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ANALYSIS OF THE POTENTIAL FOR THE INTEGRATION OF AN EV FLEET INTO THE POWER GRID

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Abstract

Uncontrolled charging of electric vehicles (EVs) could influence the electric grid in a negative way. Technical as well as economic problems could occur, if many EVs are charged at the wrong time as this may lead to a further increase of already existing load peaks.

One solution to solve the charging problem of EVs could be the participation on markets for different power products. The advantage of optimized charging would be that this process is automatically shifted in such periods where it is convenient for the market e.g., when the demand and therefore the prices are low. Beside the economic benefit for the drivers this would also lead to an advantage for the energy economy, as well – regulated charging can improve the operation grade of the power plants and simplify the integration of renewable energy into the electric grid.

To evaluate the various charging models a simulation tool has been developed. This tool allows the evaluation of various charging models for their usability concerning the energy demand of the electric mobility (EM) as well as the individual mobility requests of the EV drivers. In a further step the considered charging methods are analyzed more in detail by implicating the influence of the driving and charging process on the batteries health. Hereby the main attention is directed on the aging of the batteries, taking into account both aging processes – the calendrical and the cyclic one.

First investigations for charging a fleet with the activation of negative secondary control in the night hours have shown that this charging model is theoretically not able to satisfy the market and mobility requirements at the same time without additional efforts. Therefore maybe a combination of different charging models could allow a better integration of an EV fleet into the power grid.

In order to detect the suitable charging models, which could be used for EVs, it´s necessary to go on with further analyses.

Overview

In the near future electric and hybrid electric vehicles will be likely to substitute cars with combustion engines step by step. The German government released a concept for the development of the electric mobility (EM) /1/. One of the milestones is to get at least 1 million electric vehicles (EVs) onto the German roads until 2020. France, UK, Spain, the Netherlands and many other European countries have set similar targets.

Concerning the generation portfolio as well as the grid development, each of these countries can deal with a certain number of EVs getting charged, without any impact on the grid. But if this amount of EVs is exceeded, recharging the batteries could overload the power grid. Especially when the cars are charged during lunchtime or in the evening after returning home from work, the mandatory load peaks would be increased additionally. In order to prevent from such a scenario it is necessary to conceive different charging methods which offer an energy economic benefit without constricting the individual mobility needs.

The problem of charging a large fleet of EVs

Prior research /2/ has shown that charging a large fleet of EVs without any control could lead to several problems concerning the power delivery. The results of this analysis are demonstrated in the following figure. The first part of the figure illustrates the development of the electricity which is needed to charge 8 million cars. In Germany, uncontrolled charging of 8 million cars (around 17 % of the total cars in Germany right now) would increase the load peak by 7 GW (10 % on top of the maximum peak). The second part of the figure shows a typical weekly load curve for Germany, where the electricity demand for the EVs is added. The correlation of the already existing load peaks and the charging peaks is obvious.

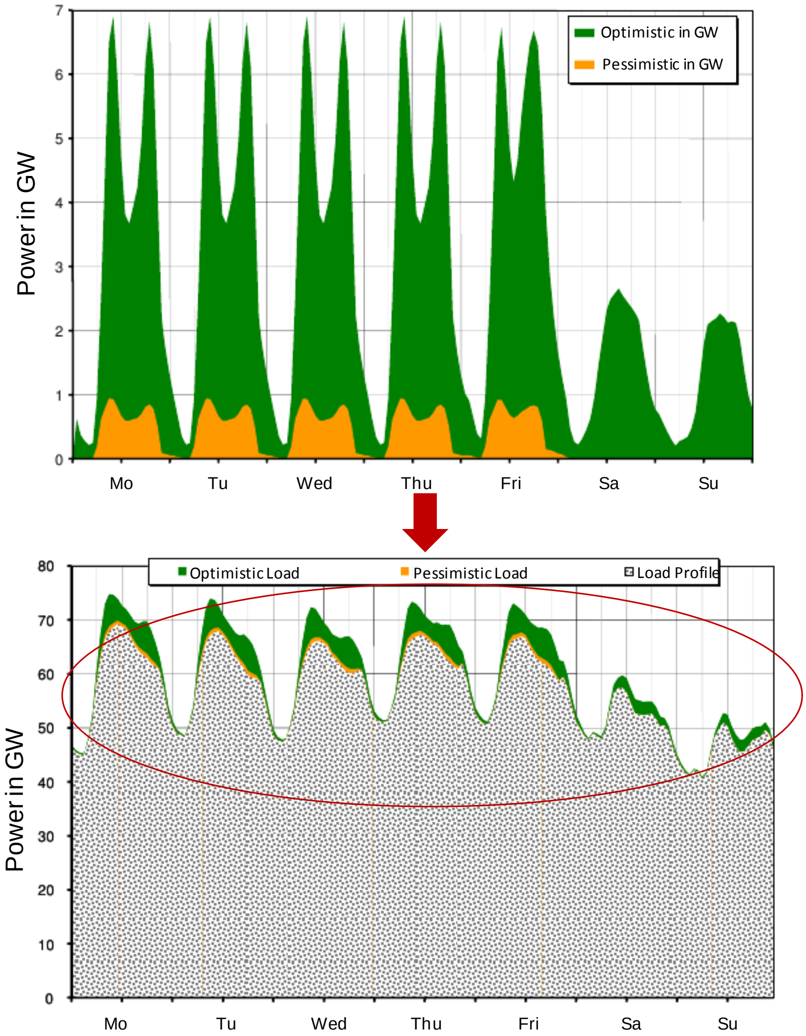


Fig.1. Additional load profiles due to the charging of an EV fleet

Whereas the German energy economy can deal with the additional electricity demand for 8 Million EVs (25 TWh), the time of charging is the issue which has to be managed by the German energy economy.

One Challenge, different markets

The main challenge is the integration of a large fleet of EVs into the traffic without causing negative effects on the electricity systems and the markets. Furthermore, the integration should ideally maximize synergies and involve positive effects e.g., a smooth integration of renewables by using the EV's electrical storage capacity. Possible charging methods for EVs as well as their system profit are shown in Figure 2.

Name	Market	EV	System profit
Direct charging	- Tarifs (Energy, Power, etc…) - Times (everyday)	- EV as a load - No control needed - No communication needed	
Charging during nighttime	- Tarifs (Energy, Power, etc…) - Times (night and Weekend)	- EV as a load - Very simple control needed - Low requirements for communication	
Day-Ahead „Peak Shaving"	- Prices - Power - Energy	- EV as a load - Bidirectional communication - **Load schedule**	
Intra-Day	- Prices - Power - Energy	- EV as a storage - Bidirectional communication, 24/7 online - Short term decisions → effect on the reported load schedule	
Control power	- Primary, Secondary, Tertiary - Prequalification and other formalities - Prices (Energy and Power)	- EV as a Storage, load and producer - Bidirectional communication, 24/7 online	

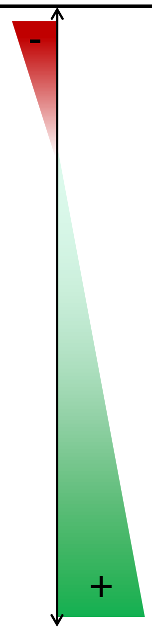


Fig.2. Markets

The first method, "Direct charging", can be compared to charging without any control. This means the cars are charged after every trip until the battery is completely recharged. There are several tariffs in this category and even special tariffs for mobility are intended for the future, e.g. traction current taxes that are actually only on fuel. For this charging method no communication and no control between the EVs and the energy economy is needed.

The second method "Charging during night time" includes a small modification in comparison to the direct charging method. This method is characterized by a cheaper tariff for energy consumption during the night and on weekends. Due to this special tariff the charging load of the EVs is shifted into the valleys of the current load profile (see figure 3). Furthermore only very simple control mechanisms, like one way radio signals are required[1]. Even a clock timer will be sufficient to shift the charging of the EV to the night.

[1] In fact, this is the way how night-storage heater are operated in Germany

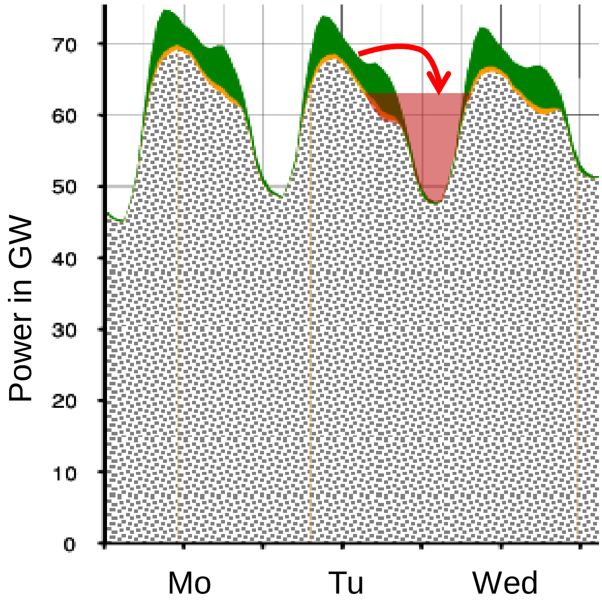


Fig.3. Shifting the charging load into the night valleys

For direct charging and charging during nighttime, the EV is seen as a simple additional load from the electricity economy's point of view. This load has to be prognosticated by the responsible balancing pool manager. Due to special night – tariffs additional load peaks during the day could be avoided without creating much additional expenditures for the EV drivers as well as for the energy economy.

The next step towards an optimized charging is to buy the electricity slots directly on the Day-Ahead market. This method implies that there is some organization[2] which can communicate with the EVs on the one hand and place the bids on the exchange on the other hand. One of the most important benefits of this charging model is that the EVs could enrich the market with their dynamics. The electricity prices on the energy exchange reflect all kinds of effects like the fluctuating renewable generation, maintenance of power plants, fuel prices, energy demand and production. In countries like Denmark and also Germany, negative prices in the Day-ahead market have been reached by reason of too much renewable energy production. The EVs, triggered by the energy price, could take advantages of these market effects and also create a certain smoothing effect.

The regulators in Germany require that a predicted fluctuation of the energy production from renewable sources should be considered on the Intra-Day market. Thereby the need for balancing energy could be minimized. The same requirements apply for other kinds of variations that can be forecasted some hours before they happen. Electric Vehicles could take part in this market, too. The requirements for the Intra-day charging method are very similar to the one for the Day-ahead model. The participation in the Intra-day market allows the EVs

[2] This organization must be big enough to be able to operate on the energy exchange, acting as a balancing pool manager

to act as storages for electricity. Therefore charging and discharging the batteries would affect the current Energy Exchange prices. The motivation of the EV drivers to conform to the Energy Exchange prices depends on the potential to save or even to earn money. Hence this potential requires further investigation.

Furthermore from the energy economies' point of view the storage capacity of the EVs could help to provide balancing energy. Balancing energy is needed to adjust the energy demand and the energy supply, in order to keep the grid frequency stable. There are three different kinds of balancing energy, the Primary, the Secondary and the Tertiary one. The usage of these three different types of balancing energy depends on the activation time. The relation between the activation time and the required type of balancing energy is illustrated in Figure 4.

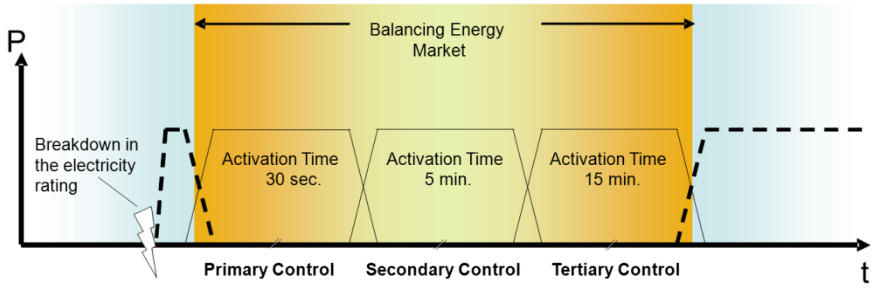


Fig.4. Balancing Energy Market

Methodology

For the analysis of the different markets and their potentials for providing a grid integration of an EV fleet, a simulation tool was conceived (see figure 4). The simulation tool is based on two main parts the "Energy economy" and the "Battery" model.

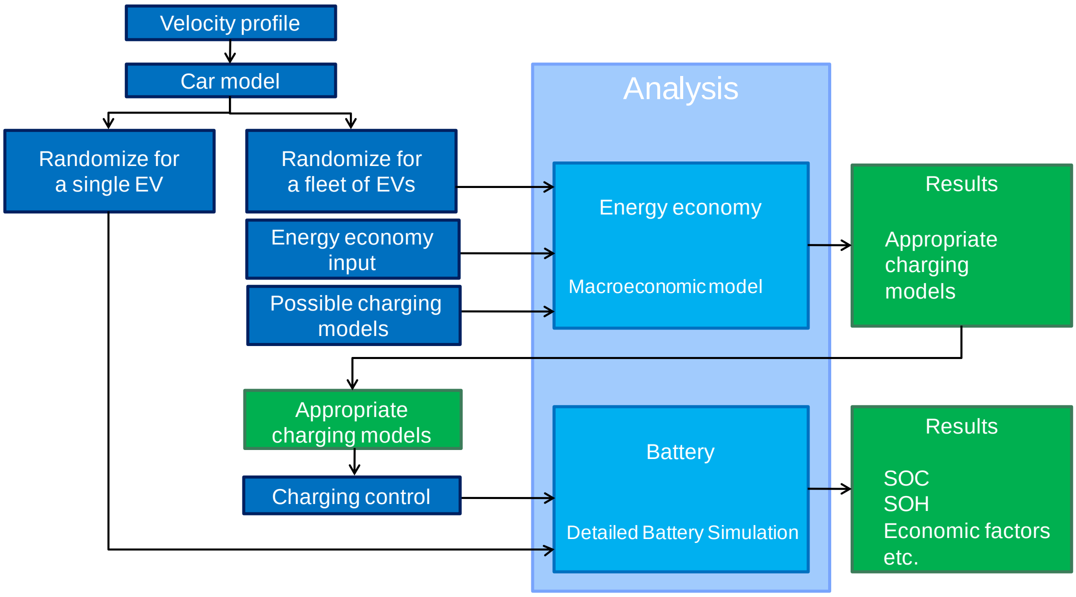


Fig.5. Methodology

The first part ("energy economy") enables the detailed analysis of possible charging models within different markets by considering the mobility request for a whole fleet of EVs. The fleet consists of a couple of superior class cars with different daily driving ranges and patterns. The calculation of the adequate driving energy is based on a car model which simulates the forces and traction resistances depending on a given velocity and height profile. The different driving characteristics derive from on the New European Driving Cycle (NEDC). The driving energy is calculated for 12 different cars and their mobility requests. In order to consider variable conditions for a large fleet of EVs a slight randomized variation is applied for every car in the fleet. The aim of the first model is the revelation of charging methods which offer an energy economic advantage without constricting the needs of the vehicle drivers. To achieve this aim the energy consumption and the parking characteristics of the EVs are compared to the features of the electricity markets.

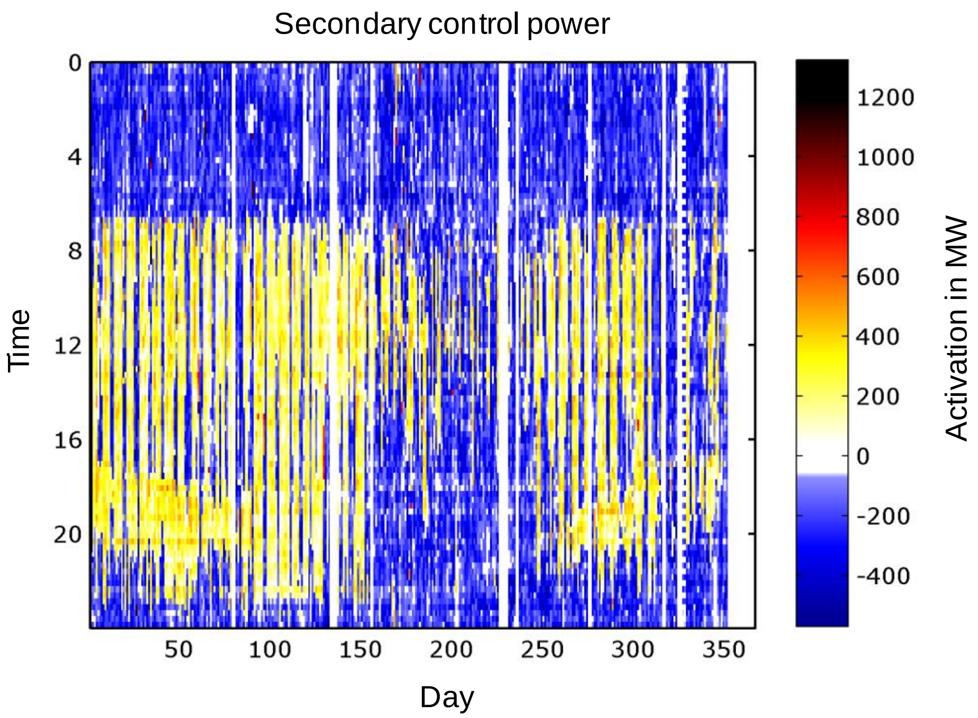
The second part of the tool (“battery model”) allows the detailed analysis of the battery and its characteristic due to different patterns of use defined by the driving profils and charging models. Based on these results the loss of the battery´s value due to the loss of capacity can be compared with the revenue of the charging models. Hereby the cost effectiveness of the different charging models in association with the usage of a single car is evaluated, which allows the estimation of charging models from the economic point of view. To receive realistic results the analysis is based on different car types and classes. The specification of the simulated fleet is shown in Table 1. Every class is split into two groups with the same number of EVs but different car models. Altogether there are six classes which were defined in a prior research /2/. Those classes represent the different mobility requests in Germany concerning the specific daily and annual driving distances. Overall 1.000.000 EVs[3] are regarded.

Table 1. mobility classes

Classes	car model	Quantity
Commuter 1	Smart ed	80.086
	Mitsubishi 1-MiEV	80.086
Commuter 2	Smart ed	75.758
	Mitsubishi 1-MiEV	75.758
Commuter 3	Mitsubishi 1-MiEV	31.385
	Th!nk City	31.385
Commuter 4	Th!nk City	12.986
	Tesla S	12.986
Business	GM Volt	53.030
	Fiat Fiorino Cargo	53.030
Privat	Mitsubishi 1-MiEV	246.755
	Tesla S	246.755
	Sum	1.000.000

First Results

First results have already been gained for the negative secondary control power markets for E.ON's transmission grid for the year 2008. The activation of secondary control for the year 2008 is shown in figure 5.



[3] The goal of the German government is to introduce 1 million EVs by 2020 in Germany /1/

Fig.6. Methodology

The data is plotted into 15-minutes carpets. The activation of negative control (blue) occurred mainly at nighttime, which means that the energy production is exceeding the demand. In the opposite positive secondary control is mainly required between 8 a.m. and 8 p.m. The illustration also shows an increase for the demand of negative secondary control during the summer months. In 2008 the range for secondary power control has lain between 1200 MW and -600 MW.

In the following section the use of control power for charging the EV is described. For negative control power, the battery is only charged in case of activation (figure 6, (a)). In case of positive control power the charging process of the car can be interrupted during the activation (b). A further step is to interrupt and discharge on activation (c). This type would increase the offered power and represents a more active way for providing positive control power.

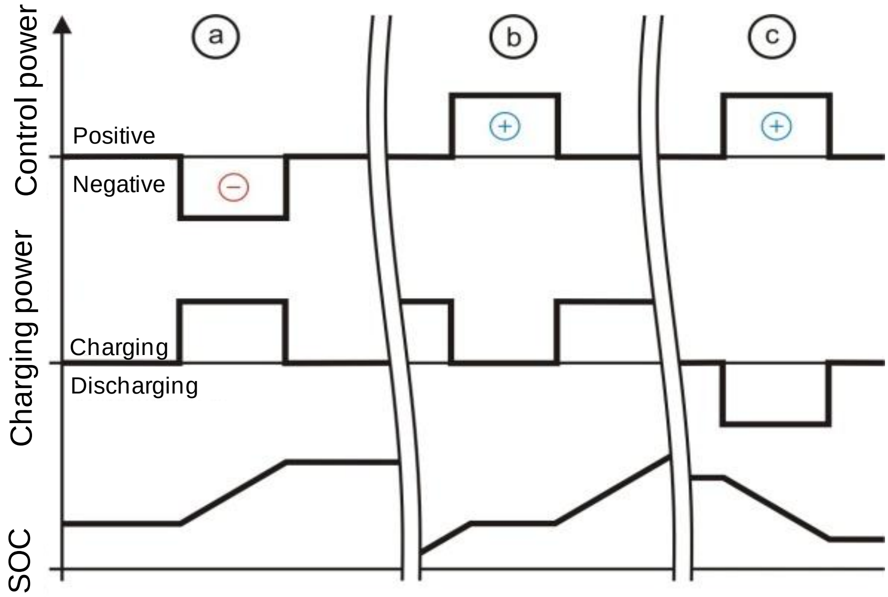


Fig.7. Details of charging method

First considerations have shown that the use of negative secondary control power could be an appropriate charging model. Reasons therefore are the high frequency of activation intervals as well as the fact that those times are mainly during the night where the probability of the cars´ availability is most.

The analysis of the potential for using negative secondary control power to charge the batteries of an EV fleet is based on a simulation where the amount of the offered power was varied between 10 % and 100 % of the available aggregated power of the fleet (in this case, the cars where plugged into standard plugs with a power of 3.5 kW).

The results of this analysis can be shown by using two indicators. The first one, i_{drive}, is the quotient of the recharged energy and the energy needed to drive. In this case the charging energy is only available during the activation of negative secondary control power. If the energy provided by the negative secondary control power is not sufficient, the EV won't be able to drive the next day. In this case i_{drive} represents a value lower than 100 %, which has to be avoided.

$$i_{drive} = \frac{E_{recharged}}{E_{drive}} \qquad (1)$$

The second indicator, $i_{control}$, represents the amount of energy that was delivered as secondary control. It is the quotient of the delivered Energy ($E_{delivered}$) and the activated Energy ($E_{activated}$)

$$i_{control} = \frac{E_{delivered}}{E_{activated}} \qquad (2)$$

Figure 7 shows i_{drive} and $i_{control}$ for the classes "commuter 2" and "commuter 4" subjected to the variation of the available electric power.

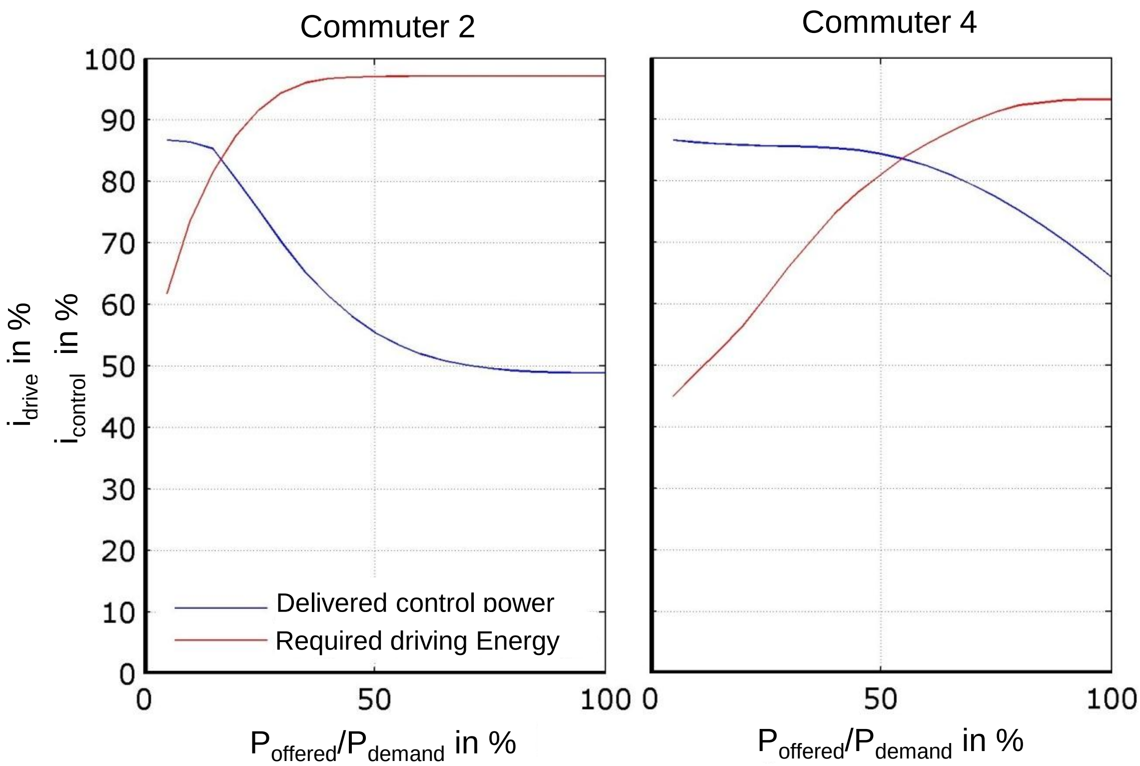


Fig. 8. Provided control energy and energy for driving

It appears that i_{drive} and $i_{control}$ demonstrate a contradicting behavior. The probability for a complete recharge of the EV´s battery increases with a rising amount of offered power. But a higher amount of offered power also leads to the circumstance that the aggregated battery capacity is not sufficient for saving the activated secondary control energy. Therefore the more Power is offered the more i_{drive} approaches the 100 % mark. In contrast the peak of $i_{control}$ correlates with the lowest amount of the offered power with a declining tendency for higher power values. However it can be recognized that the index i_{drive} doesn´t reach 100 % for the whole range of power bids in both cases. To solve this problem, a more detailed seasonal view has to be reviewed.

In Figure 8 the annual distribution of the secondary control activation referred to the offered power is illustrated. It has to be mentioned that the graph is whitened if one of the following two conditions is not achieved:

- i_{drive} is at least at 99 %
- $i_{control}$ is equal or more than 90 %

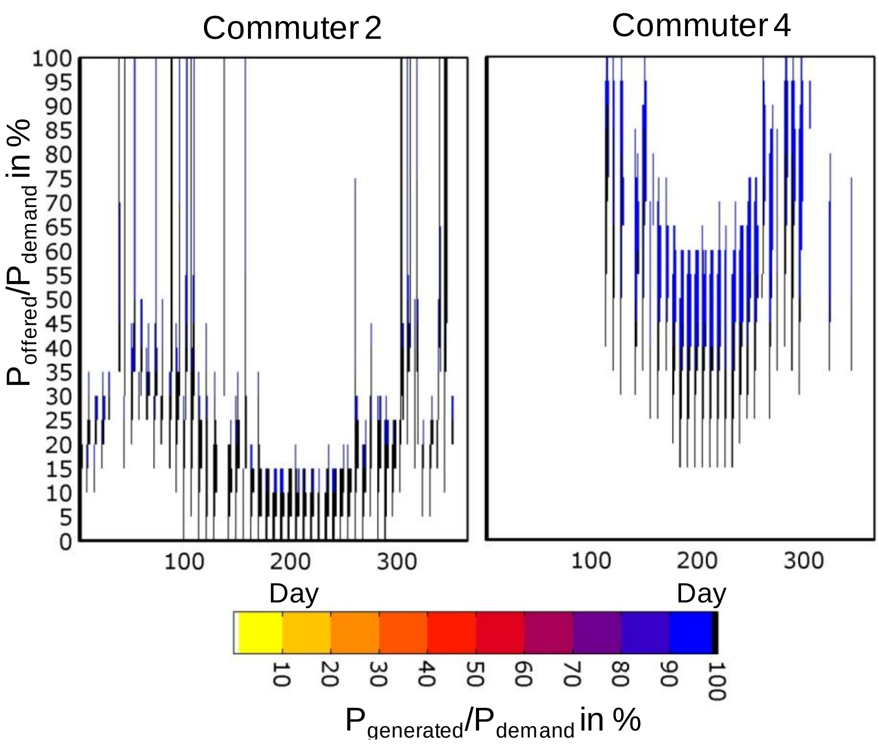


Fig. 9. Provided control energy and energy for driving

Both figures show a semi-circular shape, which indicates the different amount of energy needed for driving under cold or warm weather conditions. The higher the EV's energy consumption is, the more power can be offered for negative secondary control. Days which are entirely white represent weekends and holydays, where no control power is offered.

Figure 8 reveals depending on the energy consumption of the vehicles it could theoretically be possible to reach the requirements of mobility (i_{drive} = 100 %) and also fulfill the control activation ($i_{control}$ = 100%) over the year. This model could be realized by diversifying the offered power during the year in order to face seasonable influences. As it is almost impossible to predict the energy consumption exactly, this charging method is not recommended as an exclusive method. According to this fact a combination with an alternative charging method would be more appropriate for guaranteeing a secure supply of the requested driving energy. Such a model can be seen in figure 9.

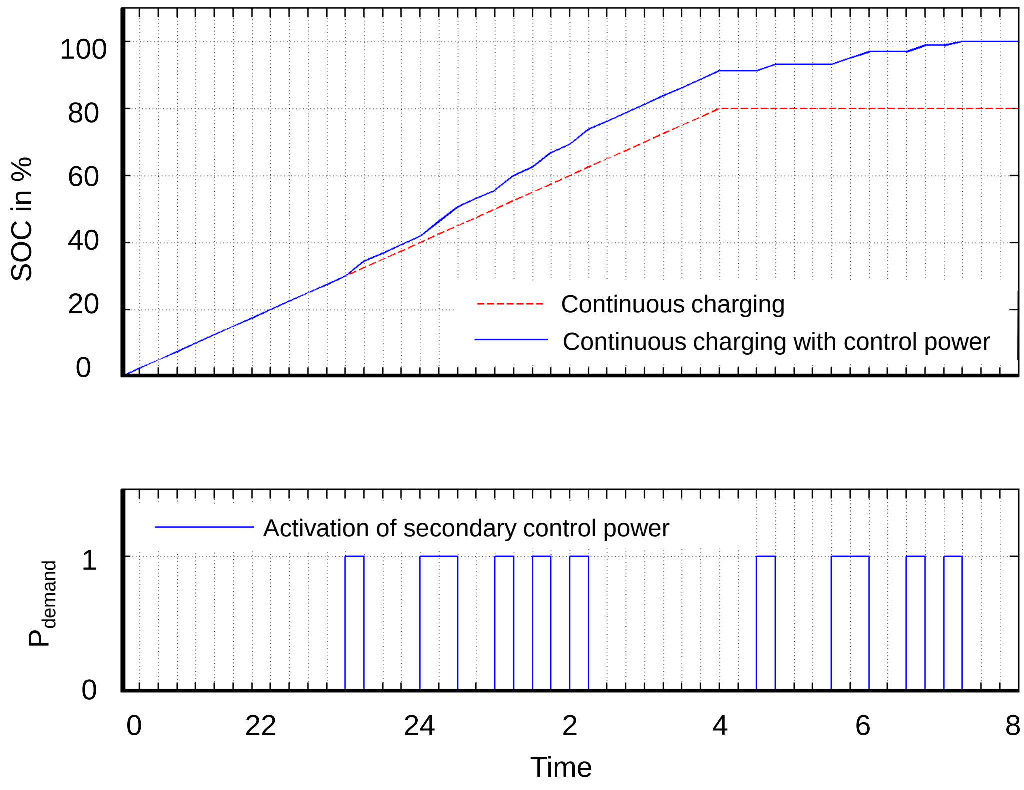


Fig. 10. Combination of secondary control and charging during nighttime

In this example, 80 % of the needed driving energy is delivered by permanent charging during the nighttime. This energy can be bought on the Day-Ahead market in advance and at the beginning of the night a correction could be done via the Intra-Day market. The remaining 20 % of driving energy can be used for providing storage for negative secondary control. This combination could allow the offering of control power without violating the market terms and secures the individual mobility requests at the same time.

Outlook

Within the next steps the specifications of other charging models have to be defined and implemented in the simulation tool. Those researches will show which electricity markets respectively which combinations of different models offer synergies for charging EVs without an additional burden for the electric grid. On basis of those results the impact on the batteries lifetime and the economic point of view are researched in detail. Therefore the “battery model” has to be accomplished and validated. For the validation a lithium-iron-phosphate battery as well as single cells are analyzed under different conditions in order to detect the values of the essential variables for the simulation.

Derived from the final results concrete concepts for possible contracts for prospective users of EVs have to be defined.

Acknowledgement

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