Peak Shaving by Means of Buffer Storages in Charging Stations

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***Abstract*—The *Mobilitätswende* in Germany is a politically desired change from vehicles with conventional engines to electric vehicles. The number of electric vehicles and charging stations has risen in the last years. In the future, on one hand vehicle's batteries will get a higher capacity. On the other hand the charging power will rise. Especially in existing LV grids challenges arise as a result of the integration of a high number of charging stations. Electric vehicles are charged in the evening hours and therefore the charge superposes with the household's daily maximum. Simultaneously more PV systems are installed. The focus of new systems is self-consumption, though their maximum is at midday. Therefore the electric vehicle as a big load cannot be charged directly and the grid is strongly stressed twice. By means of buffer storage these two maxima can be superposed fictitiously and so, the peaks can be shaved.**

***Keywords*—Mobilitätswende, charging infrastructure, peak shaving, buffer storage**

I. Introduction

In the year 2009, the German Federal Government adopted the National Electromobility Development Plan with the objective to speed up research and development in battery electric vehicle as well as their market preparation and introduction in Germany. One million electric vehicles should be on the road by 2020 [1]. Meanwhile the German chancellor Angela Merkel has indeed abandoned this aim at fraction congress in Berlin on 15th May 2017, but the expansion of electric mobility will still be promoted. The number of registration of new electric vehicles and hybrid vehicles has risen in the last few years in Germany. In the year 2016 11.410 electric vehicles [2] and 47.996 hybrid vehicles [3] were newly registered, though most hybrids are not plug-in but full hybrid [4].

For the success of the German Mobilitätswende a needs-based charging infrastructure is necessary. To this day, the number of public charging points has risen to 6.448 [5]. The German National Platform for Electric Mobility forecasts, that the charging power of public DC-charging stations will rise up to 350 kW in the mid-term. The charging power at home is currently up to11 kW. As a result to the possibility of long charging times this charging power will not rise significantly. [6]

II. Change in Households

Seen historical electric power in households was used primarily for lighting. In the last decades electric power is additionally used for electric cooking and water heating. Due to this households were included for grid planning [7]. In the last years many photovoltaic (PV) systems were implemented on rooftops and actually, in regard to the German Mobilitätswende, there is a progress from vehicles with conventional engines to electric vehicles (EV), which can be charged at home. As a result of the German *Energiewende* and Mobilitätswende and their new components there are two household's maxima at each day. PV systems have their maximum at midday. The maximum of the EV's charging is in the evening hours and superposes with the normal household's daily maximum. With these new components households turn into *prosumer*. This term consists of the terms producer and consumer. The trends for an exemplary summer day with the new components are shown in **figure 1**.

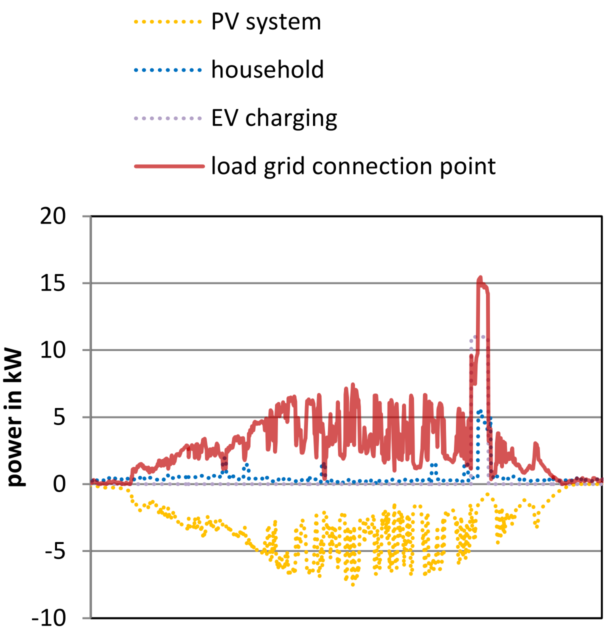

Figure 1. Profiles for an exemplary day

In comparison with a conventional household (blue dotted line), the new behavior with EV and PV systems (red line) varies widely. Therefore households take a new status in the energy system and they will pose a new challenge for it.

Partially these households have or will have additional storages which are implemented below as a first approach. The components (PV system, storage and EV) and the topology of a future household are schematically shown in **figure 2**.

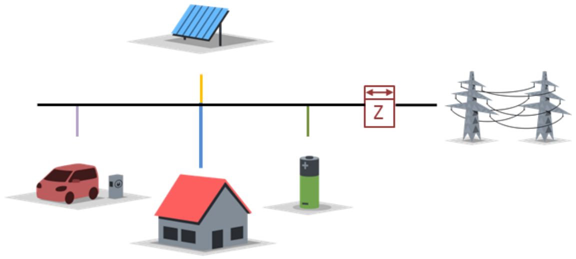

Figure 2. Topology of future households

III. ELECTRIC MOBILITY IN RESIDENTIAL AREA

For analyzing the influence of the electric mobility a real existing suburban residential area is chosen and simulated in the program DIgSILANT Powerfactory. In these areas especially single-family-houses are present, which represent the best conditions for investigating the new components and the new roll as prosumer. The analyzed grid consists of three main (A – C) lines with 72 households in total. The considered grid is schematically shown in **figure 3**.

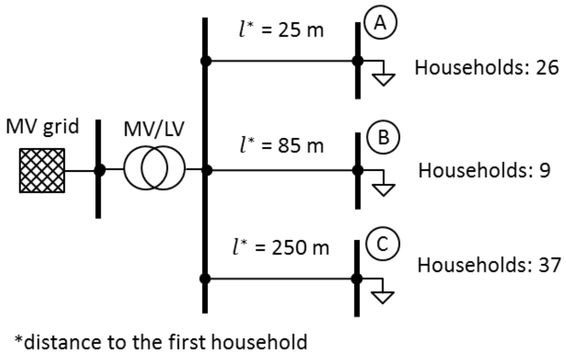

Figure 3. Analyzed LV grid (basic, without PV, EV and storages)

For the households, EV charging and PV system synthetic profiles are used. The households are set as four/five-person households with a high annual consumption of about 4500 kWh.

All PV-systems have the same behavior because of the identical geographical position. They only vary with regard to the systems power. Their rated powers are between 8.5 kWp and 21 kWp and they are limited to 70%. The power factor is set to 0.95 (inductive).

The EVs are especially charged in the evening hours, when common employees arrive at home. These profiles vary with regard to the starting and charging time. The charging power is set to 11 kW. Reactive power is not provided by the charging stations.

The capacity utilization of the line A and voltage at the end of this area are considered because there are the most households and new components. For comparison the case without EV and PV systems is also shown. As a winter month January and July as a summer month are analyzed. Three work days of each month are shown. The behavior of line A is identical, but with bigger drops, yet for the sake of clarity the presentation of the associated results is relinquished. The conditions of the analyzed cases are listed in **table I**. The cases are distinguished by the starting cases without any new component, the case with a middle number of new components and the case with a high number of new components. The Household with EVs also have a PV-system in the case II and III. In case II only eight households have a PV-system.

TABLE I. ANALYZED SCENARIOS

Case	**conditions**		
	description	***EV***	***PV***
I	Grid without new components	-	-
II	Middle number of new componentens (realistic extension)	36	44
III	Very high, equal number of new componentens (optimistic extension)	58	58

The simulation results of these cases for winter days are shown in **figure 4** and **figure 5** and for summer days in **figure 6** and **figure 7**.

For winter and summer days the influence of the new components is clearly shown. The midday maxima are the result of feeding from PV systems. These maxima are higher at the summer days because of more intensive solar irradiation and therefore the capacity utilization is higher accordingly. Furthermore the capacity utilization of the considered line rises from about 10% up to over 60% (figure 6) as a result of feeding. Figure 4 also demonstrates an influence of PV systems for the winter days. The capacity utilization rises from about 10% up to 35% at sunny winter days (08.01. in figure 4).

By means of the voltage trends it can be determined, if the high capacity utilization is the result of the feeding or the charging process. The voltage rises by 10 V at sunny winter days (figure 5) and by 20 V at summer days (figure 7) as a result of feeding by PV-system. In contrast to the PV-systems, the charging of EVs is constant through the year with regard to charging power. The evening drop as a result of charging EVs is by 15 V and remains so throughout the year because charging is independent of season in contrast to the PV system. In the evening the feeding of the PV-system and the charging of the EV superpose partially. For this reason the capacity utilization drops temporarily before it rises again due to charging of EVs and drop of feeding by PV-systems. A further expansion of new components (case III) only leads to a little stronger influence in comparison with case II.

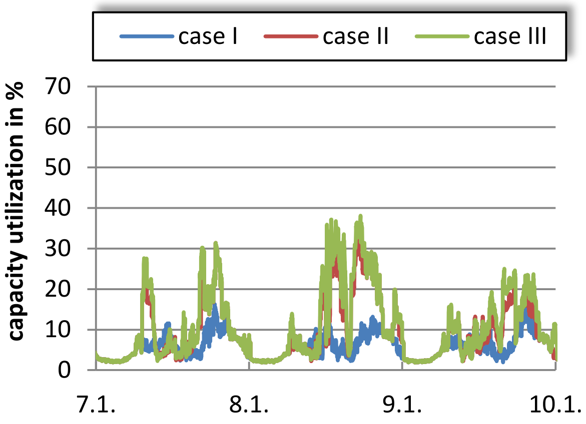

Figure 4. Capacity utilization line c (winter days)

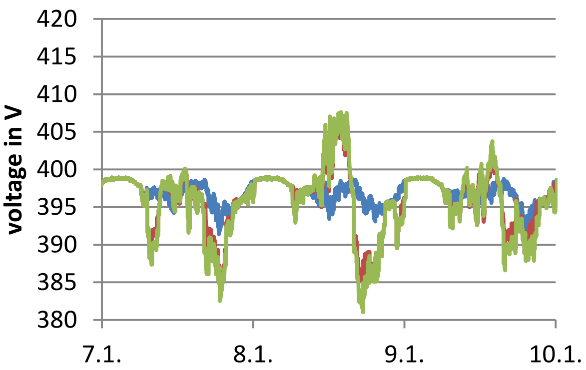

Figure 5. Voltage in area c (winter days)

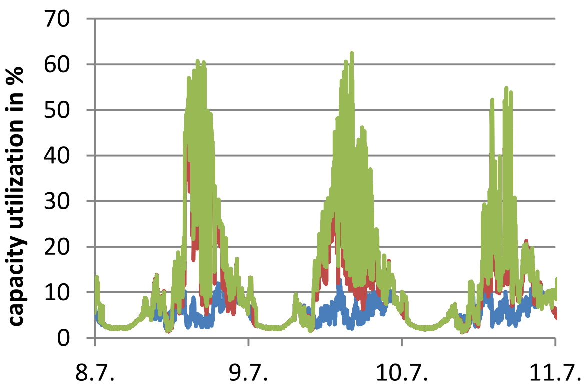

Figure 6. Capacity utilization line c (summer days)

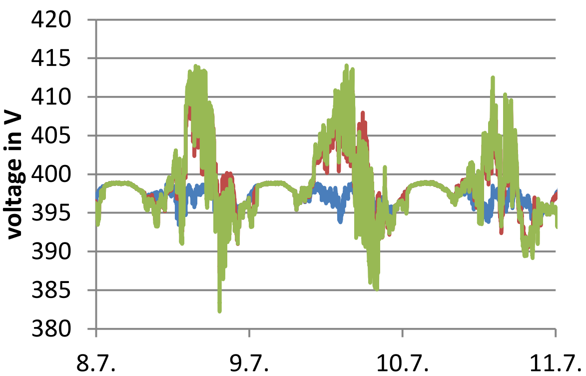

Figure 7. Voltage in area c (summer days)

A summary of all maxima, also the values at the local power transformer and line A, for winter are listed in **table II** and for summer in **table III**. The integration of the new components poses difficulties. Values outside the allowed voltage ranges are colored red [7]. Referred to [8], only 5% voltage drop is allowed in LV grids because of possible voltage drops in upstream MV grids and in transformer level. Therefore voltages in the ranges of 360-380 V and 420-440 V are colored orange. The extension of new components is problematic for the local power transformer (LPT) at summer days. Temporary overloads up to 117% are possible as a result of the high feeding by PV-systems. Overloads also occur in line A at winter days (case III) and summer days (case II and case III). In all cases with new components the voltage drops are close to the limits marginal or even exceed allowed ranges (case III, line A).

Because of the voltage values outside the allowed limits and possible overloads measures are necessary, for example expensive grid reinforcement. Alternative opportunities are puffer storages in households with PV-systems and EV in order to superpose feeding and charging fictitiously and increase self-consumption.

TABLE II. CONCLUSION OF MAXIMA (WINTER)

	case (winter)		
	I	***II***	***III***
LPT capacity utilization in %	23.32	53.52	62.63
LPT voltage at LV side in V	397.70-399.72	394.86-399.82	393.90-399.72
line A capacity utilization in %	28.12	**117.34**	**140.11**
line A voltage in V	390.97-398.99	**367.65**-416.65	**359.92**-**420.82**
line C capacity utilization in %	17.74	41.30	52.02
line C voltage in V	388.45-399.13	**378.54**-406.71	**374.32**-407.85

TABLE III. CONCLUSION OF MAXIMA (SUMMER)

	case (summer)		
	I	***II***	***III***
LPT capacity utilization in %	19.25	**94.18**	**109.00**
LPT voltage at LV side in V	398.14-399.74	393.40-399.74	391.88-399.74
line A capacity utilization in %	26.72	**126.66**	**150.11**
line A voltage in V	389.27-399.19	**378.00**-**428.80**	**371.99**-**434.94**
line C capacity utilization in %	14.30	53.90	64.79
line C voltage in V	392.78-399.00	387.15-412.71	382.23-415.35

IV. Buffer Storages as Approach for Residential Areas

The results of the simulations with new components necessitate measures. Puffer storages in households with PV-systems and EV are an approach. For this 24 households are analyzed with new components and equipped with an additional storage. The capacity of each storage is 10 kWh. This value could be optimized depending on PV-system. The analyzation points out the general influence of storages. These puffer storages are charged during feeding at midday when the set power at the household's grid integration point is exceeded. The puffer storages discharge during charging the EV. There is also a limit for the discharging. The used storage characteristic is shown in **figure 8**.

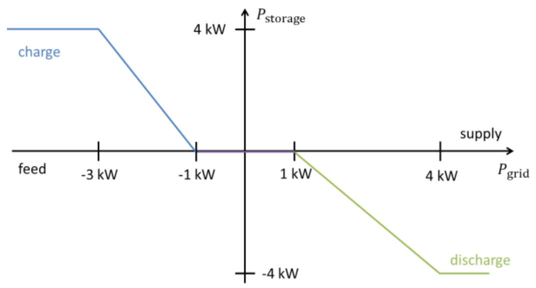

Figure 8. Characteristic of storage

The trend environment of the new components (case II) is used in conjunction with the puffer storages (case IV). In addition a case with a reinforced line A is analyzed (case V). A summary of the cases is shown in **table IV**.

TABLE IV. Analyzed Scenarios with Storages

Case	**conditions**		
	description	***EV/PV***	***storages***
IV	Integration of storages	36/44	24
V	Integration of storages and grid reinforced line A	36/44	24

The simulation results of these cases for winter days are shown in **figure 9** and **figure 10** and for summer days in **figure 11** and **figure 12**. The trend of the difference in contrast to the starting case is also shown in addition to the real trend. The changes both between case IV (new components, with storage) and case I (no new components) and case IV and case II (new components) are shown. Case V is not demonstrated because it only has an influence on line A. The result of the grid reinforcement is in the summary (**table V**). Only the results of the critical cases without storages are listed in the summary for greater clarity.

All results demonstrate a further negative influence of new components in conjunction with storages in contrast to the start case I, though there are improvements with regard on voltage and capacity utilization in contrast to the integration of the new components (case II).

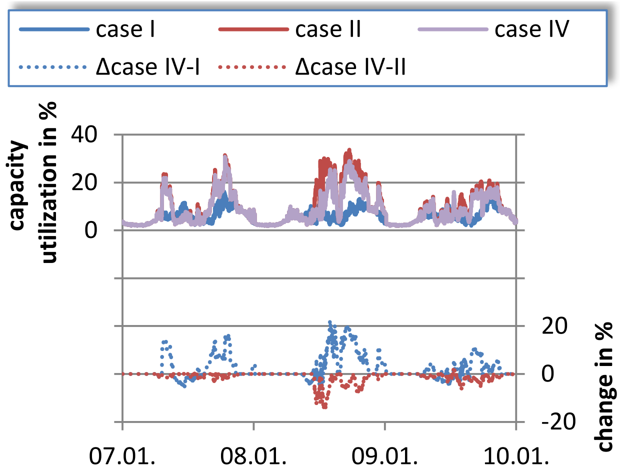

Figure 9. Capacity utilization line c with storages(winter days)

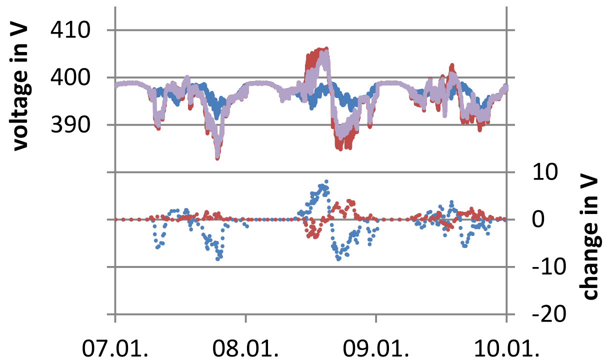

Figure 10. Voltage in area c with storages (winter days)

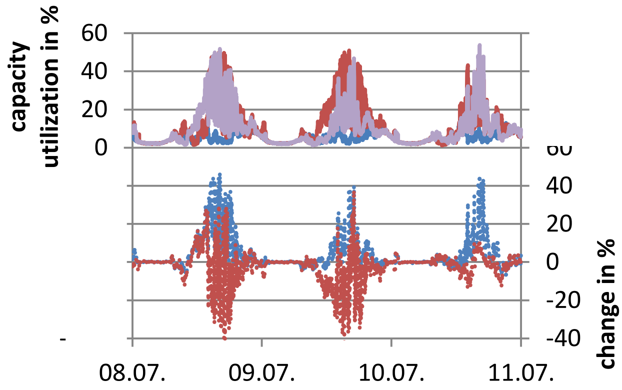

Figure 11. Capacity utilization line c with storages(summer days)

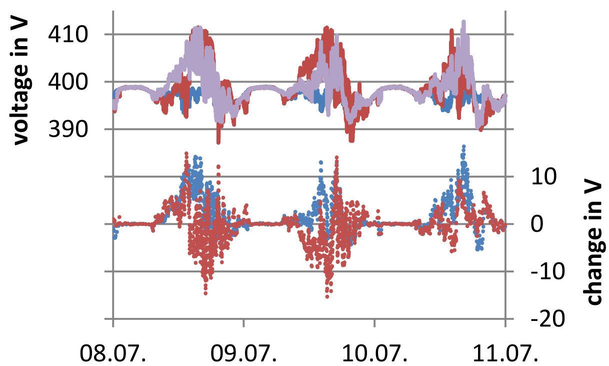

Figure 12. Voltage in area c with storages(summer days)

The improvements as a result of integrating the storages are also reflected and given in the summary (table V). The critical values can be prevented with exception of the capacity utilization of line A. A reinforcement of line A is necessary in order to remain within the allowed capacity utilization. The improvements are partially of minimal influence because of not optimized storage. For all locations the same storage model with identical capacity and operating mode is used. The storage can be full during feeding by PV-system or it can be empty during charging the EV. Therefore the changes of the maximum voltage value are low. By means of optimizing the capacity and the operating mode the voltage range will be further reduced. Additional measures like providing reactive power by battery inverter for improvement are conceivable. The charging stations in the considered grid are almost exclusively AC stations. In this charging method the onboard charging units are used. If these units get an active rectifier, they can also provide reactive power and further improve the behavior.

TABLE V. CONCLUSION OF MAXIMA AND CHANGES

	case			
winter	***I***	***II***	***IV***	***V***
line A capacity utilization in %	28.12	**117.34**	83.37	65.73
line A voltage in V	390.97-398.99	**367.65**-416.65	**373.27**-416.00	**376.79**-413.50
line C voltage in V	388.45-399.13	**378.54**-406.71	380.11-406.63	380.12-406.49
summer	***I***	***II***	***IV***	***V***
LPT capacity utilization in %	19.25	**94.18**	67.60	67.94
line A capacity utilization in %	26.72	**126.66**	**114.94**	**90.85**
line A voltage in V	389.27-399.19	**378.00-428.80**	**379,88-422.97**	382.19-418.39

V. BUFFER STORAGES IN FAST CHARGING STATIONS

The second case uses buffer storages in public high power fast charging stations. The National Platform Electricmobility hypothesizes charging stations with a power of 150 kW in the next years [6]. This high charging power will be problematic for the existing LV grid. Grid reinforcements will be necessary. A residential quarter with 160 units and 80 already integrated charging stations is the starting point. The additional high power charging station with two charging points of 150 kW each is integrated over a stub cable to the local power transformer. Synthetic profiles are used for households, charging stations at home and the high power charging station. The storage's capacity is 100 kWh. The buffer storage is charged in times without EVs. The charging power is 100 kW. It discharges during charging of EV with 200 kW. Therefore the grid is maximal loaded by 100 kW. The power at the grid integration point of the charging station is shown in **figure 13** for two exemplary days. In this figure the influence of the puffer storage is demonstrated. By means of the puffer storage the capacity utilization can be reduced in each case. The grid can be relieved even in the critical case with two charging processes at the same time.

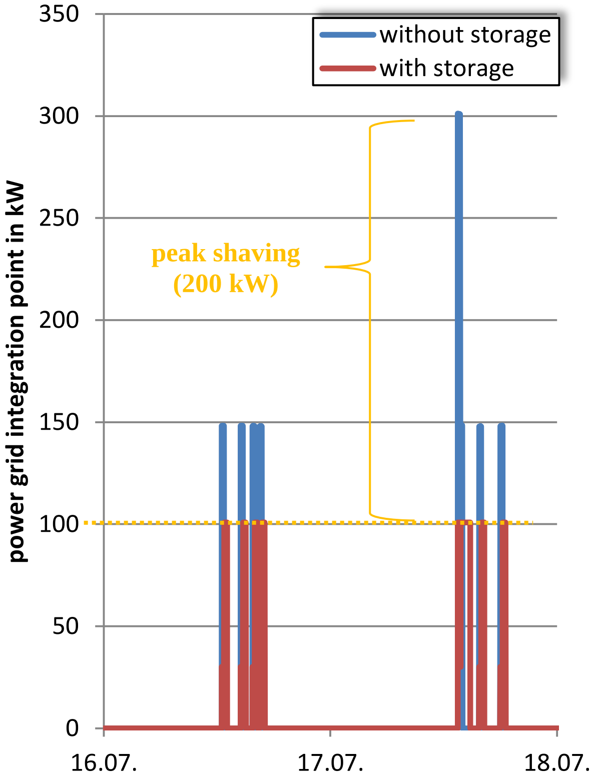

Figure 13. Power grid integration point

The voltage is in the allowed range without storage. The storage supports only the reduction of the capacity utilization.

VI. CONCLUSION

A high number of charging stations and the increase of charging power will be problematic for the existing LV grids. Expensive grid reinforcement will be necessary.

PV-systems usually have rated powers in the range of home charging stations. Therefore PV-systems could be used in conjunction with EVs for an improved self-consumption and the power at the grid connection point could be reduced. The main problem is that the maxima of feeding by PV-systems and charging of EVs are at different times. Using storages is an approach for peak shaving in this context. At midday the storage is charged by the PV-system. In the evening it discharges while charging the EV. The results show an improvement in the considered grid by using storages. The voltage range and capacity utilization of some equipment are exceeded after integration of PV-systems and charging stations for EVs. By means of buffer storage the exceedance can be prevented. The used storage models have the same capacity and operation mode. The optimization of these could yield an additional improvement. Providing reactive power by storage inverter or EV charging stations could be a further measure for a better integration. The charging stations in the considered grid are almost exclusively AC stations. In this charging method the onboard charging units are used. Therefore these units have to be an active rectifier in order to provide reactive power.

The buffer storage is also a good approach for high power charging station. By means of the storage a safe grid operation can be ensured and expensive grid reinforcements can be prevented in such cases.

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