IMPACTS OF ELECTRIC MOBILITY ON DISTRIBUTION GRIDS AND POSSIBLE SOLUTION THROUGH LOAD MANAGEMENT

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ABSTRACT

This contribution investigates to what extent the current grid can cope with area-wide deployment of electrical vehicles and renewable energies. It is also investigated at what point additional measures, such as grid reinforcement or load management systems (LMS) are necessary for stable operation. Simulations where conducted with the power grid calculation software DIgSILENT PowerFactory. Different scenarios with an increasing share of electric vehicles are implemented into a section of a rural grid model of Freiamt, Germany. It is determined from when on overload and under voltage situations caused by charging of electric vehicles can be expected.

INTRODUCTION

The upcoming wide spread distribution of electric vehicles (EV) will provide new challenges for power grids as the demand for energy will increase. This raises the question, whether it is possible for the current grid to meet the new requirements. On the other side, electric mobility may have mitigating effects on the grid as well, because battery storage in EV may be used to balance loads between peak and base load times. Renewable energies, which not necessarily supply energy when it is needed, will intensify the need for load balancing. For future grid planning, it is necessary to know what impact electric mobility will have especially on distribution grids. The biggest issue is that many vehicles may be charged simultaneously in evening hours after work. This is exactly the time, where the grid is already at its peak load. Therefore, a load management system may be necessary to charge the vehicles specifically during off peak hours or even to times, when there is low load and excess energy due to renewable energies. Vehicle to grid may be capable of resolving both the issues of increasing load and dispersed generation by using the decentralized storages of the vehicles as variable load and energy supply when needed. The aims of this contribution are to analyze whether there will be complications in near future due to electric mobility and when they are to be expected. This is achieved by using certain scenarios for future development of EV and renewable energies. In Germany, for example, the goal for 2020 is to have one million EV in operation according to the national development plan [1] and a share of about 35% electric energy produced by renewable energies, which is about 210 TWh annually [2]. Furthermore, this contribution presents a possible solution to both problems by combining them through load management.
This contribution is structured into three parts. At first, a general methodology for the analysis of a grid is described. In a second step, this methodology is applied to an exemplary grid. The results show, that there are problems to be expected with voltage levels by 2020. Finally a load management system is described to mitigate the problems.

METHODOLOGY

To answer the question, whether there will be problems due to e-mobility and renewable energies in near future at all, one has to take into account the gird topology. The analysis shows that problems caused by e-mobility mainly arise in distribution grids, especially low voltage grids.
This contribution looks specifically on one representative low voltage grid of the rural town of Freiamt, Germany, which features a high proportion of photovoltaic systems. However, a methodology is developed, which easily can be transferred and used to analyze different grid topologies with varying assumptions. The chosen low voltage grid is modelled with 42 loads, which resemble approximately about 70 households, with a maximum aggregated load of 118 kW. Applying the average of cars per household of Freiamt, there are about 100 cars in this low voltage grid. Additionally, there are 6 photovoltaic systems (PVS) with an installed nominal capacity of 96 kW. The grid is fed by a transformer with a nominal capacity of 400 kVA.
To assess the condition of the grid, it is looked at two features, namely:

- Voltage levels, which allow for a deviation of ±10% to nominal voltage according to the European norm EN 50160,
- Maximum current on grid assets, mainly transformers and lines.

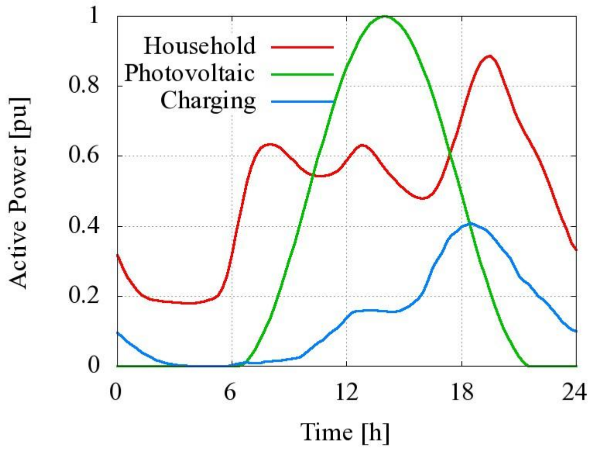

Figure 1 Standard profiles for a workday

To resemble the loads and dispersed generation by PVS standard profiles [3] are used, which are depicted in Figure 1. The VDE did a study constructing such a standard load profile for the uncontrolled charging of EV with 3 kW [4], which is shown in blue. These profiles are available for workdays, weekends and different seasons and will be used to analyze the grid and compare different scenarios for the development of renewable energies and electric mobility. For example, renewable energies will stress the grid most during summer, when PVS have their peak load, while electric mobility will stress the grid most during winter, when the residual load is biggest as well. The scenarios for the development of the load, renewable energies and e-mobility shown in Table 1 are based on extensive research of literature. These scenarios are only valid for Germany. They are remarkable especially because of the vast increase of renewable energies. However, the scenarios may easily be adapted to different circumstances and the same methodology may be used.

	Load [5]	PVS [2]	EV Share [1]
Scenario 2020	+17%	+97%	2,5% (Case 1) – 6% (Case 2)
Scenario 2030	+37%	+230%	12.5% (Case 1) – 37% (Case 2)
Scenario 2050 (fictional)	+89% (extra-polated)	+372% (extra-polated)	50% (Case 1) - 100% (Case 2)

Table 1 Scenarios for load, renewable energies and degree of electrification for vehicles

The scenario for development of PVS is conservative. More recent studies even expect a higher increase of PVS. For EV there is a conservative scenario Case 1 and an optimistic Case 2. The EV and charging stations are distributed evenly in the grid. Further assumptions are that every electric vehicle is recharged by 10 kWh per workday with a charging power of 10 kW. Additionally, only symmetrical three-phase conditions are considered.

EXEMPLARY STUDY OF A RURAL GRID

Reference Case

At first, a reference case is calculated according to the scenarios, but without EV. The grid already is stressed because of increasing loads and renewable energies. This will be the basis for comparison to later results with e-mobility. Therefore, it is possible to assess the effect of e-mobility on the grid decently, whether they are worse with uncontrolled charging or mitigating the problems with a load management system.

In the following bar charts, each bar represents one simulation. The upper mark corresponds to the maximum occurring value during the year with load flow in low voltage direction. The middle mark corresponds to the average value without load flow direction. The bottom mark corresponds to the maximum value with load flow in medium voltage direction, like they occur due to photovoltaics. Figure 2 shows the development of the transformer load for the different scenarios.

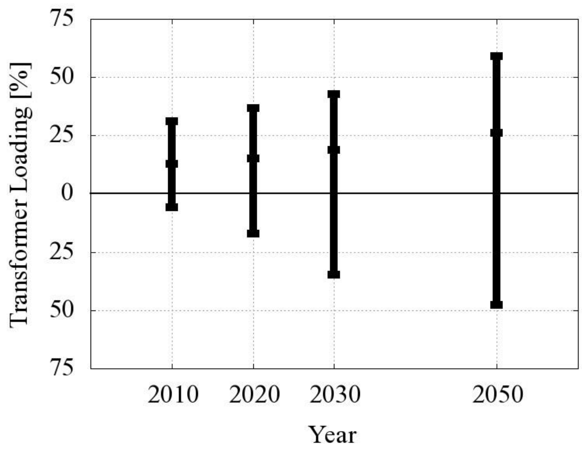

Figure 2 Development of the transformer loading.

The load on the transformer is increasing in both directions, but a little more in medium voltage direction. However, the transformer has quite some excess capacity and the additional load won't be a problem. But it is obvious that due to the vast relative increase this already may cause reinforcements in different grids, where the transformer is less oversized.

Impacts of uncontrolled charging

In the next step, the impacts of uncontrolled charging of EV are investigated.

Evenly distributed electrical vehicles

In Figure 3, the load profile of a weekday is depicted using the case 2 scenario 2030 with 37% electrification and 10 kW charging power per vehicle. It can be seen that uncontrolled charging significantly increases the evening load peak. Fortunately, however, the evening load peak and EV charging peak differ by almost 2 hours, which lowers the resulting peak shown in green. For other

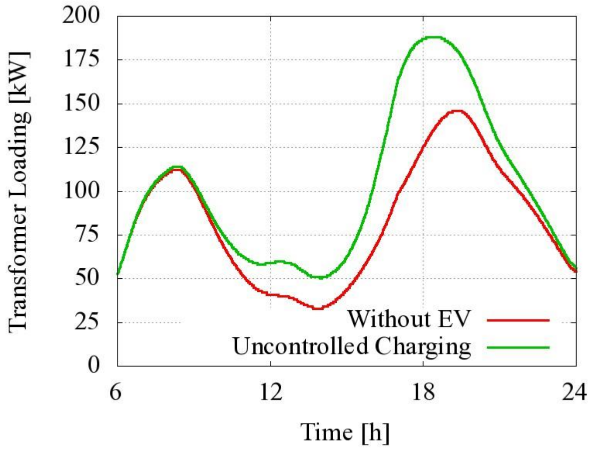

Figure 3 Load profile with and without uncontrolled EV, 2030 with 37% electrification and 10 kW charging

simulation scenarios the increase of the maximum load due to uncontrolled charging of EV is shown in Table 2.

Electrific.	2010	2020	2030	2050
Case 1	0%	1%	4%	19%
Case 2	0%	2%	20%	56%

Table 2 Increase of the maximum load by EV

The results show that up to the year 2020 the transformer loading will not be a problem, because there are only minor effects caused by electric mobility. In the year 2030, however, the load may increase up to 20% due to e-mobility in the Case 2 scenario. This is a significant increase and may require additional measures like grid reinforcement or load management. In addition to considering the transformer load, the voltage levels need to be taken into account as well. Table 3 shows the minimum voltages in the grid with uncontrolled charging of EV for the different scenarios.

Electrific.	2010	2020	2030	2050
0%	0,970 pu	0,966 pu	0,960 pu	0,946 pu
Case 1	0,970 pu	0,966 pu	0,959 pu	0,936 pu
Case 2	0,970 pu	0,965 pu	0,953 pu	0,918 pu

Table 3 Minimum voltages in the grid

The uncontrolled charging of electric vehicles does not have significant influence on the voltage before 2030 in this grid, at least when looking at evenly distributed vehicles. However, it is probable that there are local accumulations of EVs and that there are power lines with a much higher degree of electrification than the average. This does not affect the transformer load, but the voltage level severely.

Local accumulations of electric vehicles

Figure 4 shows the influence of the degree of electrification for the 2020 scenario. Considering a feeder with only 20-30 households or less, the electrification may even rise up to nearly 100%, even though the electrification on average for Germany will be at about 6%, when considering the Case 2 scenario. The chart shows, that EVs start to have a significant effect on the voltage level with an electrification of 37% in the year 2020. With a local accumulation of 50% there is a voltage drop of almost 5%, which is critical considering, that there is an additional voltage drop due to the medium voltage grid. Therefore a possible solution through load management is presented in the next section. For more details and concepts for load management the reader is referred to [6].

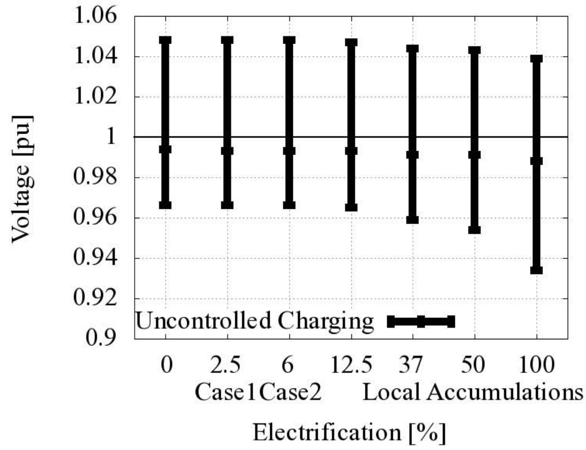

Figure 4 Local accumulations of EV 2020

LOAD MANAGEMENT

Concepts

In this study, two different concepts of load management systems are investigated. Their common goal is to control the charging of the EV in a way that the load at the transformer is balanced. Therefore, the load management system must be capable of measuring the load of the feeding transformer. The first concept has a uni-directional power flow to the vehicles and charges them by calculating a desired load profile for the transformer and controlling the load by throttling the charging rate (LMS). The second concept follows the same principle, but it also allows a bi-directional power flow from the EV back to the grid based on the "vehicle-to-grid" (V2G) concept [7]. Figure 5 shows the concept of a load management system.

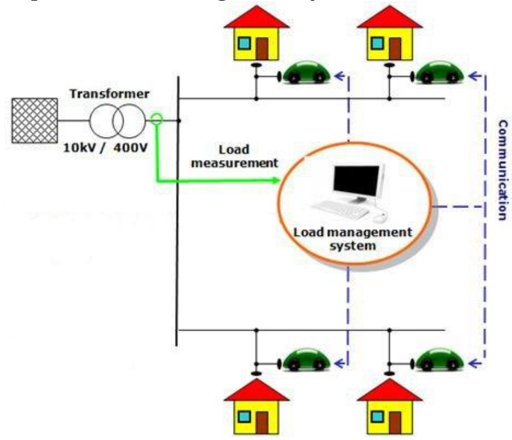

Figure 5 Concept of a load management system

Positive effects of load management

Figure 6 shows the transformer loading, depending on the type of concept for the various scenarios in the years 2020 and 2030.

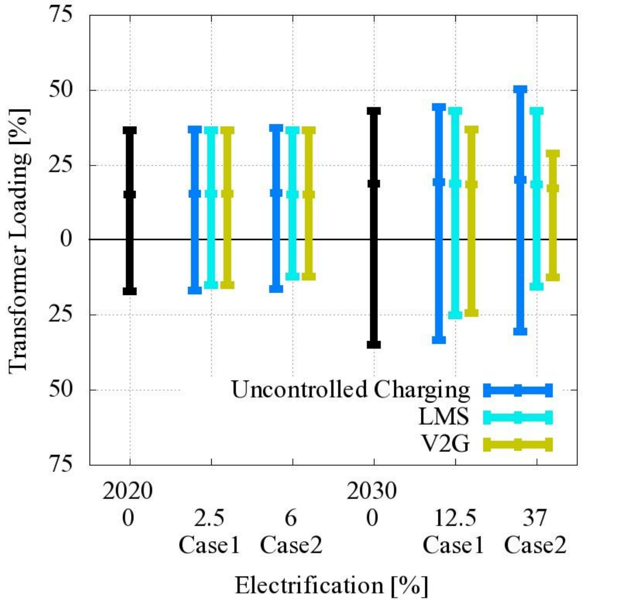

Figure 6 Reduction of transformer loading due to LMS

Because of the low electrification in 2020 there is only a small smoothing of the transformer load by using load management. In the year 2030, however, the influence of load management is much higher, especially in the scenario with 37% electrification and load management with an electricity flow in both directions (V2G). The LMS and V2G concept both decrease the transformer load by mainly shifting the charging of EVs to night time and PV peak times at noon. Furthermore, the V2G concept even feeds energy back to the grid in evening hours at peak load times. Figure 7 shows how the load management improves the voltage level especially with local accumulations and a local high degree of electrification for the scenario 2020. Depicted in blue is the uncontrolled charging for comparison, which was already shown in Figure 4. It is seen that at 37% electrification and above, where a noticeable effect occurs the first time with uncontrolled charging, the load management provides a significant reduction of extreme voltage values.

CONCLUSION

This contribution developed a modular methodology for the analysis of grids, which easily can be transferred to analyze additional grids. To show the effectiveness of this methodology a German low voltage grid was investigated. The analysis showed that this grid has significant excess capacity and therefore is capable to provide the necessary infrastructure needed for an area-wide outlay of renewable energies and electric vehicles. In other grids problems might be more severe. However, local accumulations may lead to

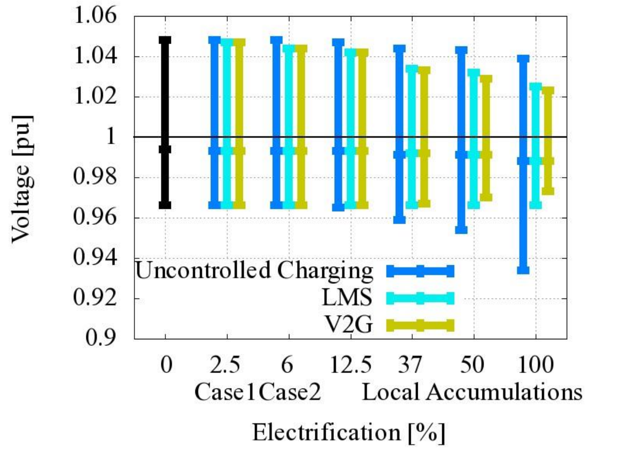

Figure 7 Max. and min. voltages with local accumulations 2020

under-voltage situations already by 2020. Hence, two load management concepts were introduced. They balance the grid load and reduce over- and under-voltage situations even with local accumulations of electric vehicles.

Further improvements to this approach may be to consider measurement data for the load profiles instead of the standard load profiles. This would especially enhance the analysis of voltage levels. Furthermore, unsymmetrical loads could be considered.

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