Comparison of Electromobility-Impacts on the Low-Voltage Level in Different Grid Regions

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Abstract—**The analysis of electromobility induced grid impacts enables a premature identification of the need for grid expansion. Three various low-voltage grids are considered separately in detail in order to compare the effects of electric vehicles in different regions. For that purpose, inadmissible voltage deviations and thermal line utilizations are determined by using long-term load flow simulations and assessed by means of standardized limits according to EN 50160. Regarding thermal line overloads triggered by peak loads, the analyzed grid regions show similar results. Nevertheless, the potential for implementing a future number of electric vehicles deviates significantly: While the urban grid on the outskirt shows little impact on voltage characteristics, even low e-mobility penetrations cause critical voltage deviations in suburban and rural grids.**

Keywords: electromobility induced grid restrictions, low-voltage level, grid regions

I. Introduction

Despite numerous environment protection directives, the amount of emitted greenhouse gases in Austria raised between 1990 and 2016 by 1,2 %. The increase of traffic related emissions was triggered by higher mileage of passenger cars and trucks. Consequently, the traffic sector was responsible for 28,8 % of emitted greenhouse gases in 2016. [1]

As a countermeasure, the accelerated expansion of electromobility represents an important cornerstone in Austria's climate and energy strategy for 2030, in which decarbonisation should be achieved, inter alia, by a carbon free traffic sector until 2050 [2]. Political measures like this aim for an increasing number of electric vehicles (EV) in the upcoming years: According to the Austrian Federal Environment Agency, ideal political and environmental framework conditions could result in an EV-penetration of 4 % in 2020 [3].

The future development of e-mobility is based on the extent of an available charging infrastructure. Most EV-charging processes take place at private charging stations [4-6]. Considering that, the divergence of private charging possibilities in rural and urban areas [7] could influence the progress of electromobility in various regions differently. Currently, the share of electrified vehicles deviates regarding area: the majority of private (78 %) and commercial (69 %) EV-users are located in cities with less than 100.000 inhabitants [8].

The consequences for power grids are hard to identify by the use of measurements only due to today's relatively low electric vehicle penetration of 0,39 % (2018) [2]. Despite the early stage of electromobility in Austria, future challenges for distribution grids - in particular on the low-voltage level [9] - have to be considered prematurely. Therefore, this study compares the impacts of future electric vehicle numbers on different grid regions with regard to voltage deviation and line utilization. The methodology of executed load-flow simulations (Section II), an extract of previous results (Section III) and a conclusion of gathered key insights (Section IV) are presented in this paper.

II. Methodology

A. Grid modelling and simulation parameters

Long-term load flow simulations using the software NEPLAN [10] are applied for analyzing the impacts of future electromobility on the low-voltage level. A time resolution of 1 minute enables the consideration of short-term peak loads. The grid modelling (Fig. 1) bases on real grid data, provided by a distribution grid operator, in order to identify critical grid elements with a high level of detail. The selected low-voltage grids are classified according to location and population density: an urban grid on the city outskirt (which has to be differentiated from city-centered grids), a suburban and a rural grid. A summary of characteristic parameters of all three grids is presented in Table I. The most relevant differences between the simulated urban (outskirt), suburban and rural grid are nominal transformer power, the number of supplied feeders and the number of grid connection nodes.

B. Modelling of consumer load profiles

The modelling of consumer load profiles for each grid connection node is based on a two-step procedure. In a first step, industrial and agricultural load profiles are modelled by phase-symmetrical standard load profiles according to [11] and scaled using real annual consumptions provided by a distribution grid operator.

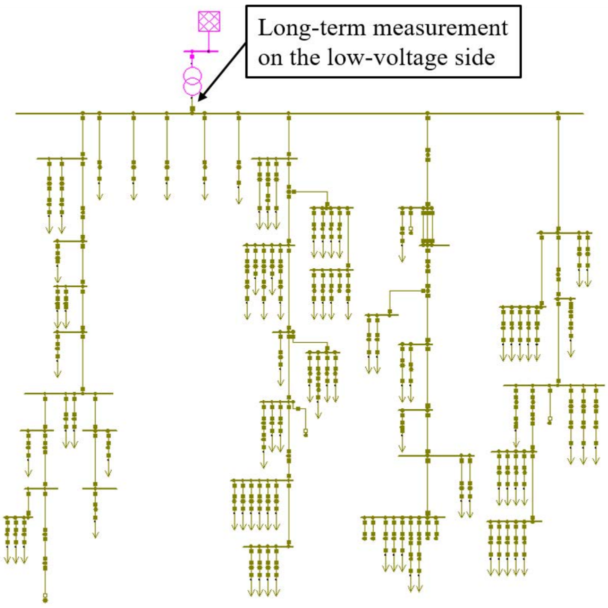

Figure 1: Grid-topology of the NEPLAN model including the measuring point for the analyzed suburban low-voltage grid

TABLE I. COMPARISON OF CHARACTERISTIC GRID PARAMETERS IN DIFFERENT REGIONS

Parameter	Grid region		
	Urban (outskirt)	***Suburban***	***Rural***
Nom. Transformer power	630 kVA	250 kVA	100 kVA
Number of feeders	14	9	3
Number of grid connection nodes	80	87	18

The behavior based load profile generator by N. Pflugradt [12] is applied in a second step in order to create 1-minute resolved loads for single households. More precisely, this tool generates long-term power profiles for a range of household devices. The phase distribution of single-phase devices enables an asymmetrical modelling of household load profiles and thereby the simulation of unbalanced grid conditions. Symmetrical industrial- and agricultural loads as well as asymmetrical household loads are aggregated for each grid connection node. Furthermore, the modelled load profiles are validated and calibrated on the basis of real data. For that purpose, active and reactive power are measured on the low-voltage side of the local transformer (Fig. 1) for several weeks.

C. Modelling of EV load profiles

Two various EV-scenarios (Tab. II) regarding charging power and single- or multi-phase charging are simulated within this study in order to investigate the relation between grid impact and charging parameters. Scenario A represents state of the art private charging procedures using single- or multi-phase charging with 3,7 – 22 kW charging power depending on the EV-model and the available charging station. Three-phase charging with 3,7 kW (Scenario B) can be considered as optimal charging scenario with respect to the prevention of peak load and power unbalance. In addition, this scenario covers an area-wide phase-balancing of several single-phase chargers. For both scenarios the modelling of EV load profiles is based on time-resolved charging patterns and measured charging data of 21 different

TABLE II. SCENARIO-DEPENDENT CHARGING PARAMETERS

Parameter	EV-Scenario	
	Scenario A	***Scenario B***
Charging power	3,7 – 22 kW	3,7 kW
Charging phases	Single- and Multi-phase	Three-phase

EV models taking active and reactive power-demand into account. Assuming, that the majority of charging processes take place at private charging stations [4-6], this study focuses exclusively on private EV charging. A probabilistic approach according to Wieland et al. [13] allows realistic modelling of temporal charging behavior for each EV-user. Therefore, the following parameters are determined by statistical data and random numbers: EV-model (battery capacity and electric consumption), installed charging power, travelled distance and time of arrival. The describing of user's mobility behavior by the latter two parameters is based on real-life data.

While this stochastic modelling characteristic enables the consideration of realistic charging patterns, it entails the risk for excluding the most critical grid conditions. To prevent that, the described procedure is executed for a defined number of iterations. For analyzing worst-case grid conditions, the most critical load profile with respect to peak load is identified for each EV from a range of iterations and used for further load flow simulations. The future development of grid impacts as a result of increasing EV numbers can be deviated by the simulation of several penetration rates (0 – 60 %).

III. RESULTS

A. Evaluation criteria for identifying critical grid elements

The evaluation of electromobility-impacts on low-voltage grids is based on the identification of critical grid elements in each grid region by consideration of following criteria:

1) *Voltage deviation according to EN 50160 [14]: 95 % of all 10-minutes mean values of one week have to be within [-10 %; +10 %] of the nominal voltage*

2) *Thermal line utilization within the line-specificion*

Due to the selection of worst-case load profiles based on peak loads, this study excludes the evaluation of inadmissible voltage unbalance according to EN 50150 [14]. Critical grid nodes and grid lines are determined by contrasting with named criteria. The comparison of consequences for different grid regions is illustrated by the proportion of critical elements (Fig. 2 and Fig. 3) in the following chapter.

B. State of the art charging procedures (Scenario A)

The results of Scenario A show significant differences between the analyzed grid models with regard to voltage deviations (Fig. 2). The urban (outskirt) low-voltage grid is able to integrate an EV-penetration of 60 % (and higher) avoiding inadmissible voltage deviations according to [14].

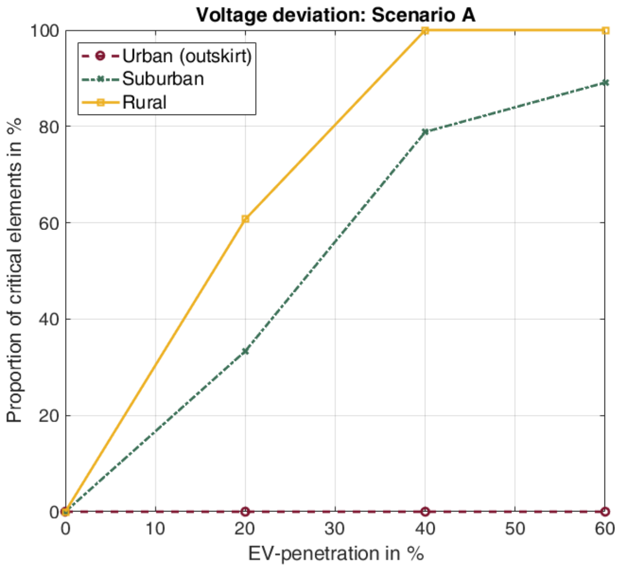

Figure 2: Proportion of critical grid elements in regards to voltage deviation

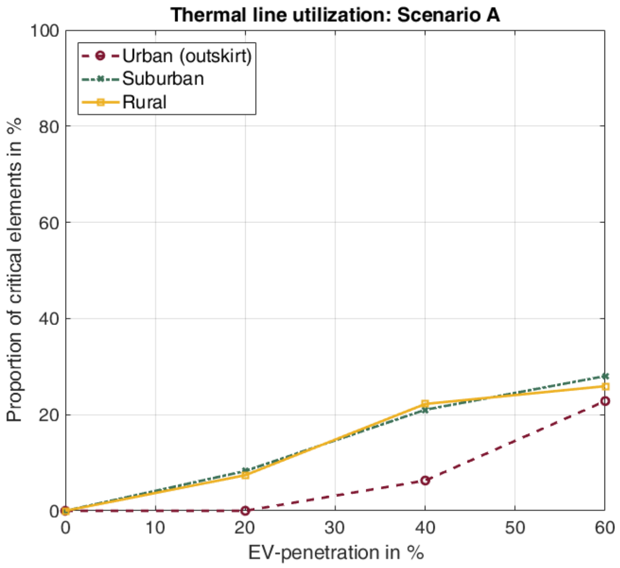

Figure 3: Proportion of critical grid elements in regards to thermal line utilization

In contradiction, an EV-penetration of 20 % results in impermissible voltage deviations in 33 % (suburban) and 61 % (rural) of all grid nodes. The most significant voltage drops occur in grid nodes at the end of long feeders. As a result, the high influence on load-caused voltage decreases in the suburban and rural grid is based on high feeder length compared to the urban (outskirt) grid.

All the analyzed grids show similar impact on thermal line utilization (Fig. 3). Peak loads at a penetration rate of 20 %, triggered by the temporal overlap of household- and EV loads, result in thermal overloads in 0 % (urban), 8 % (suburban) and 7 % (rural) of all grid lines. The higher the EV-penetration, the smaller the differences between grid regions regarding thermal line utilization. Considering an EV-penetration of 60 %, the proportion of critical grid lines is quite similar – 23 % (urban), 28 % (suburban) and 26 % (rural).

C. *Three-phase charging with reduced charging power (Scenario B)*

Three-phase charging with reduced power avoids the exceedance of grid capacities in all of the investigated low-voltage grids. An area-wide change to these charging parameters (cf. Table 2) enables the compliance with the named criteria even with a penetration rate of up to 100 %. This scenario demonstrates an easy to implement way to counteract future grid expansions by a load-based limitation of available charging power without reducing customer comfort.

IV. CONCLUSION

This study provides region-dependent grid impacts of electric vehicles by the simulation of three selected low-voltage grids. The influence of future electromobility on voltage characteristics deviates significantly regarding various grid areas. The investigated urban (outskirt) grid shows high capacity for integrating electric vehicles considering present charging technologies. With respect to inadmissible voltage deviations according to EN 50160, even a full implementation of electric vehicles can be faced without grid expansion measures. In contrast, critical voltage deviations occur in the suburban- as well as in the rural grid even at low EV-penetration. Thermal overload of grid lines can be avoided by expansion measures in about 25 % of all grid lines.

Furthermore, even a penetration of 100 % can be integrated in the analyzed distribution grids by adapting charging parameters. The simulation of three-phased charging with reduced power demonstrates the potential of regulating the available charging power in accordance to critical grid situations without any reduction in customer comfort.

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