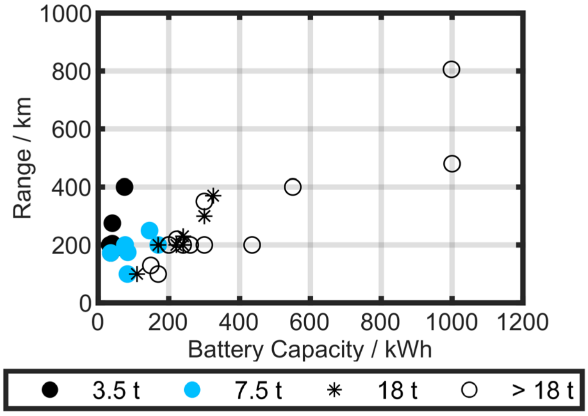

Fig. 1 Overview of battery capacity and range of 35 analysed truck models categorized by permissible total weight

The categorization according to the permissible total weight is also reflected in the travel distances achieved by the trucks, as is described in the next section. A variety of categorization possibilities exist, based on the permissible total weight. In this paper a distinction is made between small trucks up to 3.5 t, light trucks up to 7.5 t, medium trucks up to 18 t and heavy trucks over 18 t. Currently, the parameters provided by manufacturers are still inconsistent regarding the possible payload capacity. The majority of vehicles is in an area below 300 kWh battery capacity and below 300 km driving range. A tendency can be observed in the fact that heavier size classes aim to higher driving ranges.

2.2. Journey Data

To simulate the energy and power required for truck charging, data from [7] is used. Traditionally, the NHTS (National Household Trip Survey) dataset is used (e.g. [1]-[4]), but it contains only the journey records from the United States. The use of the survey in [7] allows to generate load profiles that can be applied to European grids. [7] includes real driving profiles of trucks. The study recorded almost 120,000 driving profiles of more than 70,000 vehicles for one day each. 12,000 of these profiles are attributable to the "Logistics and Transport" sector and are considered here. Figure 2 shows the frequency of route lengths in the data sample. Considering the German goods transport law, a distinction between commercial transport in Germany can be made between the transport modes local, regional and long-distance traffic. The majority of the recorded journeys in the sample focus on local transport. Figure 3 shows the size classes of the trucks contained in the different transport modes. While the lightest truck class still dominates in local transport, it can be seen that the proportion of heavy trucks over 18 t increases with increasing distances travelled.

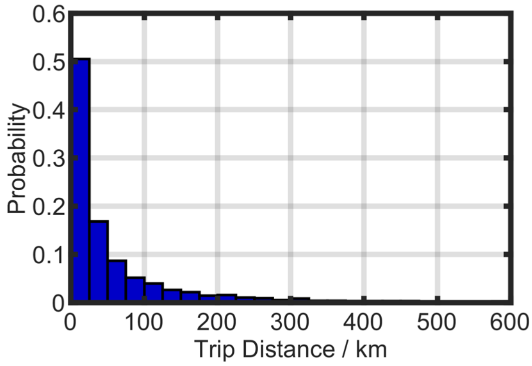

Fig. 2 (a) Distribution of route lengths in “Logistics and Transport” based on data from [7]

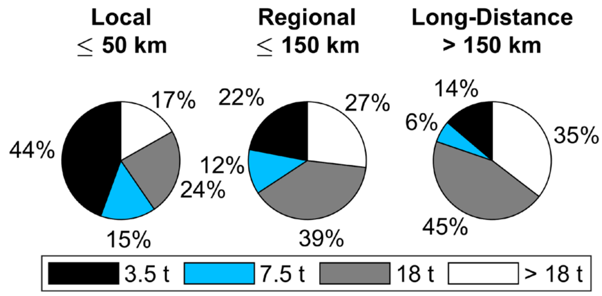

Fig. 3 Distribution of truck size classes in local/regional/long-distance traffic based on data from [7]

From the survey, the departure time and duration of trips can be obtained, from which the distributions are shown in Figure 4. The trip durations are divided into local, regional and long-distance traffic. The longer the journeys, the more evenly the departure times are distributed over the day. The trip duration increases according to the length of the journey. The analysis of the data from [7] shows that a subdivision of traffic can be useful in modelling in order to correctly reflect the purpose of the traffic.

2.3. Trip Chain Generation

Trip chain generation is used to generate synthetic mobility profiles of electric vehicles based on the behavior of conventional vehicles, using historical trip data [1]. Random journeys are drawn from a dataset of historical conventional vehicles and a new trip sequence is randomly generated. This methodology has been used to generate charging profiles of electric cars as in [1]-[4] so far, although its mechanism can be adapted to consider the behavior of trucks as well. One difficulty is that the locations of trucks are not as clearly defined as those of cars in typical daily routines (home, work, leisure time). From the mobility data presented in the previous section, new mobility profiles for potential electric trucks are created using the trip chain generation methodology.

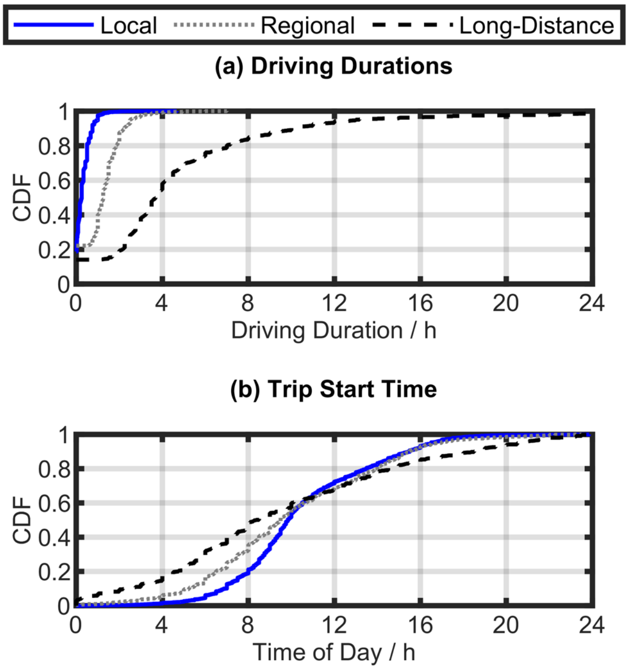

Fig.4 (a) Distribution of driving durations, (b) start times of trips in local, regional and long-distance traffic based on data from [7]

This paper focuses on the generation of trip chains for long-distance traffic, although the method can be extended to other kinds transport modes as well. Trip chains are structured in the form of annual time-series resolved by quarter-hourly intervals. They contain the location of the vehicle (hub, road, motorway service area, etc.) at each timestep and the driven distances of every trip. An overnight stay of the driver on the road for long distance trips can also be included. Random driving distances and departure times are drawn from the trip distribution. The truck then is modelled to drive the given distance at the given time out of the defined hub. If the legally permitted working and driving times are exceeded, the truck is given a compulsory break at a motorway service area, otherwise it drives all the way to the logistics center. Afterwards the next trip is added following the same process. The result is an annual vehicle movement profile, which results in a specific electrical charging pattern for the truck, including different charging locations.

2.4. Charging Profile Generation

For a given truck, a trip chain is generated, which then needs to be transformed into the corresponding charging profile. The truck model has a specific battery capacity and driving range (see Figure 1). At the beginning of the simulated year, a 100% state of charge (SOC) is considered. Based on the defined trip chain, the energy consumption from the driven routes is estimated and the SOC is updated. This process is performed for each 15-minutes period for the entire year. As soon as a vehicle reaches a location with charging infrastructure, (e.g. a hub or a motorway service area), the battery is recharged. The charging process is stopped as soon as the SOC reaches 80% or the vehicle begins with the next trip of the chain. If a trip to be driven requires more energy than the current SOC, or even the battery size, a break is assumed to be taken among the way, and the arrival time to the next destination is delayed. At the end of the process, a seasonal time-series indicating the mobility behavior of a truck (with specified model) and the corresponding charging profile is obtained.

3. Truck Charging Load Modelling at a Logistics Center

Using the example of a real logistics center, the applicability of the generation process is tested. First the modelling of the logistics center is described before the resulting truck charging load is presented.

3.1. Representation of the Logistics Center

Historical data on downtimes, number of incoming vehicles and their freight are used to determine a load profile for truck charging at the center. Data were collected at a real logistics center as part of the FELSeN research project. The logistics center is modelled with four incoming goods gates. The outgoing goods are not considered in this paper, but will be the subject of more detailed investigations in further research. Each gate consists of several ramps so that trucks can be dispatched simultaneously.

For each day, the number of incoming trucks is randomly determined based on a distribution built from historical data. Each incoming truck is assigned a specific freight, represented through number of pallets that will be loaded into the truck. Depending on the number of pallets and the truck size classes distribution at the logistics center, a random electric vehicle model is assigned to the truck. Its driving behavior can be generated using the trip chain approach. A single charging process for each truck is considered. The arrival time of the trucks is organized by the logistics center operator, as specific time-slots are assigned for each truck. The length of the slot is defined by the number of pallets that need to be loaded/unloaded from the truck. Based on this information, the charging profiles of the electrical trucks at the logistics center are obtained, considering that each ramp provides charging infrastructure.

3.2. Truck Charging Load

Figure 5 shows the average and maximum daily load curves of truck charging at all four gates. The results differ in terms of the charging powers and if the charging process is limited only for the duration of the loading/unloading of goods or unlimited till 80% of the SOC. On an average day, the trucks require 1,700 kWh of total energy. The proportion of the needed energy required, if different charging powers are considered, is shown in Table 1. With lower charging powers, only a fraction of the required energy can be provided in the limited time available. If charging only to 80% SOC would be allowed, ramps would be occupied longer and the logistics center could handle fewer trucks in the day. A reduction in productivity can be observed. It can be seen that charging power of at least 150 kW would be necessary to maximize the energy charged into the trucks and reduce disturbances in the operation of the logistics center.

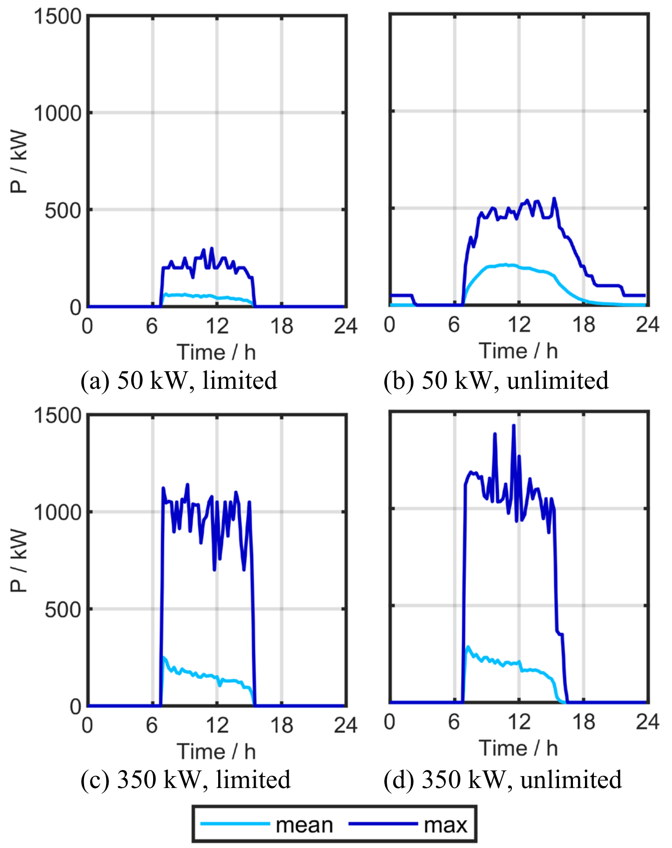

Fig. 5 Example of average a maximum daily load profiles of truck charging at the logistics center goods receipt

Table 1 Proportion of needed energy provided in truck charging at the logistics center

Charging Power	50 kW	150 kW	350 kW
Proportion of needed energy provided	24.5%	51.4%	75.5%

4. Conclusion

The methodology presented in this paper allows to generate more realistic charging profiles for electric trucks and thus an investigation of the grid integration of their charging infrastructure. For this purpose, the mobility behavior in commercial transport is simulated from historical data of conventional vehicles using a trip chain generation approach. This method has so far mainly been used to simulate the charging behavior of electric cars. It has been shown that, due to the limited service life and high mileage, the charging powers, for example during interim charging at a logistics centers, must be at least in the three-digit kW range, otherwise the energy requirement can only be covered insufficiently and the next destination cannot be reached. In addition, the infrastructure at the logistics center is otherwise occupied for too long, which would lead to a reduction in productivity. This paper focusses on battery-electric trucks, but the presented methodology also allows an assessment of the power grid effects and generation of the mobility behaviors of other vehicle technologies as well.

Future research will focus on the application of the proposed method to analysis an entire industrial area, comprised of several logistics centers and other types of factories. The research is being carried over within the FELSeN project. The objective is to provide a modelling approach that can help to assess the impact of the electrification of the goods transport in industrial distribution grids. A general problem became apparent in the modelling of the vehicle models. Information provided by truck manufacturers regarding the consumption of the vehicles is very inconsistent making it difficult to validate the synthetic profiles.

5. Acknowledgments

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