Effects of E-Cars on electrical power infrastructure requirements

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Abstract

Currently there is world-wide a strong political will to enforce the development of Electric vehicles (EV). If technical problems are solved and EV penetrate the networks in an increasing number they will set new requirements on the electrical power networks. Currently distribution networks are designed to supply an average household load of about 2 kW which will significantly increase with additional EV loads. On the other hand the storage capacity of the car battery allows the provision of new services to the networks.

This paper presents the results of an investigation within the medium and low voltage networks operated by Allgäuer Überlandwerk GmbH. This network is characterized by a high portion of distributed generation, to a large extent based on the stochastically variable sources sun and wind. The region is characterized by a high portion of commuters to a near city. The study investigates how many electric cars can be integrated in an existing network. Different charging strategies are compared and guidelines for the optimal strategy based on the requirements of the network are derived. The study also shows how an interaction between electric cars and stochastically varying generation can look like.

Introduction

In a densely populated region like Europe the typical driving distances covered by cars are relatively short per way. According to [1] 64 % of all privately owned vehicles (passenger cars and motorbikes) in Germany are mobile per working day (Monday to Friday), respectively 57 % during the whole week (Monday to Sunday). The average distance per mobile private vehicle is 57 km (Mon to Fri), respectively 62 km (Mon to Sun), leading to an average daily distance per privately owned vehicle of 35 km.

Supported by suitable incentives and with emerging battery technology it is expected that in the next years the number of electric vehicles (EV) will increase. According to the national development plan 'Electromobility' of the German government one million electric cars are expected in Germany by 2020 [2].

This amount of EV has to be integrated into the existing electrical networks. These networks are designed to supply an average load of about 2 kW per household due to simultaneity effects. If in future these households are equipped with EV with charging power up to 22 kW overloading of networks and voltage problems will arise if no measures are taken to avoid that.

On the other hand the EV batteries can provide network services, especially balancing power. With the increasing share of generation by renewable energy sources with a stochastic characteristic of the availability of the resources such as wind and solar power the demand of balancing power increases.

The goal of a study conducted in close cooperation between Allgäuer Überlandwerke GmbH (AÜW), Hochschule Kempten and Siemens AG was to investigate at the example of a part of the network operated by AÜW how many EV can be integrated in the currently existing structures of the electric networks, to what extend can this number being increased by intelligent charging control strategies and how can the interaction of the high share of generation by distributed photovoltaic power plants and the batteries of electric vehicles being optimized. The main results of this study are presented in this paper.

Charging of electric vehicles

Charging power

In the near future it is expected that either private cars that are mainly charged at home or fleets will be the dominant EV. Charging power at home is limited by the fuses. Currently, it will not exceed 3.7 kW (1-phase, max. 16 A) or 11 kW (3-phase, max. 16 A) while in future 'normal charging' at work or at a corresponding charging infrastructure will be around 22 kW (see Figure 1).

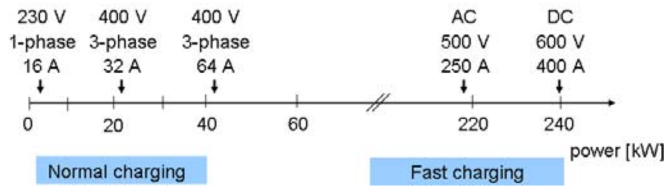

Figure 1 Charging power

Charging profiles

Full battery EV as considered in this paper require complete charging from electricity networks. Their average 'consumption' varies between 10 and 30 kWh/100 km depending on the size of the vehicle (compact car, medium-size vehicle, roadster …). Considering losses of around 20 % for charging and discharging of the battery an average consumption of 25 kWh/100 km can be assumed. Depending on the model and its required range the battery capacity varies between 10 and 60 kWh.

Many inhabitants of the studied region commute to the close city of Kempten or to other cities in the region. Based on average German mobility behaviour an average charging demand of 15 kWh per vehicle and day is assumed in this study corresponding to average distance of 60 km and average consumption of 25 kWh/100 km. To investigate the interplay between the distributed energy sources of photovoltaics and wind in that area it is assumed that the battery cannot be charged at the workplace during the day. The commuters have to charge their EV during the night when they are at home. It is assumed that all vehicles are at home and connected to the network between 6 pm and 6 am.

Charging strategies

Uncontrolled charging

The EV is charged whenever it is connected to the network. The charging power is defined by the vehicle. It is assumed to be in the range between 3,7 and 22 kW (Figure 2). This strategy is assumed to be the most likely strategy during the EV introduction phase with a limited number of EV in the networks.

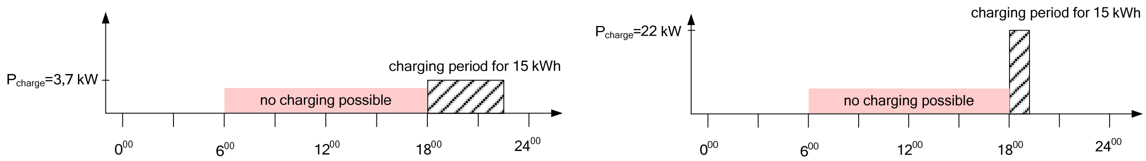

Figure 2 Uncontrolled charging, a) 3,7 kW for 4 hours b) 22 kW for 0,7 hours

Low power charging

EV are charged during their full connected time with a power which is just sufficient to recharge the necessary energy during this time. This charging strategy minimizes the impacts of EV on the networks, allowing to integrate the maximum number of vehicles with minimum enforce efforts needed (Figure 3).

Sequential charging

EV are charged according to normal charging power of 22 kW. When one car is fully charged the subsequent car at the same feeder is charged until all cars at the feeder are recharged (Figure 4).

From the viewpoint of the medium/low-voltage transformer this strategy has similar effects than the low power charging strategy described above. Because there are now higher individual loads the network stress in the individual low voltage feeder is somewhat higher depending on the number of EV per feeder and their distribution along the feeder. The advantage of this strategy is that the charging inverter does not need to be able to use partial charging power. The disadvantages are the need for an external controller that defines the charging sequence and that the battery of the last car in the order is still uncharged if needed ahead of the planned time.

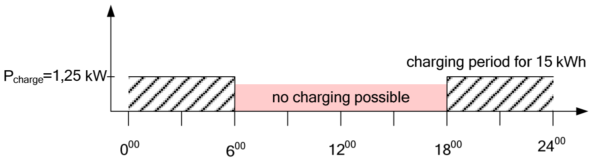

Figure 3 Low power charging strategy

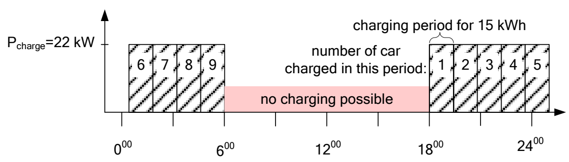

Figure 4 Sequential charging strategy

Charging according to renewable generation

The charging of the vehicle is controlled based on the availability of stochastically varying local generation. An intelligent controller optimises the use of renewable sources but also ensures that the vehicle is fully charged at the end of the predefined charging period. The charging power varies over the charging period (Figure 5).

This charging strategy requires an external controller which has access to a 12 hour-forecast of the solar and wind power generation. It also needs access to the results of load flow calculations to estimate the effects of its decisions onto the actual network. Such a management service might be provided by the utility which usually has access to the required information.

If the forecast of the solar and wind power generation is not matched by the real generation curve then at the end of the charging interval a peak above the renewable generation might occur to guarantee that the batteries are fully charged when needed.

If there is a high correlation between the spatial and timely availability of the energy source and the requirements of the vehicles this strategy might lead to a considerable relief of the stress on the network.

Market participation

Based on

- the charging state of the battery,
- the planned usage of the car,
- the current and predicted spot market prices

the EV decide their own individual charging strategy.

As a first step strategies are likely to stop and restart only the charging process depending on market requirements. In future the cars also might provide reserve power. Finally they might even sell portions of the energy stored to the market at high prices to recharge the battery later at lower prices.

The behaviour of an individual EV following such charging strategies will be very difficult to predict. For a larger group of vehicles the prediction becomes easier as it can be assumed that the vehicles behave similar according to the development of the spot market price. The stress on the network will be high because the market participation makes only sense, if the charging uses only a portion of the totally available time, increasing therefore the needed charging power. If selling energy to the market is also planned power flows will even more increase. During the connection time for this strategy the vehicle might for example need to be charged, discharged and charged again. This means during the connection period three times the storage energy of the battery has to be transported through the network increasing the loading of the lines and transformers as well as the losses (see Figure 6).

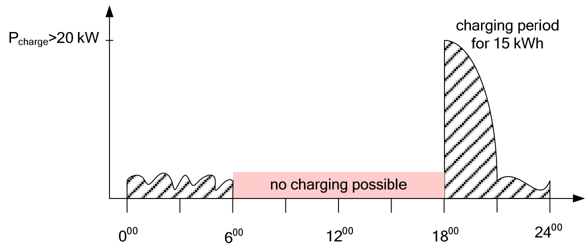

Figure 5 Renewable charging strategy

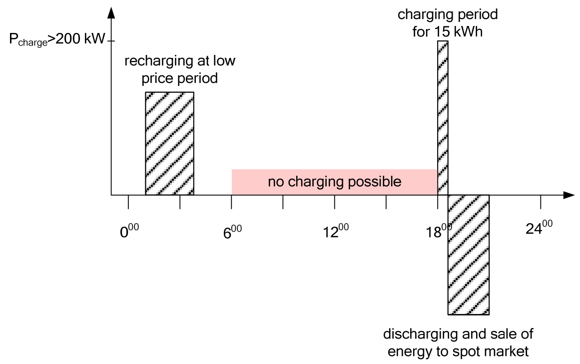

Figure 6 Market based charging

Network under consideration

This paper presents results of a study of a part of the low and medium voltage network operated by AÜW with maximum load of 8 MW. The network is characterized by a high portion of generation from small photovoltaic power plants with in total 3.6 MW_p which feed into the low voltage network. The installed power of photovoltaic generation is growing rapidly limited only by the available installing capacities because of attractive public funding. For the area there is a potential of about 36 MW_p for photovoltaic generation. In the near future it is expected that the installed generation power will exceed the peak load. As the generation and the consumption peak occur at different times there is the necessity of storage, e.g. provided by EV.

Hosting capacity of the network

The hosting capacity of a network refers to the maximum amount of EV that can be simultaneously charged. The penetration level of EV is defined as the percentage of households that have the connection of a standard-sized (e.g. 15 kWh) EV.

In a realistic network the loading of the lines and transformers is often determined by historical development. That means that with a general increase of the load in the network there will be some lines or transformers which become overloaded even with a small load increase. These are the weak points of the network. As an example, the distribution of the loading of the lines for the scenario without the generation of the distributed sources is given in Figure 7.

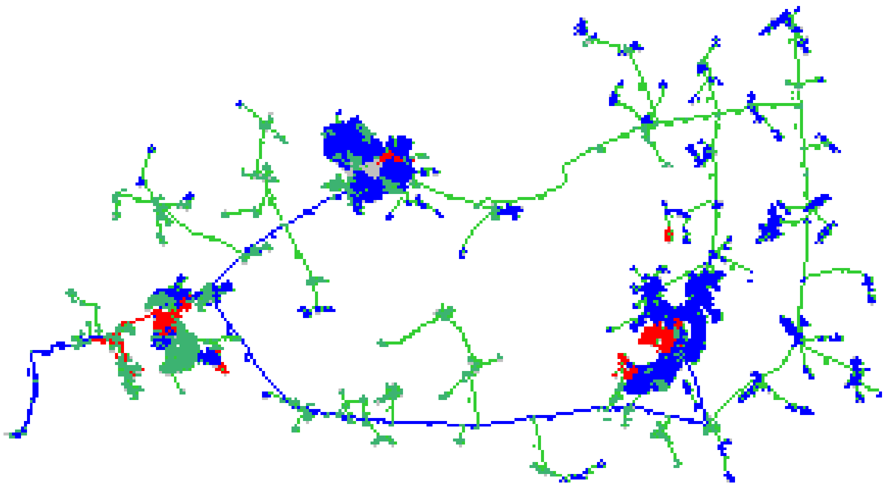

Figure 7 Overloaded lines with 40 % EV penetration and charging power of 10 kW

If the network is in an acceptable condition these weak points can be removed with only minor investments. With a further increasing load the number of overloaded elements will increase. Therefore another criterion is needed to define a limit of the hosting capacity. This is a question that cannot be answered with the conventional load flow calculations. For this the method of probabilistic load flow calculation is necessary which can provide probability distributions for the loading of lines.

Such calculations have been performed for the AÜW network. It was found that the hosting capacity of a network depends on the spatial distribution of the EV within the network, and the charging strategy.

More than 500 simulations with different spatial distributions of the vehicles have been performed to evaluate the influence of the spatial distribution in the network on the loading of lines and transformers as well as on the voltage drop. The penetration rate and simultaneous charging power of 3.7 kW for all vehicles were kept constant. A high influence on the hosting capacity depending on the location of the EV is found. If the vehicles are charged at the best locations from a network point of view a penetration level of about 50 % does not lead to considerable overloading of components. If the vehicles are charged at the worst locations the hosting capacity is nearly zero. Depending on actual vehicles positions the hosting capacity is somewhere in between.

To investigate the effects of the charging strategy different charging strategies are investigated. An EV penetration of 100 % is assumed covering all possible locations. It is found that an intelligent charging strategy can significantly increase the EV hosting capacity of networks. From the investigated strategies the best one is based on the following rules:

All EV located at ‘good’ connection points are simultaneously charged from 1 am to 5.20 am at 3.7 kW continuously. All EV located at ‘bad’ connection points are charged from 6 pm to 6 am. For these EV the charging power profile for each individual EV is defined in a way to minimize the impact on the network.

As ‘good’ connection points the connection points of the 50 % of the EV with the lowest negative impact on the network are defined; the 50 % with the highest negative impact on the network are defined as ‘bad’ connection points.

Summary

The investigations on an example network showed that the hosting capacity of a network depends on the spatial distribution of the vehicles and can be increased by the use of intelligent charging strategies. To determine the hosting capacity the use of probabilistic load flow calculation algorithms is essential.

References

[1] Bundesregierung: Nationaler Entwicklungsplan Elektromobilität der Bundesregierung, August 2009

[2] Bundesministerium für Verkehr, Bau, und Stadtentwicklung: Mobilität in Deutschland (MiD), 2008