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Charging management for full electric vehicles in the mobility-on-demand-concept "fahrE" using local renewable energy

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Abstract. Unavoidably, the aim of ecologically sustainable driving leads to the use of full electric vehicles (FEVs) and a charging process based on renewable energy. In addition to the ecologically sustainable charging, the additional and high-power load of FEVs in distribution grids can cause problems like overload of electrical equipment and deviations of the preset voltage band. To limit the load and maximize the usage of renewable energy, a management system has to be developed. In this paper, a management system is introduced with the special challenges of mobility-on-demand-concepts, which is one of the main fields of application for FEVs in the early adoption phase. In this system, the real existing local renewable energy, the limit of the electrical equipments, and the permanent availability of mobility influence a charge signal, which is the core of the proposed management. The first results show that the developed management is capable to double the renewable percentage of charging energy in comparison to a dump charging.

Key words

Charging management, distribution grid, electric vehicles, mobility-on-demand, renewable energy

1. Introduction

Many studies showed that full electric vehicles (FEV) can only be more ecologically sustainable than conventional cars, when the driving energy comes from renewable power plants [1]. To consider not only the average balance of renewable energy, it is important to charge electric vehicles when the fluctuating renewable energies are available. Those times have to be selected to charge FEVs, when there is a surplus or a high capacity of renewable energies in the grid. In Germany the renewable energy supply has reached the 20 percent mark in 2011 [2]. But measurement data showed that the amount of renewable energy in the considered local distribution area is much lower than average percentage in Germany. In the considered area, the percentage of renewable energy is about 7 %. The low amount of renewable energy would cause an unsatisfactory carbon footprint of FEVs. To improve this fact, a charging management has to charge the electric vehicle at these times, when the percentage of renewable energy is particularly high.

In addition to the ecologically sustainable charging, FEVs cause additional high-power loads in distribution grids. The distribution grids, especially the low-voltage grids (U_r = 0.4 kV) in Germany are grown according to their historic current loads. Currently, these grids are not fully loaded. But when the new and high-power loads of FEVs are connected, they can cause electrical problems in the distribution grids. Above all, in low-voltage grids, overload of electrical equipment and injuries of the voltage band are expected [3]. Such challenges are avoidable by the use of a proper charging management [3].

This paper introduces a mobility-on-demand concept and a charging management, as well as the special challenges of such concepts. Mobility-on-demand concepts will be one of the main fields of early application for FEVs.

2. The mobility-on-demand-concept "fahrE"

Studies showed that the motorized individual mobility loses importance for many people, especially for the young one. For them, it is important to have everywhere and every time the possibility to use available mobility [4]. A concept for this demand is the project "fahrE – concepts of multi-modal micro mobility using local renewable energy". In these concepts, the following three terms have to be defined:

- *Multi-modal-mobility* defines the individual movement with the use of different means of transport for a distance.
- *Micro mobility* defines in the context of traffic and transport research different mobility strategies for short and medium distances.
- *Local renewable energy* defines the energy production near the consumer, so that the transportation losses of energy are avoided.

The mobility concept "fahrE" focuses primary on the electric mobility, but also integrates the public transport. The concept is based on a classic car-sharing-system, but also integrates other means of transport. As shown in Fig. 1, the mobility platform connects the four locations of Chemnitz University of Technology (CUT) and includes electric bicycles, FEVs, bus, and tram.

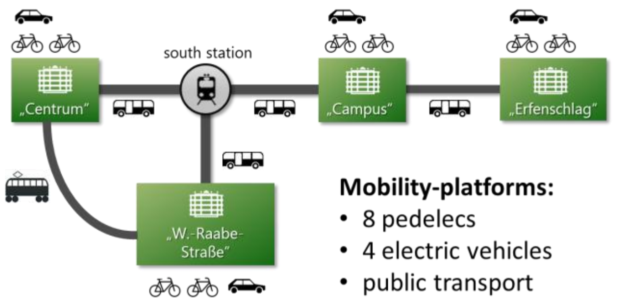

Fig. 1. Mobility options between the university sites of Chemnitz University of Technology

Users of "fahrE" apply a web interface or a smartphone application to plan their mobility between the university locations. They specify only where they want to go and the backend indicates the possible means of transport. The user gets the suggestions which mean of transport is the most sustainable, which one is the fastest, and which other options are possible. If the user chooses an electric vehicle, he has the possibility to book this vehicle immediately. After booking a vehicle, the user can unlock and start the FEV with his smartphone application or his RFID employee card. After reaching his destination at one of the locations of CUT, the user has to connect the FEV to the charging infrastructure. After the FEV is connected to the infrastructure, it will be automatically returned to the system.

The project "fahrE" is an intermodal research project consisted of four chairs in two research fields. The first field is the user studies, which contain the research of the acceptance of FEVs and public transport, as well as usability engineering. The usability engineering should ensure that every user interface will be evaluated for the simplest handling. The second main field of research is the development of a charging management with the integration of local renewable energy. The FEVs of "fahrE" are charged at a new build charging infrastructure at special parking lots at the four locations. A main challenge will be the connection of all components via LTE with a backend server infrastructure and the development of the whole software system.

The aims of the research project "fahrE" are as follows:

- Development of a integrated E-Mobility-concept
- Connection of distributed locations in a city (using the example of CUT)
- multimodality (different means of transport)
- ecological sustainable transport
- IT connection
- usability

3. The charging management

A. *Parameters for charging management*

The charging management is developed to charge FEVs when it is ecologically sustainable without having overloads and also ensuring permanent mobility. This shows already that three main parameters influence the charging management and result in a charge signal. These parameters are shown in Fig. 2 and will be explained afterwards.

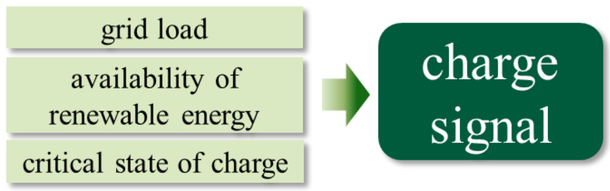

Fig. 2. Parameters of the charging management

With the first parameter – grid load – the management attends that FEVs cause high-power loads in the distribution grids. These high-power loads must not cause problems, like voltage drop or overloads in lines. Investigations showed that in urban grids, the main problem is the possible overload of the distribution transformer [3]. Hence, the load of the grid in urban areas can be minded with the total load curve which presents the sum of all individual grid loads.
The parameter availability of renewable energies is influenced by a lot of other parameters. It is important here to charge FEVs with a high percentage of renewable energy to make them more ecologically sustainable than conventional cars. Real-time data of the supplied power is the basis to lead FEVs to a more sustainable energy footprint.

For the use of the charging management in other areas, than the examined area, the real time supplied power of renewable power plants has to be determined. For photovoltaic power plants with an installed power less than 100 kW, there is no actual power measurement, so that there is no opportunity to use real-time data of these photovoltaic power plants. Because of the high number of small photovoltaic plants, it is compulsory to know their real time data. A possibility to acquire the real-time renewable power supply has to be found. The chosen alternative is to simulate the supplied power of the renewable power plants.

The simulation of the renewable energy is done using meteorological data and the characteristic curve of the renewable energy types.

- The *wind power simulation* is based on measured wind speed, which is not the speed of the wind at the wind turbine. The local wind speed is influenced by the altitude of the hub and the roughness of the terrain where the wind turbine is located. The calculated wind speed is compared with the interpolated characteristic curve. It makes it possible

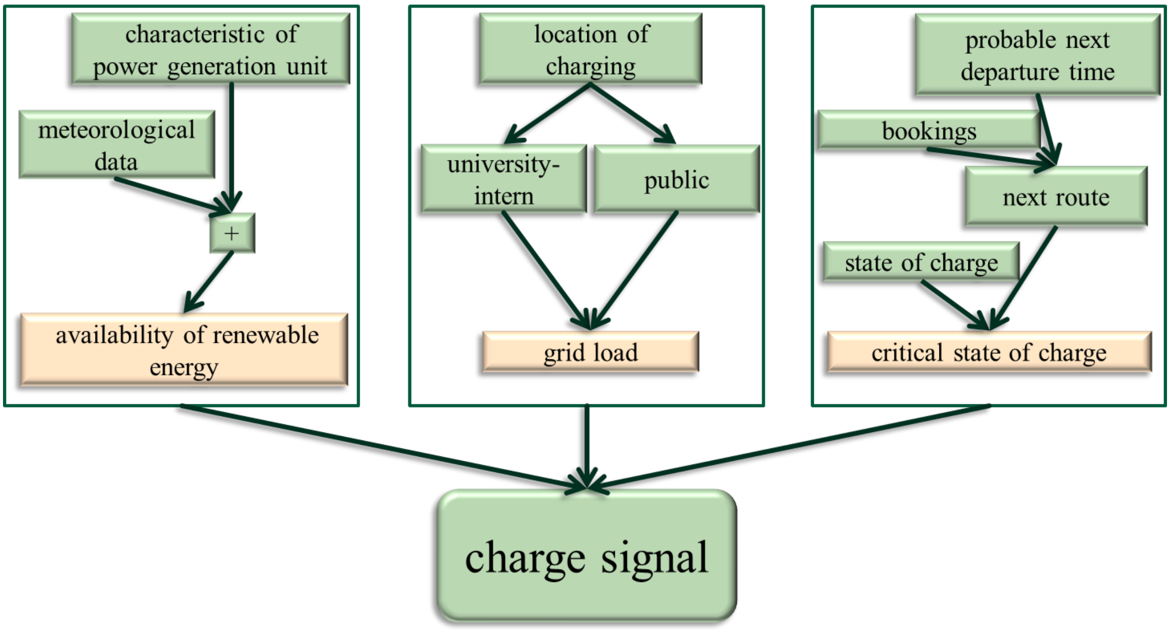

Fig. 3. Management scheme resulting in a charging signal

to simulate wind power time series from wind speed time series.

- Similar to the wind power simulation, the *supplied power of photovoltaic plants* is simulated. The simulation is also influenced by a lot of different factors, such as alignment, roof pitch, shades and the insolation.
- The power supplied by biomass power plants is assumed as constant power time series with a simultaneity factor of 0.7. This is done because biomass power plants reach a high number of full-load hours, up to 7000 h/a [4].

The last parameter is the critical state of charge. This parameter is necessary to ensure a permanent available mobility for the users of the mobility-on-demand concept "fahrE". The critical state of charge is addicted to the current state of charge and the next route of the FEV. The next route is influenced by vehicle bookings and historical mobility data. The mobility data are collected from a survey and will be collected in operation of "fahrE".

All the described Parameters are shown in Fig. 3.

B. The charge signal

In Fig. 3 it is shown which parameters affect the charge signal of the charging management. The signal is a transfer function of a closed-loop servo system, which is shown at Fig. 4.

The next paragraphs will only describe the core of the charging management, the transfer function, which describes the charge signal. As it is shown in Fig. 4 the charge signal is an addition of three function elements. These function elements describes the influence of the parameters of the charge signal. After the addition the signal is a four-dimension characteristic map.

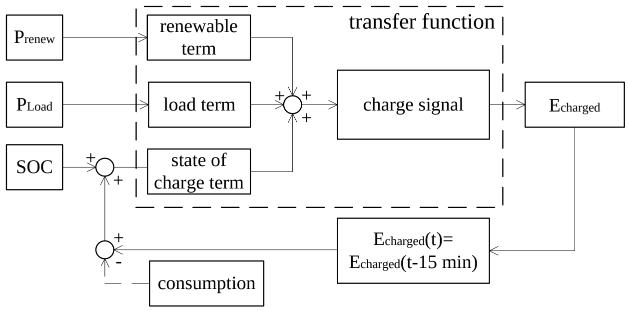

Fig. 4. Closed-loop servo system of the charging management

The first function element is the *renewable term*. This term compares the current supplied local renewable energy with the maximal potential of local renewable energy sources. High power of renewable energy supply should cause a high change of the charge signal. To reach this effect, the renewable term is a quadratic term.

The load term, as the second function element, defines the *influence of the load* in the distribution grid. Like the renewable energy term, it compares the current load with the maximum load, but subtracts this ratio form 1. The term also gets a quadratic influence to damp oscillations of the charge signal at high load times. These high load times are at day time, when the main operation time of "fahrE" takes place.

Also, the current state of charge has an influence to the charge signal, when it is compared with the maximum state of charge in the third function, the *state of charge term*. The state of charge has a cubic influence, so that the signal becomes low, when the battery of the FEV is fully charged. Additionally, the charge signal is set to "1", which means that the battery has to be charged, when the critical state of charge becomes too low to ensure the next route of the electric vehicle.

An example of the characteristic map of the charge signal is shown in Fig. 5. In the map there are three defined grid loads assumed. As shown, with higher loads, the signal gets lower. It is also assumed that the critical state of charge is 30 % of the maximum state of charge, so the signal is set "1" when the state of charge falls below this value. All values are weighted and the values are limited under "1".

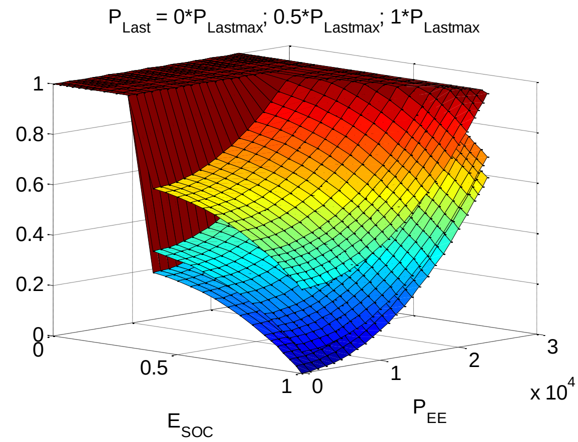

Fig. 5. Characteristic map of the charge signal

4. Results

A. Simulation setting

The simulation is done for full hour time series. The results are based on a simulation using measured data. These data include wind speed time series, insolation time series, total load curve, and characteristic curves of the already existing renewable power plants in the examined area. The consumption of the FEV is assumed to be 20 kWh/100 km and the hourly consumption simulated based on the data of a mobility survey. For the simulation of a FEV, a smart fortwo electric drive is selected, which will be applied also in "fahrE". The smart allows charging the 17.9 kWh battery with a power up to 22 kW. The simulation is performed with a power of 11 kW.

B. Simulation results

The simulated year with the time series of renewable energy, load curve, and FEV consumption shows how the signal works. The primary influence factor is the supplied local renewable power (Fig. 6). The peaks of the times series in Fig. 6 are caused by wind turbines and the base load by the biomass power plants. But it can also be seen the photovoltaic power with the typical profile in a year, this means high supplied power in summer and low supplied power in winter.

The charge signal is a binary signal. When the calculated signal is above 0.5, it is rounded to "1". When it is lower than 0.5, it is rounded to "0". But the signal is also set to "1" when the state of charge falls below the critical state of charge. The simulation result for the state of charge is shown in Fig.7. It can be seen that the general line of the availability of local renewable energy is reproduced at the state of charge. The wind calm in November causes a drop of the state of charge, so only when the critical state of charge is undershot, the FEV is charged. So the state of charge varies between 3 kWh and 10 kWh. The December with a high wind power supply, the charge signal causes that the FEV is fully charged, nearly all the time. But also the photovoltaic power supply in summer time is reproduced at the state of charge.

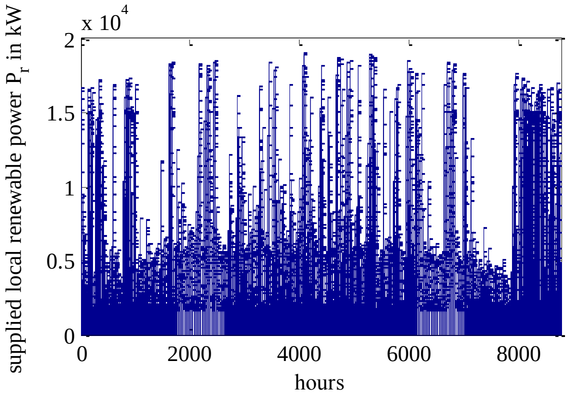

Fig. 6. Time series of local renewable power

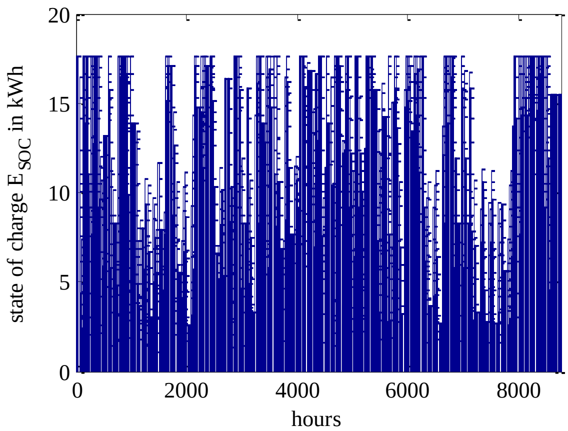

Fig. 7. Time series of the simulated state of charge

The charge signal is able to raise the cumulative percentage of local renewable energy which is charged to the vehicle up to 15.4 %. In comparison to an amount of 7 % for a dumb charging, it is more than a doubling.

5. Conclusions

This paper describes a charging management for a mobility-on-demand-concept using local renewable energy. The management combines the influences of ecologically sustainable charging of FEVs, the total load of the grid, and the challenge of permanent available mobility. The signal transforms these data to a charge signal which is binary interpreted for charging (to charge - "1", not to charge - "0").

This charge signal is able to double the usage of local renewable energy considering the load of the distribution grid. With the influence of the critical state of charge, it is possible to guarantee a permanent mobility.

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