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Electric Mobility Model Region "ElectroDrive Salzburg": Scientific accompanying research activities

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Abstract

The project "ElectroDrive Salzburg" is a co-financed electric mobility model region of the Climate and Energy Fund in Austria. The project's purposes are to offer electric mobility for companies as well as individuals through a selection of packages, to build up necessary charging stations for users and to implement new renewable energy sources, especially biomass. The research is divided into following parts: 1) Single measurements of specific car values and charging effects, 2) Repeated single measurements of specific car consumptions, 3) Series of measurements in practical use and 4) Continuous measurements of charging stations. The conclusion of this scientific accompanying research is that standby losses of Li-Ion battery systems are lower than ZEBRA batteries, but the overall driving consumptions (15-25 kWh/100km) are in the same range. The driving behaviors (distances and parking locations) of the model region drivers are different to the Austrian individuals. Most of the depths of discharges are between 30 and 60 % of battery capacity. The peak of the charging profile is about 0.33 kW/car and at 11pm if the charges of the electric vehicles are not controlled. Therefore in future intelligent charging controls are necessary to guarantee a stable grid and more renewable energy for battery charging.

Keywords: Demonstration, Energy consumption, Fleet, Infrastructure, Vehicle performance.

1 Project ElectroDrive Salzburg

The project "ElectroDrive Salzburg" is a co-financed electric mobility model region of the Climate and Energy Fund in Austria. Partners of this project are the utility company (Salzburg AG), financial firm (Raiffeisen Leasing), management consultancy (The Advisory House), federal state government Salzburg as well as research institutions (Karmasin motivation research and Vienna University of Technology). [1]
Up to now over 110 public charging spots power a range of E-bikes, Segways and electric cars with green energy. The project's purposes are to offer electric mobility for companies as well as individuals through a selection of packages, to build up necessary charging stations for users and last but not least to implement new renewable energy sources, especially biomass (biogas from field grass and manure), according to the energy demand of all electric vehicles into the system.
The packages for battery electric vehicles (BEV) are offered as leasing agreements, which includes energy from all public recharging stations, warranty insurance, service for the car and tickets for public transportation.

The public charging infrastructures are located at the most important places all over Salzburg and can be unlocked with a so called DriveCard. Additionally all BEV owners obtain an intelligent HomeBox (like a Wall box) as home charging station for safety reason.

1.1 Scientific accompanying research

In 2011 our Institute of Energy Systems and Electrical Drives started the scientific accompanying research, which have the following main purposes:

- To define a metering concept for monitoring the electric cars, charging stations and customer behaviors.
- To analyze the total car consumptions, the overall charging processes and the clients' driving behaviors.
- To evaluate the power quality effects of the charging processes in low voltage grids.

2 Metering concept

In general the cars are used by companies and a few individual persons in addition. The most important charging stations therefore are the regular parking areas at work and at home. Supplementary public charging stations can be used. The key issue, however, is the electric car itself. So the electric car itself is under the spotlight of the measurements. Fig.1 shows the observed electric car in our metering installation, including loggers for power consumption (P), GPS and power quality (PG).

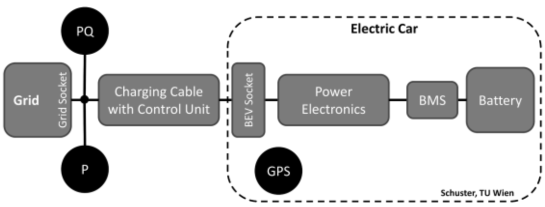

Figure1: Metering installation in and around the electric car

The whole metering concept of our scientific accompanying research in the project "ElectroDrive Salzburg" is divided into following parts:

- *Single measurements of specific car values and charging effects:* The mostly used car types, the "Mitsubishi i-MiEV", the "TH!NK city" and the "Daimler Smart ED", equipped with Li-Ion and ZEBRA batteries, are observed in detail. Data about the power demand of the whole car, power quality of the charging process, the charging station and even the GPS signal of the customer's ways (as shown in Fig.2) are collected.

Figure2: GPS route of the single measurement

- *Repeated single measurements of specific car consumptions:* Interferences like different ambient temperatures (<0°C, >30°C) or the usage of auxiliary consumers (heating, A/C, …) to the car's energy need are collected.
- *Series of measurements in practical use:* Over a period of at least 4 weeks electric cars are monitored by power and GPS loggers. So the progression of the whole power demand and the car's locations are aggregated.
- *Continuous measurements of charging stations:* In a few public charging stations intelligent load meters are installed. These meters log the general energy demand and so a broadened charging profile of more than one car is recorded.

3 Results

The electric cars of the first generation, powered by high temperature ZEBRA batteries, show high standby losses (for more information see [2]), but operate in practical use without any problems. One result of this research activity therefore will be the proof, that the next generation E-Mobility with Li-Ion batteries registers lower losses.
In the following sections charging processes and driving consumptions of all electric vehicles as well as driving behaviors, charging profiles and depth of discharges of measurements in practical use are analyzed in detail.

3.1 Charging process

Data source of following analysis are the measurements of specific car values and also the 10 e-cars in practical use. Tab.1 gives an overview of all observed car types and their characteristics. One car ("TH!NK city") has a ZEBRA battery for purpose of comparison. The capacities are diverse and between 16 and about 28 kWh. Also the maximum charging power is different and can be changed by the control unit in some cases.

Table1: Overview of all observed car types and there characteristics

Car typ	Battery type	Battery capacity kWh	Charging power kW
eSmart	Li-Ion	16.5	3.3
i-MiEV	Li-Ion	16.0	3.2
TH!NK city	ZEBRA	28.2	2.6
TH!NK city	Li-Ion	23.5	2.3 & 3.0

Because of different charging power, the charging time of the same energy demand (about 18 kWh) varied between 6 and 9.5 hours. Aside from the maximum power value the charging characteristics are similar. First the batteries are charged with constant electric current (nearly constant power) and sometimes with short interrupts (Mode 1). This delivered power is the (maximum) charging power. If the battery cells reach the nominal voltage (4.2 V [3]), the charging mode switch to constant voltage charging and the power decrease exponentially, linear or in steps (Mode 2). The duration of mode 2 varied with the vehicle and battery typ.

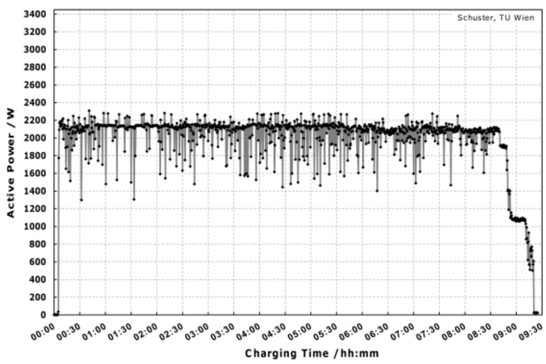

Figure3: Charging process of a "TH!NK city" with Li-Ion battery

Fig.3 shows a whole charging process for the "TH!NK city" with Li-Ion battery, which are used in the field. The maximum power is about 2.3 kW (230 V and 10 A) and the mode 2 duration is normal. The whole charging duration is highly long, because the maximum power is very low. After charging end the vehicle demand is about 25 W, if the e-car is plugged in. These standby losses are very low in comparison to e-cars with ZEBRA batteries (about 110 W [2]).

3.2 Driving consumptions

Data source of following analysis are the measurements of specific car values and also the 10 e-cars in practical use. The overall driving consumptions in kWh/100km include all losses (e.g. charge controller, battery losses, auxiliary devices) and are the whole electric energy from the socket divided by total mileage.

In the single measurements car types "Daimler Smart ED", "Mitsubishi i-MiEV" (all Li-Ion) and "TH!NK city" (Li-Ion and ZEBRA) without using auxiliary devices (e.g. A/C, radio, …) are monitored. In the series of measurements in practical use "TH!NK city" (Li-Ion) are observed. Both measurements took place from July to October 2011 (moderate temperatures).

The overall driving consumptions (as shown in Fig.4) are between about 15-25 kWh/100km. The GPS data from the Tester04 and Tester07 are partially defective or not available. Therefore these consumptions are not valid.

The "Mitsubishi i-MiEV" has by far the lowest consumptions (14.42 kWh/100km) of all. On average all "TH!NK city" (Li-Ion) need 20.24 kWh per 100 km. This value is similar to the two other car types ("Daimler Smart ED" and "TH!NK city" with ZEBRA battery).

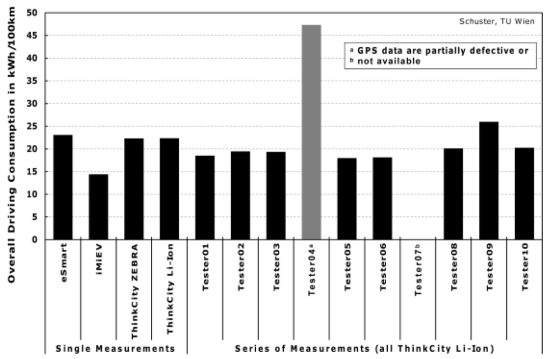

Figure4: Overall driving consumptions

Hence under the terms of moderate temperatures new car types with Li-Ion batteries have same overall driving consumptions like vehicles with high temperature batteries (ZEBRA). However, standby losses of the new battery versions are lower (see section 3.1).

3.3 Driving behaviors

Data source of following analysis are the series of measurements in practical use of all 10 e-cars ("TH!NK city" with Li-Ion battery). Important for electric vehicles are travel lengths (especially maximum lengths) and parking durations as well as their locations.

Without fast charging during the trips (e.g. for refueling) the maximum trip length of the car is directly related to the battery rated capacity and therefore to the car costs. The mean trip and daily travel distances of the electric mobility model region as well as Austrian individual cars [4] are shown in Tab.2. A daily travel is all trips of one day cumulated. In comparison to the Austrian individual traffic behavior the mean single trip of the e-vehicles in Salzburg is circa 56 % shorter. Also the mean daily travel is about 26 % smaller.

Table2: Mean length of all "ElectroDrive Salzburg" e-car trips and daily travels in comparison to Austrian individual behavior [4]

	Trip km	Daily travel km
ElectroDrive Salzburg	7.73	33.61
Austrian Individuals	17.50	45.40

Fig.5 shows the cumulative frequencies of trips and daily travels over the travel length in km. Similar to the Austrian individual traffic behavior about 70 % of all trips are shorter than 10 km. But the largest trip of the e-mobility cars is only about 85 km. In comparison to 720 km [4] for individual traffic behavior, the largest e-mobility trip in Salzburg is very small.

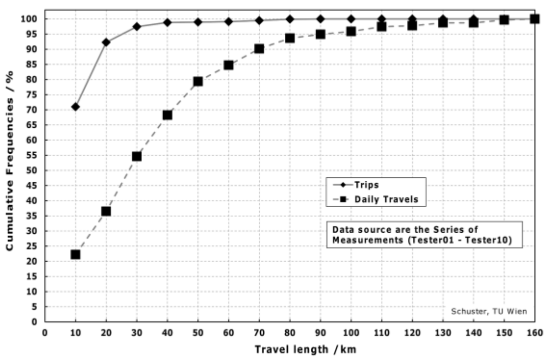

Figure5: Cumulative frequencies of trips and daily travels over the travel length

80 % of all daily travels in the electric mobility model region are shorter than 50 km and the largest daily travel is about 160 km. The practical range of the observed cars is about 120 km (see section 3.1 and 3.2). Therefore during about 2.2 % of all daily travels the vehicle had been recharged to reach all destinations. Hence, top-up charging during the day is not necessary in general, but possible for e-car drivers.

The second important facts are the parking durations and their locations. In this analysis only the location 'At Work' is considered in detail. Note that the observed vehicles are exclusively company cars (fleets).

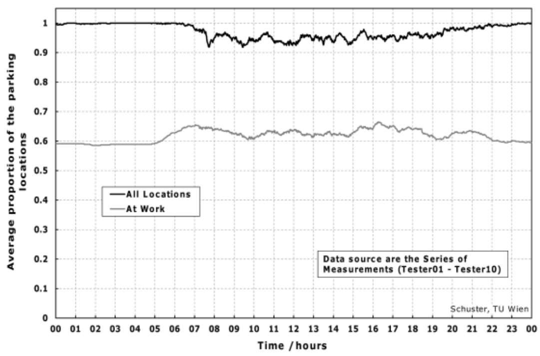

Figure6: Average proportion of the parking locations over the time

Fig.6 shows the average proportion of the parking locations over the time. At every time of day more than 90 % of all cars stand at any location. This characteristic is common in individual traffic behavior (see [5]). However, about 60 % of all electro mobility region cars are located at work overnight. In daytime between 60 and 66 % (nearly the same quantity) of all vehicles stand at work. The differences between 'All Locations' and 'At Work' are all other parking locations like 'Leisure', 'Visiting Friends', 'Shopping', etc..

3.4 Charging profile

Data source of following analysis are the series of measurements in practical use of all 10 e-cars ("TH!NK city" with Li-Ion battery). The load profile of the new demand of electric vehicles is very important for Distribution System Operators (DSO) to plan the electric grid layers. Similar to the load profile of households, information about the required power of all electric vehicles on 'All Days', 'Monday-Friday' and 'Saturday-Sunday' is collected. Finally, this collection is related to one day and one car (see Fig.7).

The minimum of the mean charging power of all days is between 5 and 10am. There are two big slopes at 10am and 8pm. The peak of the mean charging power of weekdays is circa 0.33 kW/vehicle and is very late (about 11pm).

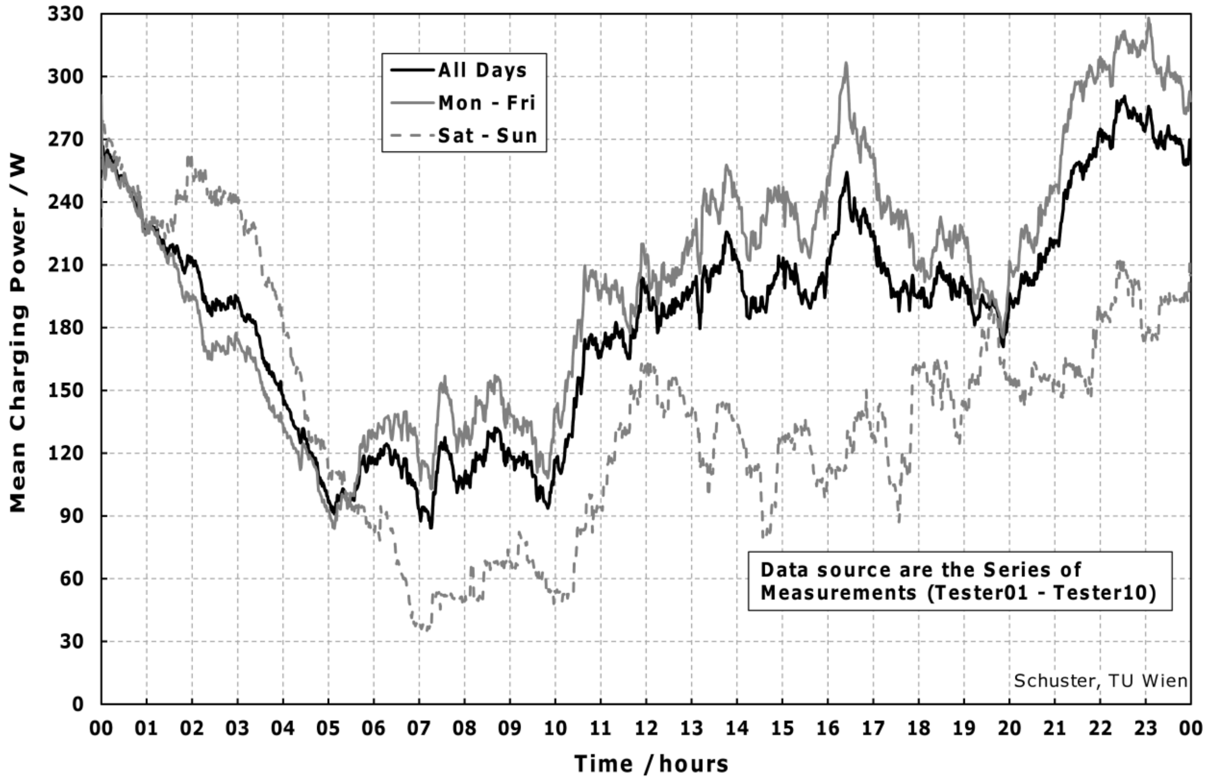

Figure7: Mean charging profile of all observed e-vehicles

Between 4 and 5pm nearly the same demand (0.30 kW/vehicle) is required, but only in a short period. Apart from the early morning hours the weekend demand is every time lower than on weekdays, but with nearly the same characteristics.

In comparison to the charging profile of the first Austrian electric mobility model region ("VLOTTE") the peak power (0.74 kW/vehicle) is very low. Also the time of peak power (between 4:30 and 7:30pm) is different. [2]

3.5 Depth of discharges

Data source of following analysis are the series of measurements in practical use of all 10 e-cars ("TH!NK city" with Li-Ion battery). The focus of this section lies on the amount of charging energy on every charging process. In case of full charges the amount is the same like the common used term depth of discharge (DOD). With these values you can see how much of the battery's capacity is really needed and how long the charging periods take place.

Fig.8 shows the number of charges in percentage of all charges over the charging energy in percentage of battery rated capacity. The most batteries charge only a small quantity (0-10%) and the number decreases nearly linear with the energy amount. Charging time for 10 % battery capacity is about 1:10 hours for this car type and charge configuration (230 V and max. 10 A, see section 3.1). Therefore the amount of a whole battery volume needs about 11 hours. In the whole measurement period 4 charges (1.4 %) began with a nearly empty battery stack.

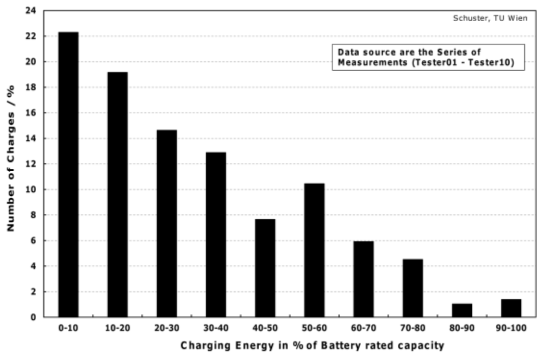

Figure8: Number of charges in percentage of all charges over the charging energy in percentage of battery rated capacity

If only full charges will be considered, the characteristic is different. Fig.9 shows the DOD trend. The characteristic is similar to a normal distribution. Most full charges are between 30 and 60 % of battery rated capacity.

In the first model region the trend of the DOD was nearly equal to all charges. In Salzburg, in contrast, the drivers charge their e-car later (if it's necessary) and need therefore more energy for full charges.

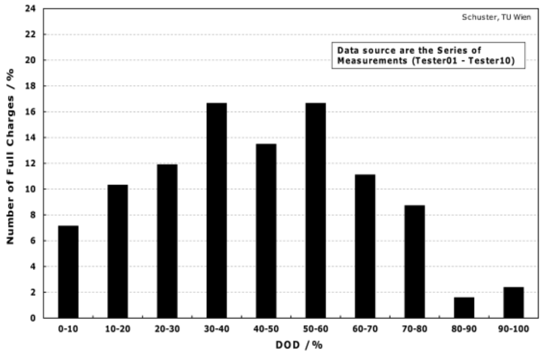

Figure9: Number of charges in percentage of all full charges over the depth of discharge

Acknowledgments

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Andreas Schuster studied Electrical Engineering (concentration of Energy Engineering) at Vienna University of Technology. Schuster finished his degree with the diploma thesis "Battery and hydrogen storage in electrical vehicles" in the year 2008. Since February 2009 he works as a project assistant at the Institute of Energy Systems and Electrical Drives in the working area electric mobility and energy storage.