TECHNICAL AND ECOLOGICAL IMPACTS OF THE NETWORK INTEGRATION OF ELECTRIC VEHICLES IN A DISTRIBUTION NETWORK OF A MAJOR CITY IN GERMANY

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ABSTRACT

It is assumed that the integration of large fleets of electrical vehicles into distribution networks will be one of the major tasks for local distribution system operators and power generation utilities. This brings up challenges which may have further impacts on structure and organization of today's power grids. No final conclusion can be provided, so far, in which areas and under which preconditions such as charging strategies, network planning ratings etc., the grid integration could be efficiently done with minimized costs and with minimum environmental impacts.
In this paper new strategies for the network integration of electric vehicles in distribution networks for a major city in Germany with 250.000 inhabitants and its technical, economical and ecological impacts are analyzed.

INTRODUCTION

The German government has strong targets for the integration of electric vehicles (EV, battery and plug-in hybrid (HP) vehicles) into the transportation system in Germany until 2020, when 1 Million electric vehicles are estimated as integrated in the German car fleet. The integration of electric vehicles in distribution networks brings up challenges for today's distribution networks that they not have been planned for. However, new strategies for network planning, communication strategies of EV with the power system and network operation strategies have to be developed. The following results have been evaluated during the E-Energy project Smart Wheels which is funded by the German Federal Ministry of Economics and Transport (BMWi) and the project E-Aix: "Nachhaltige Mobilitätskonzepte auf Basis von Elektromobilität und Stadtwerkeinfrastrukturen" funded by the Federal Ministry of Transport, Building and Urban Development. New concepts for a highly efficient transportation system in the local region of Aachen are being evaluated in combination with field trails of the ICT based (Information and Communication Technolgies) integration of electric vehicles, buses, small motorbikes and pedelecs (Pedal Electric Cycle).

EVALUATING METHODS OF THE GRID INTEGRATION OF ELECTRIC VEHICLES

This section describes the applied methods to evaluate the technical, economical and environmental impact of an increasing electrification of the mobility and heat sector on existing distribution grids.

<u>Technical and economical impact methods - Unit dispatch in distribution grids</u>

In order to evaluate the technical impact of a rising number of EV and HP on distribution grids, a method is applied, that simulates the charging behavior of EV and the operation of HP depending on different control strategies. The simulation bases on a method that optimizes the dispatch of decentralized units in distribution grids [1].

Input data of the developed method are the distribution grid to be investigated, the network customers as well as technical constraints. Network customers include undispatchable and dipatchable customers. Latter ones are EV and HP, while industry and household customers as well as generation based on renewable energy sources are considered to be undispatchable in this contribution.

The dispatch of decentralized units is optimized under cost minimization aspects. In general, this is an economic approach, but easily exchangeable with a business (e.g. profit maximization for each customer) or a technical (e.g. minimization of equipment loading) approach, depending on the control strategies to be investigated. Costs accounted in the optimization are electricity costs for the operation of EV and HP (calculated with spot market prices, assuming that the investigated system is a price taker) and costs resulting from network losses.

To allow investigating large-scale systems and considering all relevant technical constraints, a two-step approach has been developed. For the optimization, an iterative linear approach has been realized with a linearized integration of grid constraints from an AC load flow model.

The output of the developed method is the optimal unit dispatch for each dispatchable network customer within the investigated supply area.

Computer-based long term planning of distribution grids

To determine the economical impact of a rising number of EV and HP on the network costs, a computer-based long-term planning tool for distribution networks is applied [2].

Long-term planning of distribution networks is usually based on a green field approach, with a planning horizon of several decades in the future. Thus, existing assets and their age structure can be widely neglected in the planning process.

The objective of network planning is to minimize the sum of capital investment and annual operating costs of equipment as well as annual costs of power losses. This minimization is carried out with respect to geographic constraints such as substation positions and useable routes. Besides, all relevant technical constraints (maximum equipment load in normal and faulty operation, admissible voltage limits and the short-circuit currents) must be fulfilled.

By varying boundary conditions of network planning in a systematic manner, the impact of planning constraints on network structure and costs can be quantified. Based on this, impartial conclusions about the influence of EV and HP on distribution network costs can be drawn.

The computer-based tool for planning distribution systems is based on an efficient two-stage heuristic method which is capable of considering all relevant geographical and technical constraints. In a first step, an initial solution is generated with an algorithm originally developed for the vehicle routing problem. Afterwards, the initial solution is improved iteratively with a method based on large neighbourhood search algorithms.

Ecological impact methods

The ecological impact assessment is a crucial part of a holistic evaluation of the network integration of electric vehicles. Ecologic advantages are seen as one of the major benefits of electric mobility and will certainly serve as a motivation for subsidies. While the reduction of carbon emissions might be the most obvious one, other forms of emissions such as noise, NO_x or particulate matter might be the cause of equal or even higher externalities and were therefore put at the centre of the project [3].

However the analysis of local emissions requires a more sophisticated approach. While there is no need to analyse the exact driving patterns and locations of the vehicles for an evaluation of CO_2 reductions, the necessity to do so arises when assessing local effects. An agent-based modelling of the individual driving patterns of several thousands electric vehicles was implemented as a foundation for an assessment of noise and particulate matter reductions. A description of this modelling approach can be found in [4].

Methods for communication strategies of electric vehicles with intelligent local network stations and the central network control unit of a DSO

In order to protect the grid and its components on the one hand and realise ancillary services on the other hand, a DSO needs to monitor the current grid situation on low voltage level. This can be done using central monitoring equipment at the local network station (LNS) in combination with an appropriate communication technique, but also decentralised solutions with feedback from single cars or meters could be possible.

Typically a flexible way to achieve a sufficient and economic communication for a central monitoring approach is to use mobile communication modems for signalling the current load of each phase of the feeders and transformer either in fixed time intervals or on demand by defined trigger values indicating necessary actions to the DSO control centre.

Actions to be taken from DSO respectively fleet operator in charge can mean direct, individual addressing of EVs, charging at the affected phases or indirect flat controlling of EVs in order to to lower or shut down power for all EVs behind the LNS.

In any case, a simple and cost efficient way to set up control of EVs is using mobile communication. Other proprietary solutions such as power line communication (PLC) are principally possible either but are likely to interfere with other signals and frequencies on the wire. Up to now no commitment on a specific, common PLC protocol is conceivable. PLC also means to be in charge for taking good measures to filtering communication signals not to broadcast them on the entire wire. Otherwise it would increase the likelihood of interference with other PLC communication even more.

With respect to higher charging power in the long term, it is a severe need to require standardised communication to EVs. It is one of the most important but also challenging tasks to commit on and standardise solutions as soon as possible.

Essential for controlling the grid and protecting all components is a proper identification of which EV is connected to which feeder and phase. Independent from the kind of communication this needs to be solved. Neither PLC nor other communication methods provide this information automatically. Therefore such identification has to be set up manually unless other methods allow automatically assignment. One innovative possibility is modulation of telecontrol signals on the phase voltages like they are used to switch on street lighting for example. For this purpose they would have to be unique. This would allow to automatically identify to which feeder and phase(s) an EV is connected to.

Assuming a possible identification of EVs and its connection position to the grid as well as communication links as described are available, indispensible functions like load shifting, load lowering and load shedding can be set up. Furthermore ancillary services like providing reactive power and feeding back power to the grid are feasible.

RESULTS OF A CASE STUDY

Technical and economical impacts

Based on an existing German distribution grid, the optimization methods introduced in the previous section are applied. The objective of this case study is to demonstrate the feasibility of the presented methods and to show exemplary results.

The investigated network is operated with 10 kV. 70 network nodes representing local substations account for 10.000 households with a maximum aggregated electrical load of 16 MW. The subordinated lv network customers are considered aggregated in each local network substation. It is assumed that 50 % of all households own an EV, that can be charged and discharged at home as well as in industrial and commercial areas. The assumed charging power is 10 kW and the battery capacity amounts 25 kWh. Furthermore, a total of 1000 heat pumps (2 kW electrical power; 20 kWh thermal storage) are installed in the system.

Firstly, the results of the technical evaluation are illustrated. In this contribution a sales-oriented control strategy – i.e. maximization of profit – is presented. Figure 1 shows exemplary results for a weekday in winter. Besides the prize for electricity (historic spot market prize) the determined load profiles of EV and HP are depicted. Latter ones result from an aggregation of all determined unit dispatches of each single EV and HP within the observed supply area. In general, the dispatch of EVs and HPs show a high correlation with electricity prices. Whereas EVs are charged during off-peak times with low electricity prices, they are partly discharged during peak times with high electricity prices.

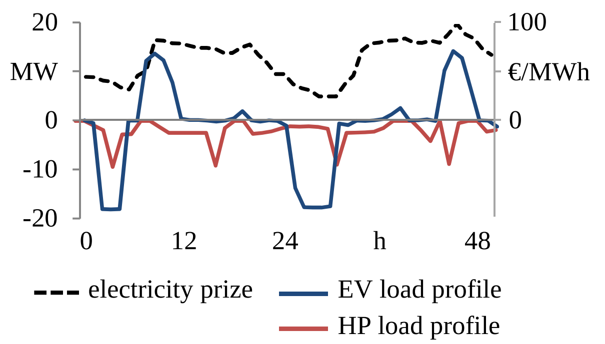

Fig. 1: Prices and aggregated load profiles of EVs and HPs

Results shown in Figure 2 prove the necessity of considering grid constraints when optimizing the dispatch of a large number of EV and HP in a supply area. Especially during low price periods, grid constraints are violated.

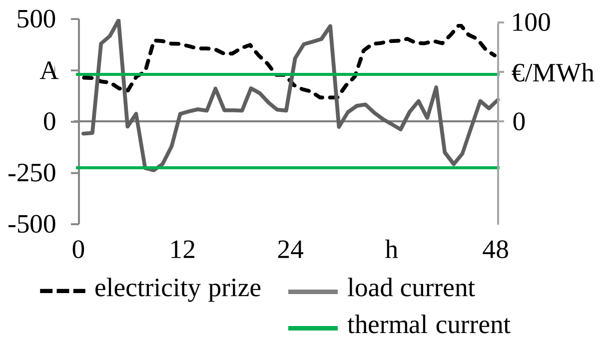

Fig. 2 Load current for exemplary lines

In the following, results of the economical evaluation are presented exemplary for an existing suburban supply area. Figure 3a shows the optimal cost-efficient network structure for the current supply task i.e. without EV and HP. This network is assumed to be the existing network structure in this area for the following evaluations.

The area is supplied via a ring network with a total line length of 32 km. Three opened rings are required for supplying the load of all network costumers without violating technical constraints. To determine the impact technical impact resulting from an increasing electrification of the mobility and heat sector, based on the current supply task the 50 % EVs and 1000 HPs were added. The optimal long-term network structure for the current as well as for the modified supply task is shown in figure 3b.

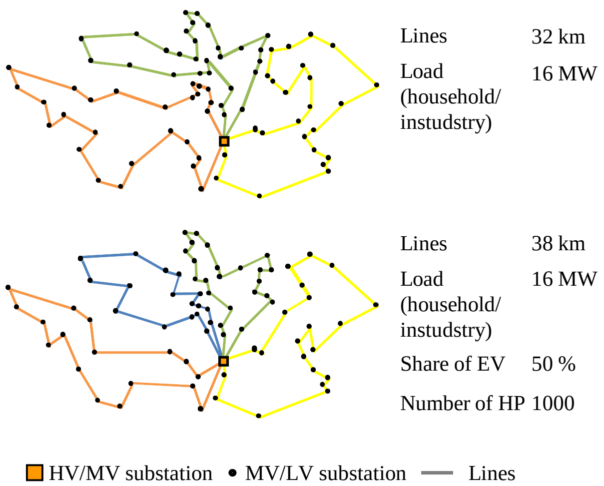

Fig. 3 a) and b) Cost-minimal network structures

Obviously, the cost-minimal network for the supply area with a large scale integration of EV and HP differs significantly from the existing network structure. In this scenario four opened rings are required, consequently the length of lines rises by 6 km. Thus, an increasing electrification of the mobility and heat sector will most likely lead to additional network costs.

Ecological impacts

Electric vehicles save up to 70% of particulate matter emissions in comparison to conventional vehicles. The remaining 30% are emitted by tyre and street abrasion, which can only be reduced marginally due to recuperation. Using these estimates as well as historic measurements, statements about the emission reduction can be made on a local level. These local reductions serve as an expected value for statistic analyses for the probability of a limit violation.

As a result of the simulation in the particulate matter category it has to be recorded, that a realistic penetration rate for 2020 would only have a small impact on fine dust in the annual average. Even a regional penetration of 10 % of electric vehicles would lead to a decrease of fine dust pollution by only approximately 1.7 % in streets with heavy traffic (see figure 4). However, this decrease might have a significant influence on the probability of the limit violation. It would fall from over 60% to under 40% in a due to current design of the regulatory framework. A noticeable improvement of quality of living would require a much higher penetration rate.

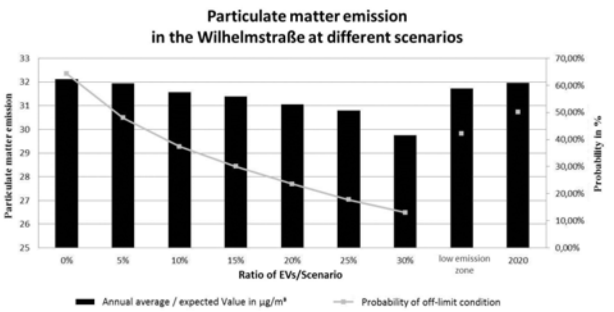

Fig. 4 Impact on EV penetration on particulate matter emissions

Traffic noises on the other hand will be enormously reduced due to an integration of electric vehicles mainly in residential areas, i.e. areas with low speed limits. Since reductions only apply to engine noise but not to roll or air resistance, the speed limit becomes a significant factor. A penetration of 10% of electric vehicles decreases noisiness about 6% in streets where the speed limit is 30 km/h, but only about 2% in areas where the speed limit is 50 km/h. Overall, a strong integration of electric vehicles unfolds its highest ecological impacts in city centres.

CONCLUSIONS AND OUTLOOK

The presented analysis shows the necessity of considering grid constraints when optimizing the dispatch of a large number of EV and HP in the analyzed supply area. New communication and charging strategies for electric and plug-in hybrid vehicles have to be implemented to avoid a violation of technical component limits e.g. a thermal overloading of cables during low energy prices.

Network investments with intelligent local network stations and a central network control unit of a DSO could be an alternative to a network expansion. Both strategies effect the long term planning of distribution networks and have to be analyzed in detail considering the local requirements to find cost-minimal network structures. Thus, an increasing electrification of the mobility and an additionally increase of electric heating systems will most likely lead to additional network costs.

Beside the technical and economical impacts the use of EV and HP lead to enormously reduced traffic noises according to the speed limit of the area and can save up to 70% of particulate matter emissions in comparison to conventional vehicles. But it has to be noticed that a noticeable improvement of quality of living with a decrease of fine dust would require a much higher penetration rates than 10%.

Overall it comes clear that the integration of electric vehicles brings up new challenges for a local DSO in network planning and sophisticated multi-parameter simulations and optimization procedures have to be done to identify cost-minimal network structures whereas under an ecological point of view the penetration rate with electric vehicles needs to be high enough to have a noticeable improvement of quality of living.

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