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A Comparison of the Influence of Electric Vehicle Charging on Different Types of Low-Voltage Grids

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Abstract

An increasing number of electric vehicles (EV) poses new challenges to the power grid. The charging processes stress the power system as additional energy has to be supplied, especially in the already peak load time period. This additional load can result in critical network situations depending on various parameters. These impacts may vary based on market penetration, the use and charging behaviour, the charging rate as well as the grid topology and the associated operational equipment. Hence, the impact of EV on the power grid is analysed for 3 typical German low-voltage grids by applying power flow calculations. One main result is that thermal and voltage-related network overloads are highly dependent on market penetration and grid topology.

Keywords: EV (electric vehicle), battery SoC (state of charge), charging, EVSE (electric vehicle supply equipment)

1 Introduction

In the current car market there is a strong trend to electrification of the powertrain [1]. However, an increasing market penetration of electric vehicles (EV) can jeopardize the power grid as additional energy has to be supplied for the charging process. Since EV, in particular, are mainly connected to the low-voltage (LV) distribution grid, the main problems will threaten at this voltage level [2], [3], [4]. These additional loads can affect the power grid and may jepoardize network stability [5]. Especially, a decreasing power quality, power losses, deterioration of infrastructure (by exceeding thermal limits of feeders, etc.), and line congestion are potential impacts [6],[7]. The crucial influencing factors besides the spatial market penetration of EV are charging rates, EV usage and charging patterns and the grid structure and the corresponding operating equipment in the power grid [8]. Due to the usage patterns of car drivers, uncontrolled charging leads to concentrated peaks in EV load during the already existing peak load of residentials at evening hours [9],[10]. But the driving behaviour, the related simultaneity of charging processes, and the resulting peak are strongly dependent of the region considered. Consequently, the following research questions emerge:

- Are there substantial regional differences in distribution grid topologies which are relevant for EV charging?
- What are the impacts on the grids caused by an increasing market penetration of EV depending on different regions?
- How important is the concurrency factor in grid analysis?

Hence, in our contribution we consider various low-voltage grids that present typical regional differences in the grid topology, different population densities and agglomerations. The main focus of this contribution is the comparison of the influence of EV charging on different regional types of German low-voltage grids.

This paper is organized as follows. In Section 2 reference grids will be identified based on different regional structural data. All relevant parameters are identified. Section 3 gives an overview of the valid regulations for grid operation in Germany. Then, the concurrency factor and the simultaneous charging behaviour of EV will be investigated in Section 4. Section 5 gives an overview of the scenarios considered. Based on the presented low-voltage distribution grids and the concurrency factor in Section 6 the influence of EV charging on different types of low-voltage grids is considered and the results compared.

2 Low-voltage grids

Low-voltage grids differ significantly regarding their dimensions and technical performance. In [11] 86 existing low-voltage grids have been analysed in detail and typical grid structures have been identified. Thereof, representative grids have been developed. Each grid is typical for a specific population density and agglomeration. There are typical grids for rural or urban areas, for instance. In total 3 of these grids will be used in this paper to compare the impact of EV charging on low-voltage grids.
In Fig. 1, the grid structure of the grid typical for a suburban area is presented. It consists of 153 grid customers in total, which are divided in 10 feeders of different length. In comparison to the rural and campestral grid, the number of grid customers is the highest, which is typical for suburban grids. The low-voltage grid is connected to the medium-voltage (MV) grid via a 630 kVA MV/LV-transformer.

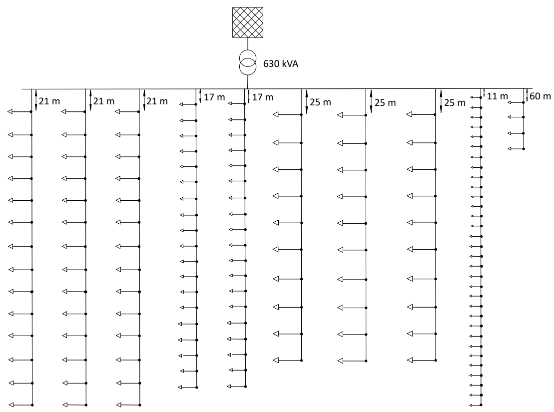

Figure 1: Grid in a suburban area

In Fig. 2 the grid which is representative for a rural area is shown. Through six feeders 57 grid customers are connected via a 400 kVA transformer to the MV grid.

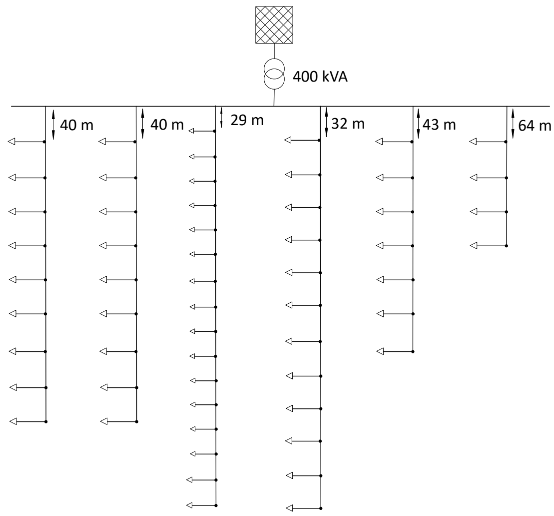

Figure 2: Grid in a rural area

In Fig. 3 a typical grid for a campestral area is shown. It consists of only two feeders including 8 grid customers. The length of the feeders in this grid is significantly higher than in the other considered grids.

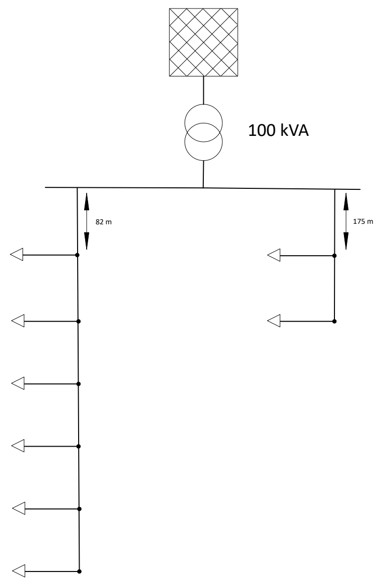

Figure 3: Grid in a campestral area

Grids for urban areas are not considered as charging of EV at home is less common there due to the fact that more people are living in rented flats and do not own a car or do not have the possibility of charging at home.
For the grid impedance, the parameters shown in Tab. 1 have been used. For all vertical lines in Fig. 1 - 3, a cable of type NAYY 4x150 mm^2 is used, for the horizontal lines the type is NAYY 4x50 mm^2. The line length is set according to [11]. The voltage at the transformer is set to the nominal voltage U_{Nominal}, which is 1 p.u. (400 V).

Table 1: Grid data

	R [Ohm/km]	L [mH/km]
NAYY 4x150 mm^2	0.206	0.256
NAYY 4x50 mm^2	0.641	0.270

3 Limits for grid operation

In order to ensure network stability, there are network operating conditions which must be observed. The standard EN 50160:2010/A1:2015 [12] defines the valid regulations for grid operation in Germany and distinguishes between guidelines with regard to voltage deviations and equipment utilization.

At the interconnection point to end consumers the maximum voltage deviation must not deviate $\pm 10\%$ of the nominal voltage. The grid operators split this deviation between the different voltage levels. In this paper, the maximum voltage drop for the LV grid is set to 5% of the nominal voltage. As the voltage at the transformer is set to U_{Nominal} (1 p.u.), the minimal allowed voltage $U_{\text{Min,Limit}}$ is 0.95 p.u. (380 V).

With regard to the thermal limitation, the nominal capacity of the operational equipment must not be exceeded. Therefore, limits of transformers and lines are taken into account in our simulations. Additional equipment (e.g. protection devices) is normally coordinated with the thermal limits of lines and transformers. Hence, an additional review of these thermal limits does not have to be considered.

4 Energy demand of the households and EV

The power grid transports and distributes energy to all clients at any time and hence also the valid limits for grid operation have to be fulfilled all the time. To check the compliance with the given limits, it is sufficient to consider only extreme points of time. If the limits are fulfilled at these times, they are considered at all the other times, too. As the scope of this paper is to compare the influence of EV charging on power grids, we will consider a high-load scenario as EV are an additional load.
Considering several consumers in the power grid, it is not probable that they show their individual peak power P_{Peak} at the same time. Therefore, a concurrency factor c(n), which is depending on the number of involved grid customers n, is used to characterize the contribution of each load to the total peak load. For the calculation of the power-flow at high-load times, the power consumed at each load P(n) is calculated using the following formula:

$$P(n) = c(n) \cdot P_{\text{Peak}} \qquad \forall \ n \tag{1}$$

In comparison to a time series based approach the number of necessary power flow calculations can be reduced significantly using the concurrency factor. For each scenario, only one power flow calculation at the high-load point of time is sufficient.
In this paper, we use different concurrency factors for the power consumption of the households P_{HH}(n) and the EV P_{EV}(n) during high-load times, which are explained in the following sections. The total power consumed by a grid customer P_{Total}(n) is then calculated adding both. Consequently, we assume that the households and EV (uncontrolled charging) loads show their peak-power at the same time. This assumption is reasonable as households have the highest power demand in the late afternoon when also EV are mainly charging.

$$P_{\text{Total}}(n) = P_{\text{HH}}(n) + P_{\text{EV}}(n) \qquad \forall \ n \tag{2}$$

Besides the active power, the reactive power is also taken into account using a power factor $cos\,\theta$ of 0.95. The number of involved grid customers n, which is used to calculate the concurrency factor, depends on the limit for grid operation, which has to be verified. To calculate the utilization of the transformer, the number of involved grid customers n is equal to all grid customers in the regarded grid. To calculate the utilization of the lines and cables and the voltages, the number of involved grid customers n is the number of grid customers that are connected to the same feeder. Only these grid customers are affecting the considered values.

4.1 EV charging

When determining the impact of the charging process on the power grid, the charging power is the decisive factor. The charging power depends on the car model. The assumed distribution of charging powers in this paper can be seen in Table 2.
Market penetrations of EV by 0%, 12.5%, 25%, 37.5%, 50%, 62.5%, 75%, 87.50% and 100% will be considered in the calculations. Thereby, a penetration of 100% means that exactly one EV is connected to each grid connection point, i.e. one EV per house.
As mentioned before, we want to calculate the concurrency factor in a high-load scenario. Therefore, we are assigning input data randomly to EV to calculate the daily maximum concurrency factor for each scenario. We are doing this over the time period of one year to calculate the maximum yearly concurrency factor. As we are assigning input data randomly, this value is subject to statistical deviations. Therefore, we are determining the yearly maximum concurrency factor a 1000 times and are using the average of

Table 2: Charging power

Charging power	Share
3.7 kW	72%
11 kW	20%
22 kW	5%
44 kW	3%

these values for our calculations. The difference between the simulations of the average yearly maximum concurrency factor is lower than 0.5%.
The daily maximum concurrency factor is calculated as follows:

1. The number of EV in each low-voltage grid is calculated multiplying the number of household with the penetration of EV. The EV are split between the different feeders according to the number of households in each feeder.

2. In the second step, values for the charging power P_{Char}, energy capacity E_{Cap} of the battery and energy consumption E_{Con} are assigned to each EV. In this paper, these values are set to P_{Char} = 7.06 kW (Mean value of the charging power as shown in Table 2), E_{Cap} = 15.7 kWh and E_{Con} = 14.1 kWh/100km. The values are set to representative values for the German EV market.

3. To calculate the daily concurrency factor, now an arrival time T_{Arr} is assigned to each EV randomly using the probability distribution shown in Tab. 3.

Table 3: Arrival Time

Arrival time	Probability	Arrival time	Probability
0:00 - 1:00	1.1%	12:00 - 13:00	5.4%
1:00 - 2:00	0.1%	13:00 - 14:00	5.1%
2:00 - 3:00	0.1%	14:00 - 15:00	5.1%
3:00 - 4:00	0.9%	15:00 - 16:00	6.7%
4:00 - 5:00	1.3%	16:00 - 17:00	9.1%
5:00 - 6:00	2.0%	17:00 - 18:00	10.1%
6:00 - 7:00	4.0%	18:00 - 19:00	7.1%
7:00 - 8:00	4.6%	19:00 - 20:00	6.8%
8:00 - 9:00	3.6%	20:00 - 21:00	4.3%
9:00 - 10:00	3.4%	21:00 - 22:00	4.1%
10:00 - 11:00	4.9%	22:00 - 23:00	2.3%
11:00 - 12:00	6.9%	23:00 - 24:00	1.0%

4. In the fourth step, the stored energy E_{Sto} in the battery of each EV before the charging process is determined. The stored energy depends on the chosen scenario and is therefore explained in detail in Chapter 5.

5. The duration of the charging process T_{Dur} is determined as follows:

$$T_{\text{Dur}} = \frac{E_{\text{Cap}} - E_{\text{Sto}}}{P_{\text{Char}}} \tag{3}$$

6. The end-time of the charging process T_{End} is calcuated using the arrival time T_{Arr} and the duration of the charging process T_{Dur}.

$$T_{\text{End}} = T_{\text{Arr}} + T_{\text{Dur}} \tag{4}$$

7. In the seventh step, the maximum daily concurrency factor is determined considering T_{Arr} and T_{End} of each EV. At first, the maximum number of simultaneously charging cars is reviewed for the grid and each feeder. This number is then divided by the total number of cars in each grid or feeder. Finally, the result is multiplied by a factor of 0.78 to calculated the maximum daily concurrency factor. Most cars are not used daily, this is taken into account by the factor 0.78 [13].

4.2 Energy consumption of households

In addition to the EV charging, also the energy consumption of the households is included to calculate the load-flow in the low-voltage grids. For each household a peak power P_{Peak} of 8 kW is assumed. According to [14], the concurrency factor of several households $c_{HH}(n)$ can be approximated with

$$c_{HH}(n) = s + (1 - s) \cdot n^{-3/4} \qquad \forall \; n \tag{5}$$

where n is the number of households. The factor s is deduced from measurement data and following [14] between 0.12 and 0.15. As no exact data is available for the used reference grids, we set this value to 0.15.

5 Scenarios

By means of a comprehensive analysis, all important aspects and parameters concerning the grid impacts of EV should be taken into account. The aim is to define probable future-oriented and crucial scenarios. Therefore, the core parameters market penetration, charging power distribution, battery capacity, charging time, concurrency factor, SoC, and the additional charging possibilities are considered. In the scope of this contribution three scenarios, generated from the parameters presented above, are analysed. An overview of the different scenarios and the associated parameters is given in Table 4.

Table 4: Scenario parameter

	Scenario 1	Scenario 2	Scenario 3
Charging power distribution	√	√	√
Battery capacity	√	√	
Charging time			
SoC 100%	√	√	
Driving distance 40 km			√
Concurrency factor	√	√	√
E_{Sto}=0%		√	

For all three scenarios, the market penetrations mentioned in Chapter 4.1 are taken into account. The corresponding charging power distribution is presented in Tab. 2.

Scenario 1 and Scenario 2 represent the case of ”daily full charging”. In these two cases, it was attempted to create realistic user profiles. Based on these profiles all EV are fully recharged each day (SoC 100%) under consideration of the concurrency factor and the battery capacity. In Scenario 1, the calculation of the stored energy E_{Sto} in the battery before the charging process is based on these driving profiles and is following the distribution in Fig. 4. In comparison, in Scenario 2 the E_{Sto} is assumed to be 0% at the start of the charging process.

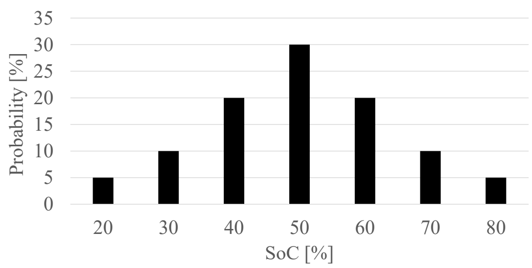

Figure 4: SoC Distribution at the beginning of the charging process

In Scenario 3, it is assumed that all EV have a daily driving distance of 40 km. Therefore, the required recharge quantity corresponds exactly to the energy quantity consumed for the 40 km. Based on the consumption of the EV and the charging rate, the charging duration was calculated for the daily driving distance average of 40 km.

6 Results

The results in this section have been produced doing load-flow calculations in MATPOWER [15]. The low-voltage grids have been modelled as described in Chapter 2 and the loads have been modelled as described in Chapter 4.

6.1 Concurrency factor

In Fig. 5, the calculated concurrency factors of the EV charging for the rural grid and Scenario 1 can be seen. In case of a penetration of 0%, the concurrency factor is set to 0.78. The concurrency factor for the whole grid includes all EV in the grid, whereas the concurrency factor for the feeders just include the corresponding number of EV in each feeder.
As the concurrency factor for the whole grid considers the highest number of EV, it is the lowest factor for all penetrations. The concurrency factors for the different feeders increases with decreasing number of households. As the number of EV is increasing for higher penetrations the concurrency factor is decreasing.

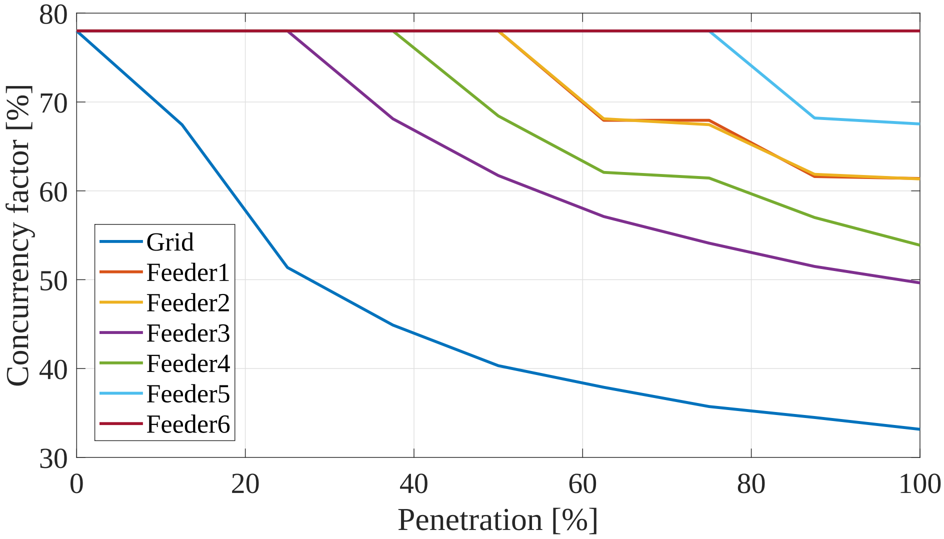

Figure 5: Concurrency factors for the rural grid in Scenario 1

In Fig. 6, the concurrency factor for the whole rural grid is shown for the Scenarios 1 - 3. Hence, the blue line in Fig. 6 is equal to the blue line in Fig. 5. In comparison to the other scenarios, Scenario 2 (orange) has the highest concurrency factor for all penetrations. In Scenario 2, we assume that the battery is completely empty before starting each charging process. This results in the longest charging duration and therefore in the highest concurrency factors. Scenario 1 & 3 cause similar results, whereas the concurrency factor for Scenario 1 is slightly higher for all penetrations.

6.2 Grid utilization

In Fig. 7 the maximum utilization of the transformer and the lines as well as the minimum voltage in the rural grid is shown for the different scenarios. Even for a penetration of 100% no grid limit is violated. Comparing the different scenarios, Scenario 2 causes the biggest impact on the rural grid. This is a consequence of the higher concurrency factors in Scenario 2 (see Chapter 6.1). Considering Scenario 2 and penetration of 100%, the transformer utilization is increased from 23.0% to 66.7% and the minimum voltage is reduced from 395.14 V to 385.40 V through EV charging. Hence, EV charging has a significant impact on the rural grid, although no grid limits are violated.

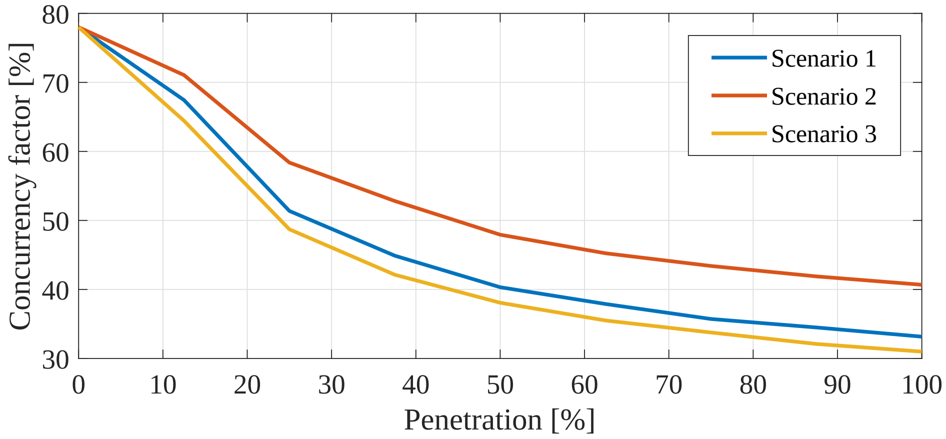

Figure 6: Concurrency factor for the whole rural grid for different scenarios

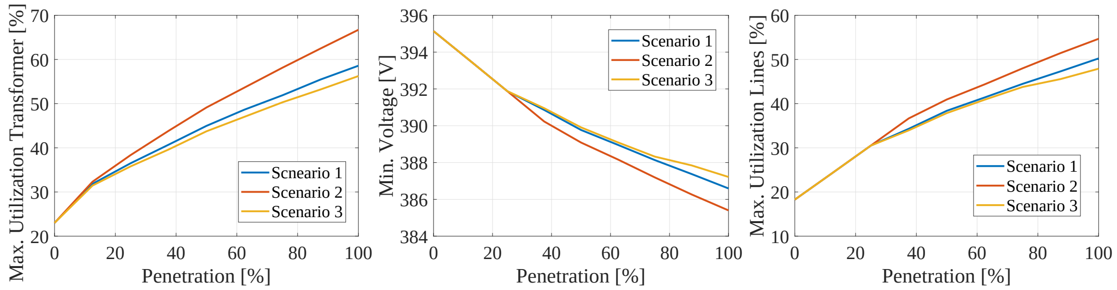

Figure 7: Grid utilization for different penetrations of EV in the rural grid

In addition, in Fig. 8 the maximum utilization of the transformer and the lines as well as the minimum voltage in the rural grid is shown for the different scenarios. Also for the suburban grid no grid limit is violated for all penetrations. In comparison to the the rural grid, the maximum utilization of lines and the transformer is higher and the minimum voltage is lower. These results are also valid if no EV (penetration = 0%) are considered.

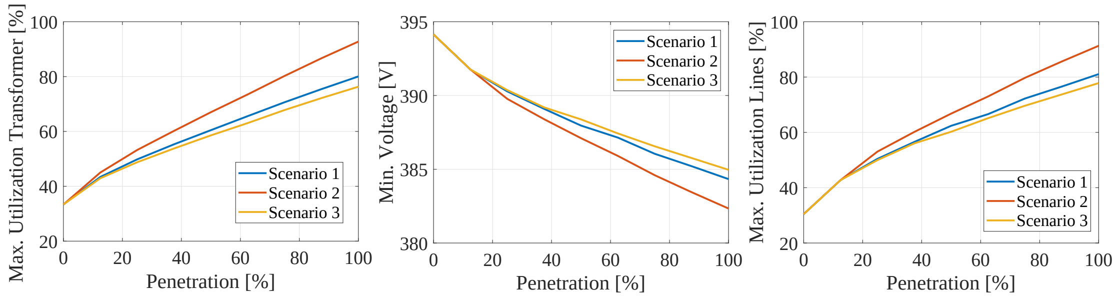

Figure 8: Grid utilization for different penetrations of EV in the suburban grid

Finally, in Fig. 9 the maximum utilization of the transformer and the lines as well as the minimum voltage in the rural grid is shown for the different scenarios. For all penetrations no grid limits are violated.

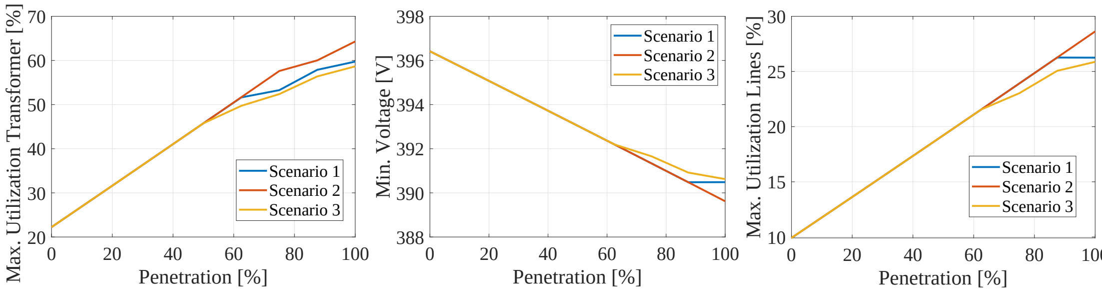

Figure 9: Grid utilization for different penetrations of EV in the campestral grid

The maximum utilization of the lines is lower than the utilization of the transformer for most cases. Only when considering a penetration level of 100% in the suburban grid, for Scenario 1 and 3 the maximum line utilization exceeds the transformer utilization slightly.

To compare the impact of the voltage limit in comparison to the transformer utilization limit, the Voltage Limit Utilization (VLU) is introduced, which is calculated as follows:

$$VLU = \frac{U_{\text{Nominal}} - U_{\text{Min}}}{U_{\text{Nominal}} - U_{\text{Min,Limit}}} = \frac{400\,V - U_{\text{Min}}}{400\,V - 380\,V} \tag{6}$$

U_{Min} is the minimal voltage in the grid for the considered scenario.

In Tab. 5, the Voltage Limit Utilization is compared to the transformer utilization. If the Voltage Limit Utilization is higher than the transformer utilization, the voltage limit is more critical regarding a violation of the limits than the transformer utilization. For the campestral and suburban grid, the Voltage Limit Utilization is lower than the transformer utilization. In contrast to that the Voltage Limit Utilization is higher than the transformer utilization for the rural grid.

Table 5: Comparison of voltage limit and transformer utilization for Scenario 2 and a penetration of 100%

Grid	U_{Min}	Voltage Limit Utilization	Transformer Utilization
Campestral grid	389.62 V	51.9%	64.3%
Rural grid	385.40 V	73.0%	66.7%
Suburban grid	382.34 V	88.3%	92.8%

In Fig. 10, the grid limits are shown for the different grids considering only Scenario 1. As mentioned before, the suburban grid is the most critical regarding the violation of grid limits. For the transformer utilization, the rural and campestral grid show a similar course, whereas the rural grid is more critical considering the minimum voltage and the utilization of the lines.

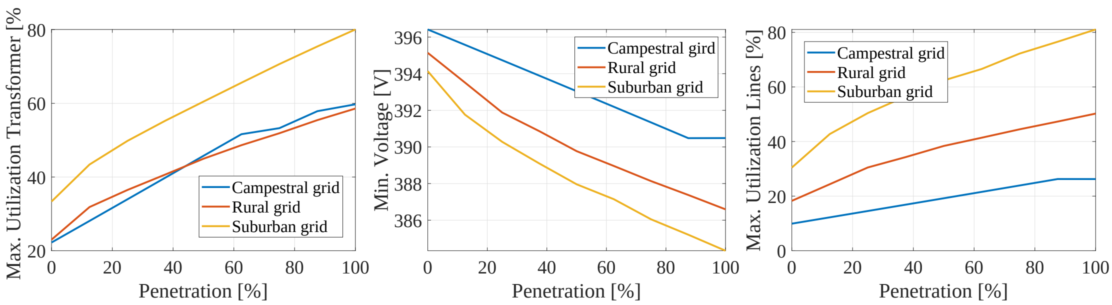

Figure 10: Grid utilization for different penetrations of EV for different types of LV grids in Scenario 1

7 Summary and Outlook

In this paper, three low-voltages grids that are typical for a specific agglomeration in Germany have been modelled including the power demand for households and EV charging. For the EV charging, concurrency factors have been calculated using realistic input data to determine the maximum yearly power demand. The developed models have been used to perform load-flow calculations to determine the impact of the EV charging on the grid operation. Therefore, the compliance with limits given in standards is verified.
As an overall result, it can be said that EV charging has a significant impact on the low-voltage grids, although for penetrations until one EV per grid connection point no limits are violated considering our input data.
In the future, higher penetrations are possible assuming that more than one EV is connected to a grid connection point (e.g. in an apartment house). Additionally, a trend to higher charging powers and energy capacities can be observed in the last years. This would also increase the impact of EV charging on low-voltage grids. Modern houses often use heat pumps for their heating in Germany. This would increase the energy consumption of the households and especially the peak power per household P_{Peak}. The input power of a heat pump is in a comparable order like P_{Peak} (8 kW) in this paper. Summarizing the future developments of the input data, it can be found that the utilized input data, which is representative for the current situation, only allows quite conservative statements about future impacts of EV on low-voltage grids.
The authors plan to include the mentioned effects about future developments in their future work. Additionally, further low-voltage grids will be regarded to analyse the impact of EV charging.
To be able to supply their clients reliable in the future, grid operators have to consider these developments. In particular, it is necessary to have trustworthy models of the low-voltage grids as well as information about charging points with the corresponding charging power in the low-voltage grids. Then, reliable decisions about the supply of large numbers of EV with charging energy are possible.

Acknowledgments

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References

[1] International Energy Agency (IEA) *Global EV Outlook*, Paris, 2018.

[2] Clement-Nyns, K., E. Haesen, J. Driesen, *The impact of charging plug-in hybrid electric vehicles on a residential distribution grid*, IEEE Trans. Power Syst., vol. 25, pp. 371-380.

[3] Clement-Nyns, K., E. Haesen, J. Driesen, *The impacts of vehicle-to-grid on the distribution grid*, Electric Power Systems Research, vol. 81, pp. 185-192, 2011.

[4] Habib, S., M. Kamran, U. Rashid, *Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks-A review*, Journal of Power Sources, vol. 277, pp. 205-214, 2015.

[5] Yong, J.Y., V.K. Ramachandaramrthy, K.M.Tah, N. Mithulananthan, *A review on the state-of-the-art technolgies of electric vehicle, its impacts and prospects*, Renewable and Sustainable Energy Reviews, vol. 49, pp. 365-385, 2015.

[6] Rolink, J., *Modellierung und Systemintegration von Elektrofahrzeugen aus Sicht der elektrischen Energieversorgung*, PhD dissertation, Dortmund, 2013.

[7] Shareef, H., Md.M. Islam, A. Mohamed, *A review stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles*, Renewable and Sustainable Energy Reviews, vol. 64, pp. 403-420, 2015.

[8] Tie, C.H., C.K. Gan, K.A. Ibrahim, *The impact of Electric Vehicle Charging on a Residential Low Voltage Distribution Network in Malaysia*, IEEE Innovative Smart Grid Technologies, 2014.

[9] Nobis, P., *Entwicklung und Anwendung eines Modells zur Analyse der Netzstabilität in Wohngebieten mit Elektrofahrzeugen, Hausspeichersystemen und PV-Anlagen*, PhD disseration, TU Mnchen, 2016.

[10] Babrowski, S., H. Heinrichs, P. Jochem, W. Fichtner, *Load shift potential of electric vehicles in Europe*, Journal of Power Sources, vol. 255, pp. 283-293, 2014.

[11] Kerber, G., *Aufnahmefähigkeit von Niederspannungsnetzen für die Einspeisung aus Photovoltaikkleinanlagen*, PhD dissertation, TU München, 2011.

[12] DIN e.V., *Voltage characteristics of electricity supplied by public networks*, German version EN 50160:2010/A1:2015, 2016.

[13] Figenbaum, E., M. Kolbenstvedt, *Learning from Norwegian Battery Electric and Plug-in Hybrid Vehicle users*, Institute of Transport Economics, Norwegian Centre for Transport Reasearch, 2016.

[14] W. Kaufmann, *Planung öffentlicher Elektrizitätsverteilungs-Systeme*, VDE-Verlag GmbH, 1995

[15] R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, *MATPOWER: Steady-State Operations, Planning and Analysis Tools for Power Systems Research and Education*, IEEE Transactions on Power Systems, vol. 26, no. 1, pp. 12-19, Feb. 2011.

[16] Wenig, S., W. Schulze, G. Moraleda, T. Gebel, M. Suriyah, T. Leibfried, G. Walker, *Probabilistische Auswertung des Einflusses zukünftinger Elektromobilität auf vorstädtische Netze in Süddeutschland*, 3.OTTI-Konferenz, Zukünftige Stromnetze für Erneuerbare Energien, Berlin, Germany, 2016.

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