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Vehicle to Grid: Realization of power management for the optimal integration of plug-in electric vehicles into the grid

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Abstract

It is necessary that future energy system has much more renewable sources to avoid the dependency of exhaustible resources and reduce emissions related to electricity production. Therefore load management is needed to balance future energy supply and demand. Effective grid operations can be assured by synergy effects between fluctuating energy supply of renewable energies and flexible load and storage capacity of electric vehicles (EVs). To be able to use advantages of EVs and realize large scale operation of EVs charging and discharging has to be controlled and new infrastructure for communication of the grid and the billing system is necessary. EVs are a new type of bidirectional electricity consumers, sometimes called “prosumers”.

An onboard “metering and control device” is an optional solution to manage charging and discharging. This device communicates with the onboard management and the smart meter of the grid. It considers needs of vehicle user (distance, time of next trip), battery (status, possible load), grid (need for storage/ load), infrastructure (cable, possible power) and the local grid situation. The idea is to provide the optimal charging and discharging strategy of the battery system.

Nevertheless, the implementation of new infrastructure as well as EVs itself will not profitable in the near future which leads to new feed in regulatory framework. Renewable energies, Co-Generation and Energy Efficiency are supported by the German law through the “Renewable Energy Sources Act” and the “Energy Economy Law”.

This paper discusses the grid integration of EVs with a focus on the modulation of supply and demand through controlled charging and discharging. The paper gives particular suggestions how EVs could be integrated into future energy systems.

control system, EV, infrastructure, load management, V2G

1 Introduction

The fleet test “E-mobility” initiated by the German government provides proper conditions in which the discussed charging control and infrastructure will be developed and implemented. E.ON, VW, GAIA and Evonic/Li-Tec (battery developer), Institute of Transport Research DLR, Fraunhofer Gesellschaft, IFEU and University of Münster take part in this project [1]. This paper is based on the work of the Fraunhofer Institute for Solar Energy Systems which concentrates on the bidirectional interface between vehicle and grid.

1.1 Necessity of power management

The expected growth of energy production from renewable sources, as wind turbines and photovoltaic plants [2], needs modern techniques to secure grid stability. With controlled charging and discharging EVs are able to provide manageable demand and storage.
Advantages of plug-in vehicles cannot be used, if charging is just controlled by vehicle driver requirements. Most drivers are likely to park their cars and connect them to the grid, to have a fully charged car for the next journey. If a high share of EVs and a lack of power management are assumed there is likely to be additional load during peak times.

Figure 1 and Figure 2 give a rough estimation of effects by unregulated charging. This shows that controlled charging is inevitable, if there is a high electrification of the vehicle fleet.
Basic assumptions of this scenario are that 100 % of the passenger cars in Germany (41,321,171 in 2009 [3]) are substituted by EVs with a battery capacity of 40 kWh and an average consumption of 0.2 kWh/km.

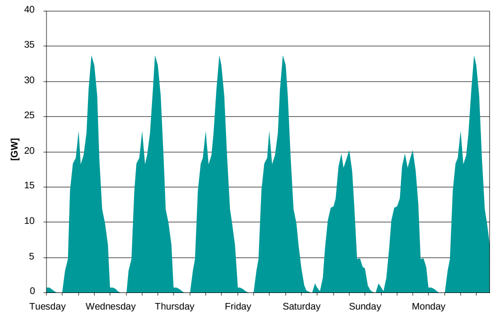

Figure 1: possible charging action

Figure 1 shows the estimated demand of EVs according to driven distance and arrival time of EVs. The times, when vehicles reach their destination and driven distances, are based on a statistical analysis of the dataset "mobility in Germany 2002" [4].
The highest peaks are around 34 GW and at 5 pm. There are lower peaks around 23 GW at noon. From 4 to 6 am is the lowest load, less than 40 MW.

The lower area (green) in Figure 2 presents the load of the transmission grid in Germany for the 14th – 20th October 2008. The load of the transmission grid is an indicator for energy demand. The blue area above presents additional demand of EVs (see: Figure 1). Most electricity demand emerges around midday (12 – 1 pm) and early evening (5 – 6 pm). These times of peak demand are similar to the ones generated by EVs.

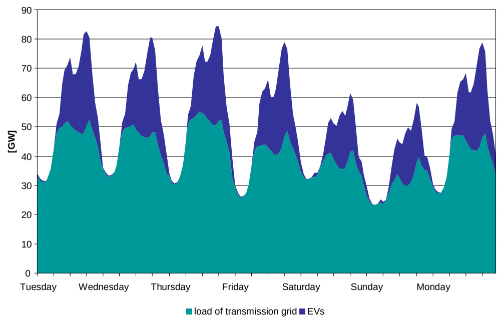

Figure 2: load of transmission grid and demand of EVs

This leads to a higher grid load. 2003 to 2006 the secured and available additional power capacity of the German generation system were around 2 – 5 GW [5]. The additional load of EVs is higher than 30 GW. Therefore the existing generation system cannot handle load of uncontrolled charging by 41,000,000 EVs.
If the electrification of the vehicle fleet is high, controlling is necessary to shift the demand and avoid expensive peaks, which leads to extension of the generation system.

1.2 Vehicle to Grid

In future energy systems, with a high electrification of the means of transport, Vehicle to Grid (V2G) concepts offer storage capacities and more flexible demand to counter fluctuations of renewable energies [6]. Load and storage capacities of vehicles are able to realize an effective power management [7]. Batteries can be charged during times of surplus energy within the grid and are able to use energy to support the grid in case of a shortage. Hence batteries can be used to balance demand and supply [8].
Not only the potential of additional storage capacity [7] is a reason to optimize charging and discharging of EVs, there are also great benefits in choosing the best time to charge. Well integrated EVs create a surplus for the energy sector.

2 Future energy systems

The introduction of EVs into the energy system is a process which is expected to take place over the next decades. Due to political and social action the energy system is likely to change drastically over the next years. The future of EVs cannot be considered without the future energy system.

There are different studies concerning future energy systems in Germany, like “BMU Leitstudie 2008”, “EWI/Prognos – Ölpreis-szenario 2030”, “VDEW, Energiewirt-schaftliches Gesamtkonzept 2030”. Several of these studies are based on the targets for industrial nations to reduce greenhouse gas emissions until 2050 to 20 % of the emissions in 1990. These studies agree that there have to be more renewable energies integrated.

The “Leitstudie 2008” written by Nitsch and edited by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety includes EVs, which are neglected by the other studies mentioned above. According to Nitsch [9] the share of renewable energies for end energy production in 2050 has to be 52 %. The transportation sector will use more renewable energies, 75 % of passenger cars, 50% of the freight vehicle and 50 % of the air transport is going to use renewable energies.
In case of passenger cars this study includes EVs and hydrogen cars. There will be a total use of 205 TWh/a in electricity (35 TWh/a for EVs and 170 TWh for hydrogen) [9].

The comparison between the sources of electricity generation in 2007 (Figure 3) and in 2050 according to Nitsch [9] (Figure 4) shows that the share of power sources which can provide basic load will decrease. Thus load which can be shifted and additional storage are needed.

2.1 Emissions of electric vehicles

Compared to vehicles with combustion engines EVs have no local emissions. However that does not mean that they have no emissions at all. Their emissions depend upon the fuel sources of electricity production.
The electricity production of today emits 616 g CO_2/kWh [10]. For instances if a vehicle consumes 0.2 kWh/km, the emissions would be 123 g CO_2/km.

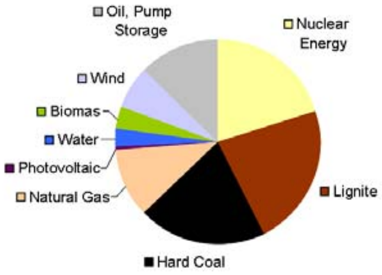

Figure 3: sources of electricity in Germany 2007 according to BDEW [11]

The European target for 2012 is that vehicles with combustion engines emit 120 g CO_2/km. The average today is around 170 g CO_2/km. However, an efficient compact car today is able to emit 81 g CO_2/km (VW Lupo 3l.45 kW) [12]. Thus to avoid emissions the change to more efficient engines and smaller cars is one way with less emissions then the change to EVs driven by electricity generated with fossil sources.

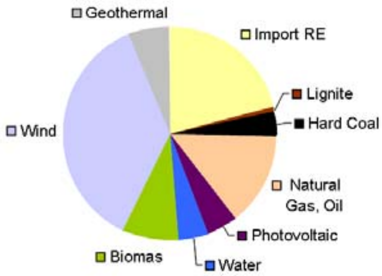

Figure 4: sources of electricity in Germany 2050 according to Nitsch [9]

In 2050 according to Nitsch [9] emissions of electricity production could be 55 g CO_2/kWh and therefore 11 g CO_2/km for EVs are possible (assumed consumption of EV: 0.2 kWh/km).
EVs with a demand for renewable energies are one possible driver towards a sustainable energy system.
To show the connection between CO_2 emissions and sources of electricity generation Figure 5 compares emissions of different EVs pursuant to their consumption and average as well as targeted emissions for vehicles with combustion engines. The emissions for produced electricity in gram CO_2 per kWh are plotted on the x-axis. The grey highlighted areas point out ranges for emissions

based on different sources of electricity generation or mixes of sources. For example the CO_2 emissions of coal power plants vary from 800 g CO_2/kWh to more than 1000 g CO_2/kWh depending on power plants as well as quality of coal.

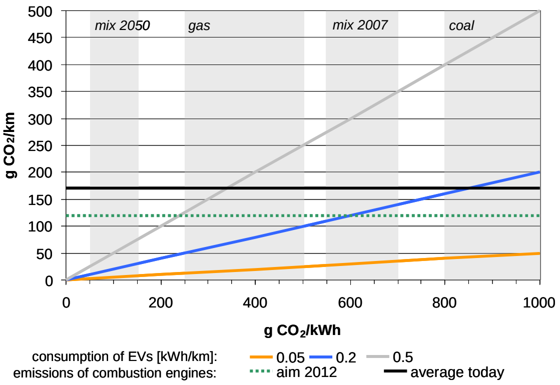

Figure 5: emissions subject to consumption

The emissions in gram CO_2 per km, plotted on the y-axis, are due to the coherence between emissions per kWh and the consumption kWh/km. The black line shows average CO_2 emissions of today's cars with combustion engines (170 g CO_2/km). The dotted green line indicates targeted emissions for vehicles with combustion engines in 2012 (120 g CO_2/km). Vehicles like the CityEL (lowest line [orange] in Figure 5) with a consumption of 0.05 kWh/km [13] emit even in the worst case only 50 g CO_2/km (less than half the emissions which are targeted for vehicle with combustion engines in 2012). However an EV with a high consumption, the grey line with 0.5 kWh/km, has almost double of the average emissions of a passenger car with combustion engine while driven by electricity produced with today's sources.
Therefore to reduce emissions of EVs the supplying fuel source for electrical driving is crucial. Without controlling the fuel sources are determined by the electricity mix within times of charging.

3 Supporting regulations

To use controlled charging of plug-in vehicles a change in infrastructure is necessary. To implement new infrastructure different regulations are helpful. The following part presents regulations which are already dealt within the German law.

3.1 Renewable energies

To integrate renewable energies into the energy system the German "Renewable Energy Sources Act" (EEG) is a legislative instrument. The law guarantees priority feed-in and defined payment for energy from renewable sources.

An amendment of the EEG in 2009 guarantees a payment for solar energy which is used by the plant operator itself instead of feeding the energy into the grid. Terms and conditions are that the plant has an output up to 30 kilowatts and the consumption has to be verified. Target of the regulation is to enhance decentralized use of solar energy.
The average electricity tariff for households in Germany is around 20 ct/kWh. Over the last seven years this tariff increased around 4 % each year [14]. Payment for electricity generated by a PV system which begins to operate in 2009 is 43.01 ct/kWh, if the electricity is fed into the grid. Payment for self use of electricity generated by similar PV plants, which includes charging of EVs, is 25.01 ct/kWh. If the electricity tariff gets higher than 18 ct/kWh it is an economic incentive to use as much as possible of the generated electricity by oneself.

Another German law which supports decentralized use of electricity is the "combined heat and power law". A bonus of 5.11 ct/kWh is paid for every kWh produced by a combined heat and power plant with an electric output up to 50 kW. So if the electricity is used for charging EVs instead of fed into the grid the bonus is in addition to the saved payments for electricity.
Thus the use of energy during specific time periods is supported. Therefore manageable demand is necessary. EVs combined with a control system are able to provide this kind of demand.

3.2 Smart Meter

Use of intelligent electricity meters or smart meters is inevitable for handling of dynamic tariffs as well as billing and purposeful adoption of EVs.
The deregulation of metering and measurements in Germany is based on the Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC, implemented in the "Energy Economy Law". User of an electrical connection can choose a company for metering (former right of network operators). Thus new companies are able to enter

the market. To be more attractive than the former metering operator, the new companies need to offer additional services for connection owners. Examples for new services are customized tariffs and billing. To provide these services smart meters are helpful.
Starting 2011 customers of household electric connections get the right to ask for demand or time variable tariffs. These tariffs should provide an incentive to safe energy. Handling of such tariffs can be easily implemented with electric meters, since they are able to show the actual demand and time of use. Beginning 2010 it is mandatory to install electric meters in new buildings and during renovations. It is also mandatory from 2010 to provide monthly billing. Restrictions are that this has to be technical and economical feasible.
This leads to new possibilities for the billing of EVs. If customized tariffs are realized special tariffs for EVs are a possible next step.

4 Controlled charging and discharging

To use storage and the demand provided by EVs the time which is needed to charge the battery for the next trip is important. If charging takes longer, shifting of demand is more limited and time to provide storage is shorter.
86 % of all driven distances in Germany are less than 20 km [4]. This means that charging of the required amount of energy does not need to be long. If the assumed consumption of EVs is 20 kWh per 100 km, they need 4 kWh for 20 km. The connected power of a household in Germany is 3.5 kW. Thus the battery can be charged in little over an hour. Around 50 % of all driven distances in Germany are less than 5 km [4]. A distance of 5 km needs a charging time of 20 minutes. Parking times of passenger cars are on average 93 – 96 % of their lifetime [15].
So charging takes only a little while and the vehicles are available for more than 95 % of their lifetime. Therefore charging can be shifted from hours of peak load to hours with less demand and if necessary the battery can be used as additional storage to support the grid.
Figure 6 points differences between controlled charging and charging based on user behavior out. The lower green area shows the demand in Germany (14th – 16th October 2008) without EVs. The black line shows demand including unregulated charging of EVs. The upper blue areas indicate shifted demand of EVs. The demand is shifted to produce as less peaks as possible.

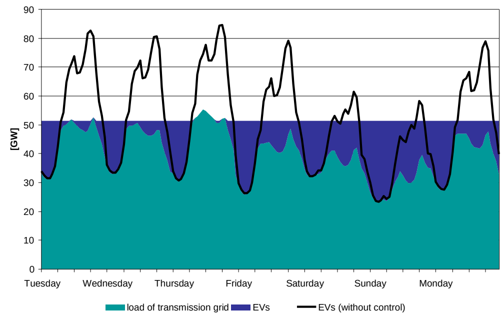

Figure 6: load of transmission grid and adjusted demand of EVs

4.1 Integration of renewable energies

Shifting of charging and additional discharging can be used to modulate demand and supply. To avoid emissions and to integrate energy from fluctuating sources (like wind) into the grid, charging of EVs has to be controlled.

In Figure 7 the green area presents the energy demand in Germany for one week during October 2008. The blue line shows the power supplied by wind power plants over the same period.

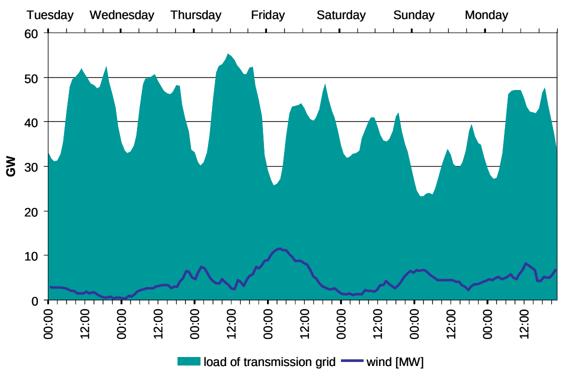

Figure 7: load of transmission grid and supply by wind energy in Germany (14. – 20. 10 2008)

The supply by wind power cannot match the demand today but with further expansion of wind power plants the share is likely to become large. According to Nitsch [9] the share of electricity provided by wind energy in 2050 is likely to be as six times as high as in 2007.
In Figure 8 the blue line presents the expected energy provided by wind in 2050, with the installed wind power plants according to Nitsch [9] (onshore 34 GW, offshore 37 GW).

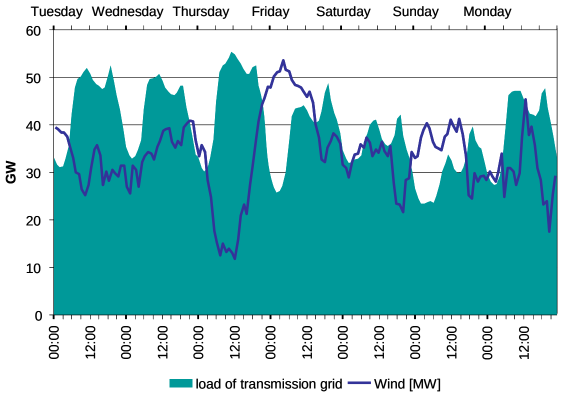

Figure 8: load of transmission grid and supply by wind energy in Germany 2050

Wind cannot be controlled like other power plants. So the comparison of the shapes of the area and the curve indicate that without further load management and storage the supply by wind power cannot match the demand.
EVs can be controlled in that manner, that charging and discharging will take place when it is most needed. Thus to reduce the emissions of EVs and to stabilize the grid energy supplied by wind or the like should be the indicator for controlling.

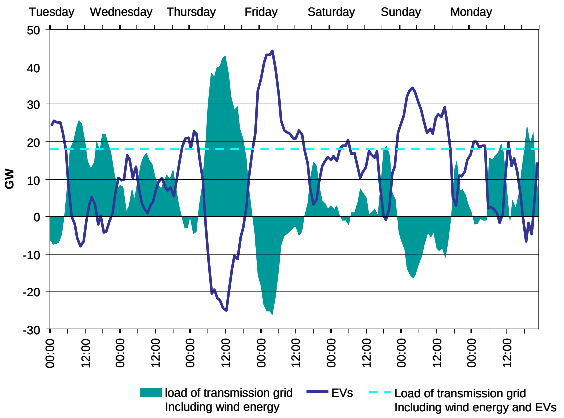

Figure 9: Integration of electricity provided by wind energy via EVs

Figure 9 give a fiction to point out the possibilities with controlling of EVs.
With controlled charging and discharging the energy demand can be constant and less than 30 GW (indicated in Figure 9 by the dotted line). This demand represents the dispatch of other power plants (PV, biomass etc.). The demand can be modulate to match the supply and do not need to be constant. In Figure 9 the green areas illustrates energy demand (without EVs) minus energy generated by wind (according to the amount of wind in October 2008 and the estimated installed wind power plants in 2050 [9]). The dark blue line points charging and discharging of EVs out. It is assumed that 100 % of the vehicles in Germany (approx. 41,000,000 [3]) are driven electrical.
To maintain the constant demand in this example EVs need to provide demand around 45 GW Friday at 4 am to cover the high wind supply.
Due to the house connection (3.5 kW) 40,000,000 EVs can provide a maximum demand of 140 GW. It is unlikely that all EVs are plugged in and able to charge at the same time. However 30 % of the EVs can provide the needed demand.
The demand peak at Thursday noon is around 43 GW and therefore the EVs need to provide 25 GW to keep the overall demand constant. This can be provided if 18 % of the EVs plugged in and able to spare electricity.

4.2 Different ways to control charging and discharging

There are different ways to control charging and discharging of EVs. The control can direct or indirect be performed by concerned parties, e.g. grid operator, electricity provider or new companies which focus on the control of EVs.

Direct and central control is used with wind power plants today. In case of electricity surplus generation grid operators can reduce or shut down some wind power plants, if the grid cannot handle the load. To realize this kind of controlling for EVs charging stations or EVs and grid operators have to communicate. Since EVs are mobile it could be easier to control the charging stations, however the advantage to charge almost everywhere is gone.
To get a manageable demand grid operators need access to EVs or charging stations. They need information where the vehicles are and how much energy is available case of a shortage. Managing this is going to be a challenge in terms of logistic and protection of data privacy for grid operators.
If the grid operators are able to shut down all EV loads, it might lead to undersupply of EVs. This can cause a lack of customer satisfaction. An emergency mode for grid control could provide a solution for this problem.
Another challenge is the availability and location of vehicles in different distribution grids: For energy sale the location is less important, for grid control however much more.

Indirect control of charging can be done via dynamic tariffs. Control via tariffs shortens the amount of information which needs to be communicated. Tariffs could be composed with national, regional and/or vehicle specific elements. Controllers (grid operator, energy provider) do not need to know where exactly the vehicles are or how much energy they need. This can be assumed due to statistics and forecasting. Tariff signals, which represent the needs of grid operators and energy providers, could be used.

If lots of vehicles optimize their demand locally with the same tariff, overload and additional peaks could be caused. To avoid that, a tariff structure has to be flexible and dynamic. Another way to avoid this is to instruct the charging strategy to use a random method. This leads to an equipartition of charging in time periods with the same tariff level and avoids additional peaks.

Tariff signals need to be developed in order to balance the demand and supply of energy. The saturation of more fluctuating energy sources in the grid makes it essential to provide tariffs which support renewables for operating EVs. Therefore tariffs can be a linkage between energy demand and renewable energy supply. On a high demand and low wind potential the tariff should be high, and vice versa if wind energy is available.

Control via tariffs could create a new business area. Tariffs can be planned by a service provider. Provider could coordinate a certain vehicle fleet.

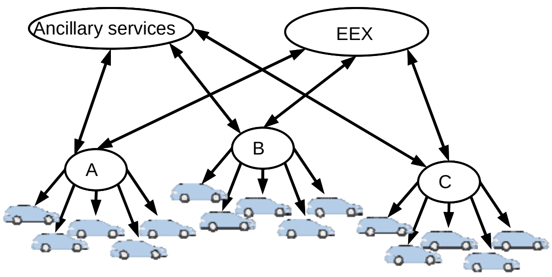

Figure 10: example tariff generation

Figure 10 A, B and C illustrates these service providers. They generate a tariff for their vehicle fleet. They get energy at the energy stock EEX (with long or short term contracts depending on the profit) or obtain energy from other producers and provide ancillary services for the grid operators. The characteristic of their vehicles is well known. So they can control charging upon tariffs and provide ancillary services if necessary based on their knowledge of the response of the fleet to short term tariff variations.

5 Control device (dispatcher)

The suggested method to manage EVs during the fleet test "E-Mobility" is embedded control devices integrated into the vehicles. The control devices manage charging and discharging locally according to flexible tariff signals. The gird integration is done by already upcoming smart metering technology.
As mentioned earlier there are other solutions to avoid the problem of creation of additional peak demand and the call for ancillary services. One option could be the manual operation of the vehicle user who plugs the vehicle in when the tariff is low or when he can provide energy to support the grid. This can be automated with a timer [16]. However this is a rather inefficient way. How to deal with short term changes to request ancillary services?

The control device is integrated into vehicles and calculates the optimal charging and feed-back strategy by taking the different influencing factors into account. The optimal schedule consists of time and amount of energy (charged or discharged). The computation of the optimal schedule is based on a new algorithm.

5.1 Influencing factors and function of control device

Influencing factors are vehicle user, energy supply, grid operating state and battery data.

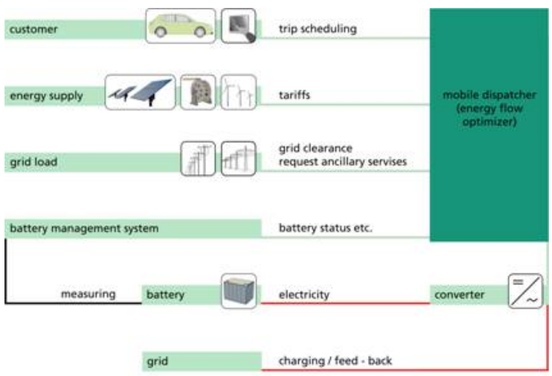

Figure 11: influencing factors

The vehicle user provides data of the next planned trip (time and distance). Optional is the input of a certain distance which should be reachable at any time (e.g. next hospital). The control device uses

this data to calculate the time frame for charging/discharging and the required state of charge of the battery.
The battery management system provides data of state of charge, capacity and faults. The charging station provides further information concerning maximum power level and dynamic tariffs. The need for ancillary services can be included due to short term changes of the tariffs.
To calculate the best charging strategy the influencing factors have to be as reliable as possible.
The control device (dispatcher) provides the charge schedule to the controllable inverter and monitors the state of charge of the battery. If necessary, a new schedule is calculated.

5.2 Design of optimization algorithm

Calculation of the optimal charging and feed-back schedule is based on an algorithm, which uses quality factors from the influencing factors.
There are different options to compute an optimal schedule. The common way of solving this problem is by mixed integer linear programming. However, with computation times of up to 30 seconds per calculation, this approach turned out to be slow.
Thus a fast combinatorial algorithm, which is described below, is chosen. The optimality and correctness of the algorithm can be proven formally. The authors intend to describe it in an additional publication, since this would be beyond the scope of this article.
In simulation runs this algorithm took less than 10^{-4} sec per day of computation on 2.5 GHz ATLON 64 4000+ processor.
A simplified description of the planning algorithm is presented below.

The algorithm uses as input two price curves, which represent the costs per energy for charging and the gain per energy fed into the grid (discharging) at a given time step. A precondition of the algorithm is, that the gain for discharging at a given time step is never higher, than the price for charging at the same time step. Second, the algorithm uses a function *load(t)* which represents the consumption of the vehicle at a given time step.
As output the algorithm constructs the schedule, which is a function *P(t)* representing the changing of the battery state at a given time step. $P(t)>0$ means, that the battery is charged at time step *t*, $P<0$ means, that the battery is discharged, either for feeding energy into the grid or for own consumption of the vehicle.
The goal is to minimize the costs for charging minus the gain for discharging, under the condition, that the own consumption load can be satisfied and considering the maximum and minimum charging state of the battery.

While the algorithm constructs a schedule it will – whenever it plans either consumption of energy by the vehicle or feeding of energy into the grid – at the same time determine one or several time steps, at which the required energy is obtained. In this context *obtaining energy* means that the battery is either charged (up to a maximum charging rate) at those time steps or that a previous decision, to feed energy into the grid, at that time step is nullified or that the amount of energy to be fed into the grid is reduced. In all cases it is easy to determine the costs for obtaining the energy and to identify the cheapest available time steps, under the condition that the maximum charging state of the battery is observed.

Now the algorithm works as follows: It iterates through all time steps. At each time step *t* there are two cases:
1. If $load(t) > 0$, the battery must be discharged by *load(t)* at that time step. Hence the algorithm obtains *load(t)* energy at the cheapest possible earlier time steps and discharges the battery at time step *t* by setting $P(t) = -load(t)$.
2. If $load(t) = 0$ it is possible to feed energy from the battery into the grid at that time step up to a certain maximum discharging rate. In that case the algorithm determines how much energy can be obtained at earlier time steps, so that this obtaining and feeding increases and maximizes the gain. Then the algorithm plans to feed this amount of energy into the grid at that time step, and to obtain the energy earlier.

5.3 Demonstration of optimization algorithm

Figure 12 and Figure 13 illustrate examples of different schedules, calculated by the described algorithm. The dark blue line shows the EEX spot market price of 14th – 16th October 2008 [17]. This price is used as a tariff sample for the optimization. The green area shows the state of charge (in %). It is assumed that the vehicle has an average consumption of 20 kWh per 100 km and a battery capacity of 20 kWh. The EV is plugged in over night. The lowest prices for energy are at night around 3 to 5 am. Thus the charging process takes

place during this time period. Different trips are scheduled and various charging periods take place during the day. The control device has a priority to avoid discharging under 70 % if possible.
The grey highlighted areas, with the needed range in kilometers, indicate times when the vehicle is used. The capacity decreases according to the driven distance, however not according to the real manner since driving style, breaks etc. are not known.
The yellow highlighted areas indicate charging. The battery capacity increases according to the amount of energy which can be charged at a house connection with a capacity of 3.5 kW.
After each trip an update charging strategy is calculated. So the vehicle user only schedules the next trip, which will take place.

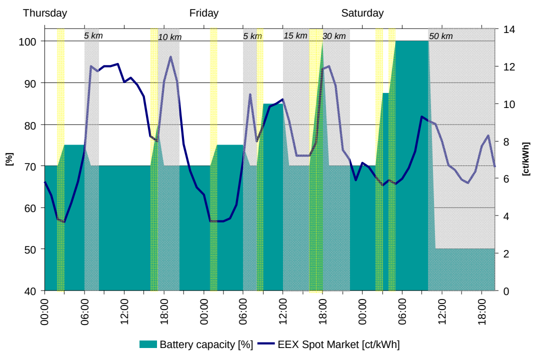

Figure 12: charging, short forecast

Figure 13 shows the same example as Figure 12 with a longer forecast. Thus there is less charging at daytime, because the trips during the day are so short that the time at night, with lower tariffs, is long enough to recharge the battery.

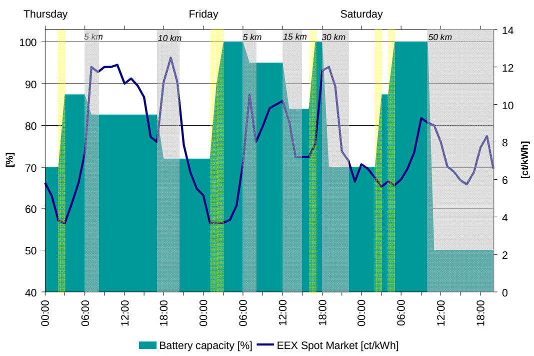

Figure 13: charging, longer forecast

The second way to optimize requires more scheduling from the vehicle user. He has to be clear about the trips which will take place over the whole day. So planning of the best charging strategy depends on possible forecasts. Better forecasts leads to a better strategy. A weekly forecast seems possible, but if tariffs are linked to wind energy or the like it is not feasible to make reliable forecasts that long.

6 Billing and metering solutions

Integration of EVs into the grid needs to fit into structures of billing and metering systems.
To integrate EVs into the grid, the metering system should be capable. Billing of electricity in Germany is today is based on estimated consumption of the annual, since the meters are read only once a year. Also metering and billing is based on a stationary measurement, which is not capable for mobile submetering.

An option is a smart charging station which uses authentication and billing for example via credit card. To allow also discharging much more information is needed.
Integration of EVs into advanced metering systems is another vision. Smart meters provide more features like handling of variable tariffs, or real time access. An option for EVs is that vehicles have onboard metering systems; so far there are no standards for the communication concept.

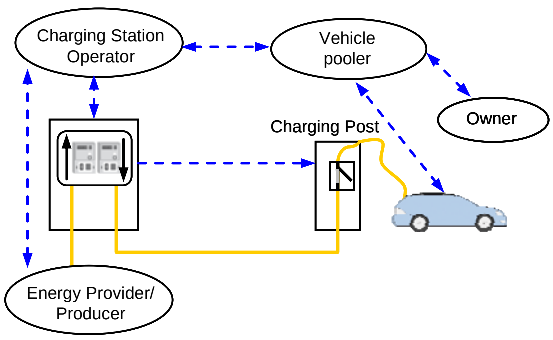

Figure 14: solution for billing and metering of EVs according to Engel [16]

Figure 14 shows a possible metering and billing solution according to Engel [16]. This solution creates new business areas. The so called vehicle pooler is in charge of a certain number of EVs. He provides electricity for EVs and has agreements with grid operators to provide ancillary services. A charging station operator maintains and operates charging stations.
The vehicle owner has contact with the vehicle pooler. This agreement contains sort of billing and

tariffs. The EV can charge on different charging posts (depending on the contract with the pooler). The vehicle pooler has got agreements with the charging station operators. These agreements concern the electricity tariffs on the different charging posts.

The authentication process between vehicle and charging post will take place as soon as the vehicle is plugged in. After identification process the vehicle contacts the pooler and asks to activate the charging post. To activate the charging post after checking request the pooler contacts the charging station operator. If everything is correct the charging station operator contacts the charging station and gives the instruction to accept charging on the particular post [16].

An advantage of this solution is that the billing by the energy provider is independent. The charging station operator has a contract and so the energy provider has not the problem to bill various mobile consumers or storages. The two new business areas (charging station operator and vehicle pooler) can be adopt by the energy provider or grid operator or other service providers.

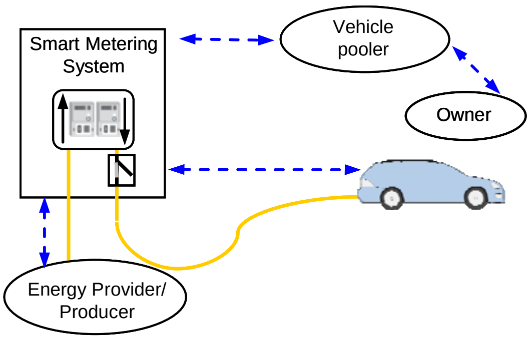

Figure 15: solution for billing and metering 2

A similar solution which integrates the presented control device is described through Figure 15. The metering and billing of EVs is integrated into “smart metering systems”. These systems could replace present domestic metering sytems.
The bill for driving electricity is based on tariffs generated by the vehicle pooler (see: Figure 10) and can be amended by the local situation. The authentication takes place between metering system and vehicle. The metering system needs to send authentication data to the vehicle pooler and he activates the charge process.

To charge several vehicles at the same station, mobile meters are necessary. During the charging process the metering and submetering system compare the power flow (especially necessary if more than one vehicle charged at the same time). Then the metering system sends the data to the vehicle pooler to bill the vehicle owner. The data is also provided to the grid operator to separate the loads for domestic use.

The advantage of this system is that it can be a part of smart metering systems. More than one vehicle can charge or discharge at the same time at the same station.
A disadvantage is the increased need for standardization. There has to be communication between different vehicles and metering systems as well as between metering systems and vehicle pooler and vehicle pooler and energy provider.

7 Implementation

The fleet test “E-Mobility” provides a platform to build and test the integration of EVs into the grid. To use the additional energy storage for ancillary services a billing unit, based on smart metering technology, is also considered. To reduce the time of charging additional fast charging concepts are realized.

The three basic concepts which are to be realized are:

- 230 V AC / 3 kW normal power outlet
  - Unidirectional, only charging
  - Recording of charge process via mobile smart meter
  - Billing by the energy provider via electric meter of the household
- 230 V AC / 3 kW smart metering billing unit
  - Bidirectional, charging and feed back
  - Communication between vehicle and billing unit
  - Recording of charge process via stationary smart meter
  - Direct billing by the energy provider
  - Dynamic tariffs to bill the bidirectional energy flows
- Fast charging station (~15-30 kW) DC connection to vehicle
  - Bidirectional, charging and feed back
  - Communication between vehicle and billing unit
  - Recording of charge process via stationary smart meter

- Direct billing by the energy provider
- Dynamic tariffs to bill the bidirectional energy flows

The tariffs, which are used to control the charging and discharging, are linked to wind energy and energy demand in Germany. There will be different scenarios with different shares of renewable energies in the electricity production and different predicted future energy demands.

8 Summary and Conclusion

The future energy mix includes more fluctuating renewable energy sources and a higher share of EVs. Controlled charging of EVs by using dynamic tariffs and decentralized optimization is an option to save the grid problem. Control device (dispatcher) optimizes charging and discharging with flexible tariffs for the individual use of the vehicle. This solution can adjust fluctuating energy supply by renewable sources without realizing direct control access. Smart metering with a mobile sub metering system which is described will be used in the fleet test "E-Mobility".

Over the past months lots of activities concerning electric vehicles, including different fleet tests, took place in Germany. These kinds of activities are a good way to create public awareness. To bring electric vehicles into the marked and use their advantages standardization is a big issue which needs to be dealt with today.

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