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Generation of stochastic load profiles for mobile energy storages

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Abstract

The rapid growth of the power demand in the transport sector results in a dramatic increase of carbon dioxide emissions. This is only one of many reasons why alternative drive concepts, especially electric mobility, have never been more in focus than today.

A future change from combustion engines to electrical drives leads to additional loads, which gives rise to the necessity to take corrective measures in the energy supply sector. In order to be able to scrutinize the impacts on the power grid, a model has been developed with the help of the software MATLAB to generate stochastic load profiles for electric vehicles. The model exclusively deals with electric vehicles with lithium ion batteries. All parameters originate from the transport statistics of the motorized individual traffic in Austria. In the end the calculated outcome of a driving profile mix for 100 battery powered electric vehicles is consolidated into a total load profile. The resulting implications of some uncontrolled and controlled charging scenarios are discussed. As a consequence of the assumption that most charging processes take place in residential areas, a comparison of the overall load profiles with standardized load profiles for regular households is carried out.

If the charging processes are started immediately after the respective arrivals at home without being controlled, this will result in a rise of the evening load peak. It is shown that by means of several load cycles per day - provided the expansion of the charging infrastructure - this negative effect is limited. Anyway, the overall goal is a well controlled consumer-oriented charging process in order to shift the energy consumption to the night load depression. For this purpose several scenarios are elaborated and its advantages and drawbacks are described. Finally various approaches for the implementation of the highlighted scenarios are presented.

Keywords: stochastic load profile, battery powered electric vehicle, controlled consumer-oriented charging process, household scenario, charging infrastructure

1 Introduction

The electrical mobility is no universal remedy, but possibly the best alternative to gasoline and diesel. The power requirement of the traffic sector grows with an incredible speed, in particular stronger than in all other sectors of the final consumption and therefore the carbon dioxide emissions rises too. To achieve a reduction in greenhouse gases, the search for alternative drive concepts and energy sources must be given the highest priority. This inevitably leads to the electrical mobility.

The infrastructure for charging the batteries in electric vehicles is essentially given by the electrical distribution grid. However the change-over from the internal combustion engine to electrical drive causes an additional grid load and an increased electrical energy demand. Whereupon it must be reacted with an adaptation of the power plant capacity and the power grid structure. Such changes take many years from planning to the conversion. Therefore it is necessary to estimate the behaviour of a large number of electric vehicles in the electrical grid. In this work a bottom-up approach was chosen, which is based on the modelling of the load profiles from each individual vehicle.

2 Data collection and parameter settings

There are no traffic statistics which were only made for battery-powered electric vehicles (BEV). Therefore statistics about the motorised individual transport in Austria ([1], [2], [3]) were used and they lead to the parameters shown in Fig. 1.

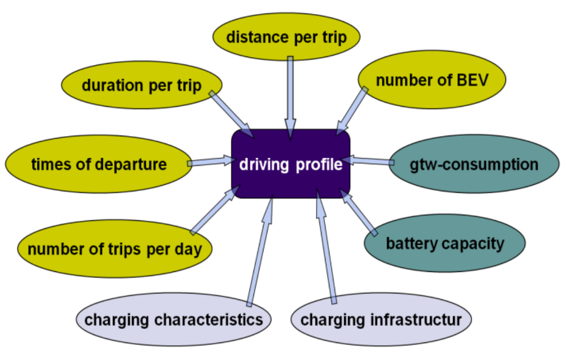

Figure 1: Input parameters for the driving profiles

They refer to workdays (Monday to Friday). From these statistics the four most common trip purposes – those are: commuting, private business / shopping, business and leisure – have been selected to build the used driving profiles. Electric vehicles with the same properties are members of one driving profile.For the following modelling of the load profiles Lithium-ion batteries were chosen [4].

The finally selected numerical values of the most important parameters of all four driving profiles are listed in Table 1.

Table 1: Values of used input parameter

Driving profiles	**Com-muting**	**Business**	**Personal business/ shopping**	**Leisure**
Battery Capacity (kWh)	20	25	10	10
Spec. Consumption (kWh/km)	0.14	0.16	0.12	0.12
Distance / day (km)	28.8	71	29.6	22.1
Duration / trip (min)	24	36	16	25
Number of trips / day	2	3	4	2
Charging after trip 1	at work	no charging	no charging	no charging
Charging after trip 2	at home	no charging	no charging	at home
Charging after trip 3	---	at home	no charging	---
Charging after trip 4	---	---	at home	---
Number of BEV	37	16	30	17

3 The stochastic load profiles

The goal of the self-made MATLAB routine [5] is to construct charging profiles of the electric vehicles, corresponding to the adequate driving profiles.

The resulting charge profiles of the four driving profiles are summed up to one total load profile. This total load profile represents the output of the model and it is subsequently used for comparisons with household load profiles and to create different scenarios and charging strategies.

3.1 Normal distribution of the trip departure

In this paper, the departure times of the trips are modelled stochastically using normal distributions. As a basis the trips in progress by time of workdays which refer to the motorised individual transport in Austria are used. In Fig. 2, the replication of the start times of the trips is shown as an example for the commuter driving profile.

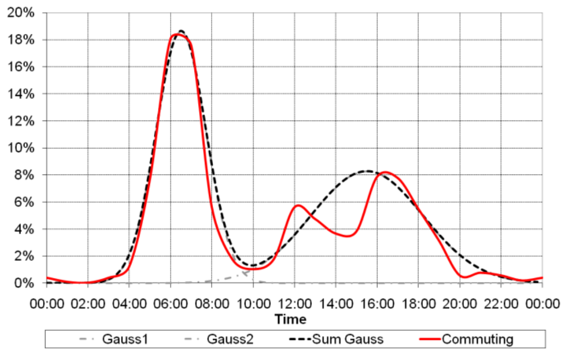

Figure 2: Reproduction of the trips in progress for the driving profile "Commuting"

3.2 Charging profiles of individual BEV

The MATLAB model uses the stochastic distribution, the values of duration / trip and distance / day for creating a route profile for each BEV. The combination of the route profiles with the energy consumption per kilometre and the charging characteristics of the battery results in a charging power profile for each electric vehicle. In the used model the batteries will be charged immediately after stopping, only if the battery is not full and a possibility to charge is given (see Table 1). The maximum power, which is used in this examination, is 3.68 kW (single phase 230 Vac, 16 A). Under consideration of a charger efficiency of 90% a maximum constant charging power of 3.31 kW results. The charging process ends when the battery is fully charged or at the beginning of the next trip, regardless of the SOC value.

4 Results and comparisons

Fig. 3 shows the charging profiles of the four driving profiles (100 BEV) and their sum. This sum is equal to the charging profile of the entire driving profile mix (subsequently referred to as total load profile). The total load profile shows a distinct peak at 7:00 pm with an output of 115 kW.

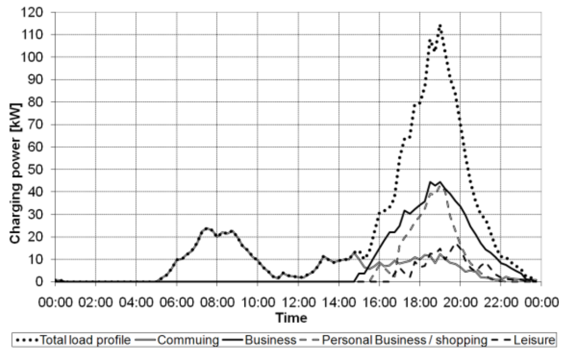

Figure 3: Charging profiles of the four driving profiles and their sum

The sum of the charging energy needed from all driving profiles (100 BEV) is 418 kWh / day. The average power consumption of an entire day is 20.7 kW.

It is important to note that the curves in Fig. 3 are only the result of a single calculation. Any further calculation using the MATLAB program, which is based on the normal distribution of the trips in progress per workday, leads to a different shape of the total load profile.

5 Charging concepts and implementation strategies

Charging the batteries of electric vehicles happens generally in two different ways. Either by uncontrolled charging or by controlled charging. In this chapter several charging-scenarios are created and analysed. The obtained total load profile (100 BEV) of the different scenarios is compared to an adapted VDEW standard load profile (H0 winter, worst case) for 200 households (average consumption of 4.417 MWh per household for the year 2008 [6])

5.1 The uncontrolled charging

Today the uncontrolled charging is the general form of recharging batteries. The charging process starts immediately after connecting the charger. Below are two different scenarios reflecting varying expansions of charging infrastructure.

5.1.1 Charging once a day in the considered grid

In this case all BEV of the four driving profiles are charged only after the last trip and in the same electric grid. It occurs when there is no charging infrastructure outside of the settlement. Thus results in a high charging demand in the evening with a peak of about 297 kW (see Fig. 4).

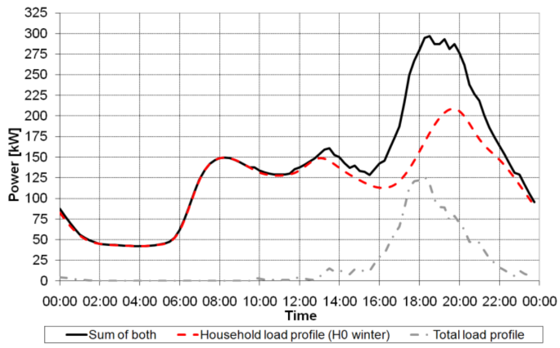

Figure 4: The total load profile for uncontrolled charging of 100 BEV, the load profile of 200 households and the sum of both. Charging after the last trip in the considered grid (settlement)

5.1.2 Charging after each trip in different grids

In this scenario the batteries are invariably recharged after each trip, but only after the last in the considered grid. The other charging operations are in other places and thus carried out in other electric grids. This means, that a possibility to recharge the battery after each trip must be available. This scenario describes a future in which the charging infrastructure is fully developed.

Fig. 5 shows the total load profile of the BEV and the household load profile, as well as the sum of both. It can be seen, that the maximum of the charging power in the evening has been reduced to relatively small 43 kW.

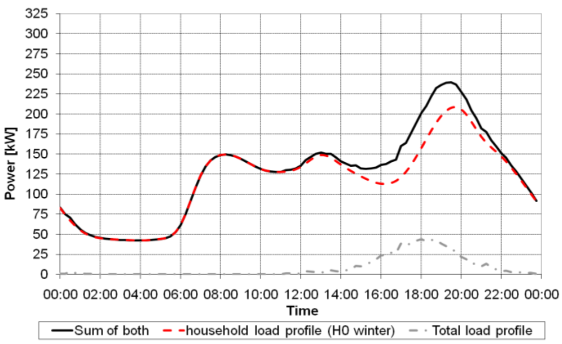

Figure 5: The total load profile for uncontrolled charging of 100 BEV, the load profile of 200 households and the sum of both. Charging after each trip, but only after the last trip in the considered grid (settlement)

5.2 The controlled charging

When controlled charging is in use, the starting times of those charging processes are manipulated from outside to change the shape of the total load profiles. This paper considers only scenarios of consumer-oriented controlled charging and.

5.2.1 Distributed charging in a time frame

So that too many charging processes do not happen together, in these scenarios an equal distribution of the starting times of the charging processes is used.

All charging processes start in a period of several hours. An example with a time frame of 10:00 pm to 02:00 am is shown in Fig. 6. The maximum of the sum of the total load profile and the household load profile is approximately 209 kW.

An extended version of the normal ripple control (for night storage heaters) could be used for controlled charging processes within a time frame.

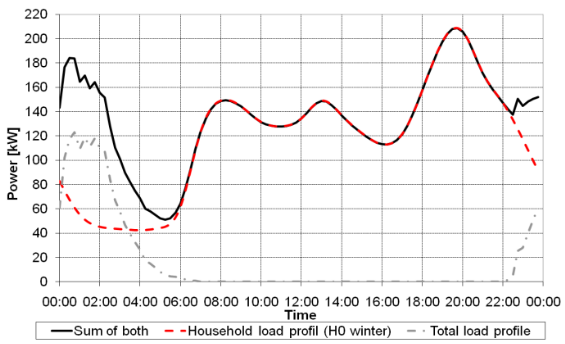

Figure 6: The total load profile for controlled charging in a time frame of 100 BEV, the load profile of 200 households and their sum. The charging frame range from 10:00 pm to 02:00 am

5.2.2 Optimized charging

In the above described scenarios only the starting times of the charging processes have been moved to the load minimum at night. In this scenario also the value of the charging power will be varied to form the shape of the total load profile in an optimal way. Fig. 7 represents the results of the optimized charging in the load minimum at night. The resulting plateau extends from 11:00 pm until after 06:50 am with a constant total power of around 115 kW.

To realize this form of controlled charging an extended version of the normal ripple control would not be enough. One would have to build a two-way communication between the central control unit and the consumer unit.

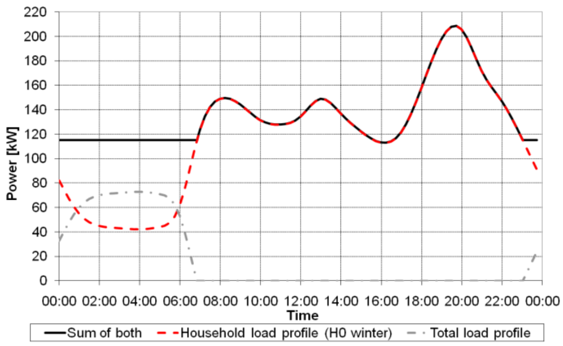

Figure 7: The total load profile for optimized controlled charging of 100 BEV, the load profile of 200 households and the sum of both

6 Conclusions and summary

In this paper the four most common workday trip purposes of the Austrian motorised individual transport are used as driving profiles. With the help of the MATLAB program, the corresponding charging profiles for 100 BEV in a settlement of 200 household were calculated.

If the total load profile for uncontrolled charging and the household load profile are summed up, the evening load peak increases from 209 kW to the 1.4-fold. The charging energy is about 418 kWh / day and represents approximately 18% of the energy demand of 200 households. If in future a large number of electric vehicles in wide ranges of Austria are in use, an adaption of the power grid and power supply will possibly be necessary in order to avoid traffic congestion and bottle-necks.

A possibility to reduce the peak load is to re-charge the batteries after each trip. In this case the household load profile peak only rises about 32 kW. This clearly shows that intensive expansion of the charging infrastructure on public places leads to a smaller load in the electric grid at the residential area.

As shown, the household load maximum was increased by using uncontrolled charging. This can be prevented by the consumer-oriented con-trolled charging. In this case the necessary energy for charging is moved to the household load min-imum at night. The kind of controlled charging, which leads to the lowest charging load peak, has a constant total output of 115 kW in the night. This value is about 55% of the daily peak load of 200 households at a winter workday. To imple-ment a controlled charging, one would have to develop a communication between a central con-trol unit and the battery chargers. This can lead to enormous expenses.

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Markus Litzlbauer studied Electrical Engineering at the Vienna University of Technology and wrote his diploma thesis on the topic „Modelling of stochastic load profiles of mobile energy stores“. Since November 2009 he is active as a project assistant for research at the Institute of Energy Systems and Electrical Drives at the Vienna University of Technology in the range of grid integration of EV.