Impact of Increasing Electric Mobility on a Distribution Grid at the Medium Voltage Level

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***Abstract*—The increasing number of charging stations for electric vehicles and renewable energy in power grids are suspected to cause a decrease of supply security and grid stability. An easy to apply power grid model based on the cellular approach is presented in order to study interactions between electric mobility and renewable energy plants at medium voltage level.**

power grid, electric vehicles, renewable energy, cellular approach, load flow analysis

I. Introduction

To achieve the aims of decarbonisation, it is necessary to change to alternative drives in the field of traffic. For example electric mobility. In case of this, it is important to provide the increasing energy demand for charging processes from renewable energy. In order to establish electric mobility, it`s necessary to set up an area-covering charging infrastructure. This integration of an increasing number of electric vehicles in existing grid infrastructures represents a new challenge. To identify optimum installation sites for charging stations of various size concerning charging power, the overlap of the existing demand of households and industry with future charging processes and the interaction with renewable energy plants with its fluctuating energy generation need to be considered.

During the FFG (Austrian Research Promotion Agency) research project "Move2Grid" a grid-model based on a cellular approach for an urban distribution grid at medium voltage level (approximately 30.000 inhabitants) is developed. The cellular approach method for grid infrastructure for power-, heat- and gas grids, is a flexible analysis method with the primary objective of simplifying complex grid structures. It represents a compromise between accuracy and calculation time. [1] [2] Following the development of this model and the determination of photovoltaic potentials as well electric mobility charging curves, load flow calculations with annual load profiles are performed for different scenarios and are benchmarked in terms of equipment overloads and deviations of the voltage range. The scenarios (see 0consider different degrees for the implementation of photovoltaic potentials and for electric mobility penetration. Furthermore, residual loads and the level of self-sufficiency are determined and analysed. The residual load (P_{Res}), see equation (1), is defined as the demand minus the local renewable energy production. The level of self-sufficiency (SS) is defined by equation (2).

$$P_{Res}(t) = P_{Demand}\,(t) - \; P_{Renewable\ Production}\,(t) + \cdot P_{KWK}(t) \qquad (1)$$

$$SS = \frac{E_{Production} + E_{PV\ Potential,used}}{E_{Demand} + E_{electric\ mobility.used}} \qquad (2)$$

In order to avoid equipment overloads and deviations of the voltage range causing the necessity of grid expansion, demand side measures and the use of electrical storages are implemented in the power grid model. The analysis of the discussed parameters bases on load flow calculations.

II. Methodology

A. Development of a distribution grid model

To design a simplified grid model based on the cellular approach, the 1st step is a cell classification in consideration of the grid topology. Based on the cell classification and the original topology of the power grid, all electrical equipment (transformers, lines, cables, etc.), consumers, producers and storage units are identified and classified. Figure 1 shows, next to the cell classification for this task, in the top right corner examples for the identification of consumer, producer and storage units on the level of local grid transformers.

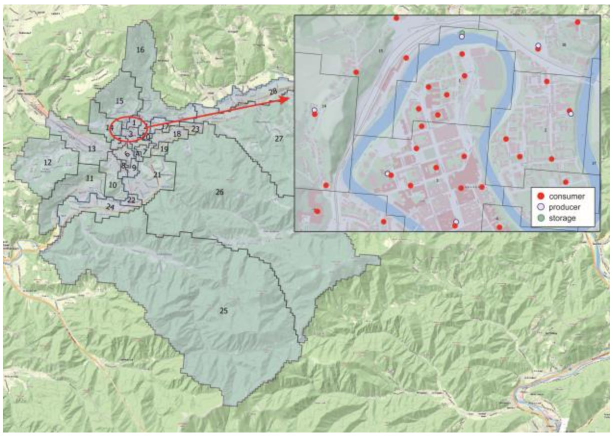

Figure 1. Cell classfification Leoben, Austria [6]

In a 2nd step, the maximum and minimum power peak and the time resolved data of all consumers, producers and storage units within a cell is aggregated into energy nodes. Based on the annual energy demand of each cell, annual load profiles are determined by the use of standard load profiles from the BDEW [3] and synthetic load profiles from the Austrian regulation agency (e-control) [4]. In a 3rd step, the Software NEPLAN [5] is used to design the power grid model. Finally, the accuracy of the model is checked by the comparison of the load flow for the highest possible load-case between model-results and existing grid measurements. [6]

The result is a simplified model representing the status quo of the distribution grid at medium voltage level, which and enables time resolved load flow calculations with annual load profiles. After the development of the model, it is possible to integrate electrical production potentials, charging stations for the electric mobility and other elements allowing a flexible use (heat pumps, power to heat plants, etc.). This enables the determination of the cells that are susceptible for grid instabilities. Those cells can be analysed for the grid-related impacts of a specific technology.[6]

B. Determining photovoltaic feed in potential

The determination of time resolved photovoltaic potentials is based on data from the “Styrian Solar-Roof Land Register” [6] and radiation and temperature data from the Austrian Central Institute for Meteorology and Geodynamics (ZAMG) [8]. The land registry contains all roof areas, which are suitable for solar-energy production. The areas are divided according to their size, inclination and shadowing into “very good” and “good” roof areas. Based on the cell classification previously done, all suitable roof areas are aggregated in energy nodes (located at the centre-point of each accordant cell). In combination with the radiation and temperature data we calculated time resolved annual photovoltaic potential profiles for each cell by using MATLAB [10]. The results can be altered up to a potential-integration rate of 100%. [9]

C. Determining load profiles for charging stations

The flow diagram in Figure 2 shows the basic steps for determining load profiles occurring from charging stations. In step 1, traffic analysis, which is received from traffic planners, is processed and aggregated at cell level. This analysis differs between seven user groups. The classification for the user groups is divided by the purpose of the trip. For example, a distinction is made between a trip home, a trip to work, a trip for shopping, etc.

For each cell, in addition to the number of trips per day, the distribution over the distance travelled is obtained. Furthermore, the origin-destination matrices according to Bosserhoff are prepared for further modelling. These matrices are based on the statistical evaluation of traffic behaviour for a specific time interval and area. In step 2, probabilistic approaches according to Probst [11] and Wieland [12] are used to determine the distance travelled, the time of arrival and departure for each trip. In step 3, the time resolved load profiles with focus on lithium ion batteries for the selected simulation period are modelled. For this purpose, the charging power (P) depending on the state of charge (SOC) is calculated by (3) for each trip. Initially the battery is charged by a constant current (meaning a constant power (Pconst)). At the change-over point (s) constant voltage charging follows. The correction factor (kL) considers the nominal capacity and the switch off of the charging power [13]. Finally, all trips are aggregated to one time resolved load profile located in the cell’s centre-point.

$$P = P_{const} \cdot e^{\frac{s-SOC}{k_L}} \quad (3)$$

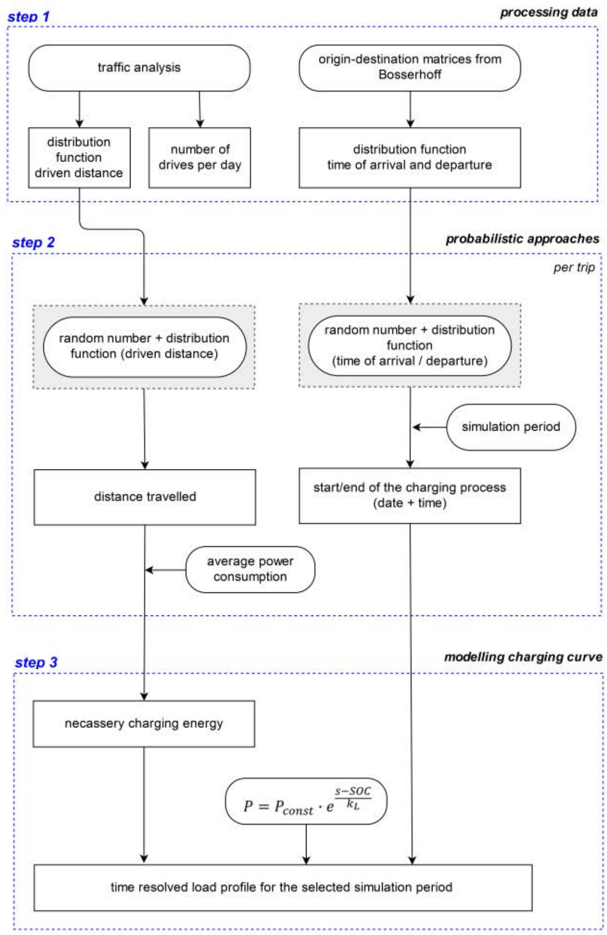

Figure 2. Methodology for the determination of time resolved annual load profiles for charging stations

III. RESULTS

For the results presented below, different scenarios are considered. Table I. gives an overview of the scenarios. Scenario 1 describes the status quo. The existing demand and production is combined by using standard load profiles and measured data for each cell. Based on the status quo scenario, photovoltaic potentials and load profiles for charging stations are integrated into the model for different rates of penetration (scenario 2 to scenario 4).

TABLE I. OVERVIEW SZENARIOS

Overview scenarios				
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
photovoltaic potential (PV)	0	0	25	50
electric mobility (EV)	0	100	100	100

A penetration of 100% electric mobility means that every private vehicle is considered as an electric car. A penetration of 100% Photovoltaic potential indicates that every roof area, which is suitable for solar-energy production, is used for photovoltaic generation. For the different rates of penetration of both, a linearization based on the 100% scenarios across all cells is assumed. However, in the case of electric mobility, the modelling of the load profiles for each penetration rate must be repeated for the calculation of lower penetrations, because probabilistic nature of calculation, in order to avoid the equalisation of charge peaks. Furthermore, the presented scenarios consider 1-phase charging with 3.7 kW and 3-phase charging with 11 kW in the low voltage level depending on the user group. For example, 1-phase charging is selected for the user group “trip home”, 3-phase charging for the user group “trip for shopping”, respectively. Moreover, it is assumed that the energy demand therefore is evenly distributed over all three phases in the medium voltage level (distribution grid).

Besides the determination of the self-sufficiency level (see equation (2)) load flow calculations with annual load profiles are performed and are benchmarked in term of equipment overloads and deviations of the voltage range for each scenario. This is done by using a newly developed evaluation tool. With this tool, a quick determination of areas which are susceptible for equipment overloads and deviations of the voltage range, as well as the exact time of them and their duration for further analyses becomes possible. After the load flow calculation with annual load profiles of the selected scenario, the result files are read into a MATLAB tool. All necessary information for further processing is read out of these files and is prepared. The first diagrams are then created automatically. These diagrams show, for example, the maximum load of all cables in the grid. Afterwards, each scenario can be examined individually or a scenario comparison can be performed. For this purpose, the desired cables or nodes are entered, which are studied in detail. Further diagrams are created for the selected equipment, as shown in Figure 3 and Figure 5, for example.

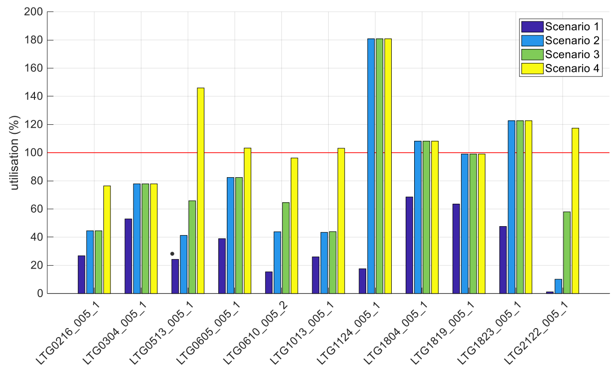

Figure 3. Comparison of the maximum utilisation of the cables with an utilisation of more than 70% in one of the presented scnerios

Figure 3, shows a comparison of the maximum utilisation of the cables with an utilisation of more than 70% in one of the presented scenarios. In addition to the impact of increasing electric mobility on the grid, the effects of the integration of PV potentials could seen. The maximum utilisation of the cables is increasing due to the higher energy demand of electric mobility. The integration of PV potentials does not lead to a change in the maximum capacity utilisation of the cable on the one hand and to an increase in it on the other. This means that there is a time difference between the feed-in PV-peak and the demand peak of electric mobility. This should be illustrated by means of Figure 4 for cell 18. Based on these results, measures should be taken on the demand side or storage opportunities should be considered to avoid expensive grid expansion. In case of cell 18, the demand peak of electric mobility is caused by the user group "trip for shopping". Since this user behaviour is difficult to influence, the integration of a storage unit is a better opportunity than controlled charging.

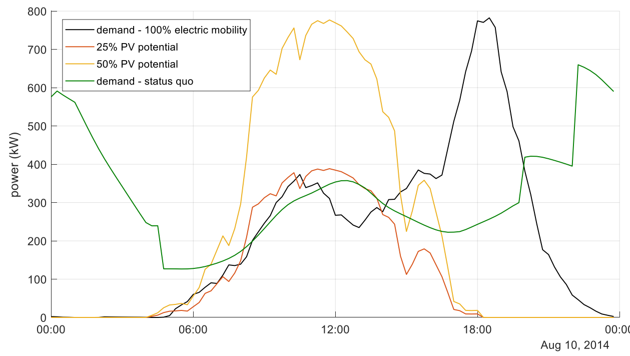

Figure 4. selected time slot of the simulation - demand vs. photovoltaic production for cell 18

The integration of PV potentials influences both the duration and maximum value of utilisation. Figure 5 illustrates the duration of cable utilisation. These cables are susceptible for overloads in scenario 2 wherein the most stressed cable (LTG1124) is overloaded for a total of 240 hours during a year (8760 hours).

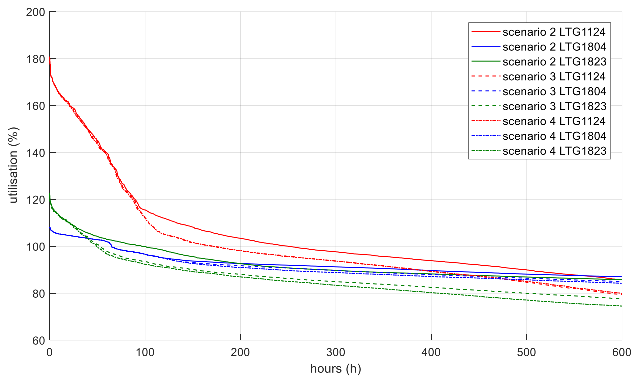

Figure 5. Duration of the utilisation of selected cables

For this cable, the duration of the overloads can be reduced to 165 hours by integrating 25% or 50% PV potential. This reduction in overload duration is caused by the summer months. In the affected cells, the electric mobility demand peaks are during the evening. In contrast to winter, the PV potentials in summer still feed power into the grid in the evening and overloads can be avoided. The duration of the overloads for cable LTG1823 is reduced from 100 hours to 52 hours and to 48 hours. The integration of a PV potential has no influence on overload duration for cable LTG1804.

IV. Conclusion and Outlook

For the 100% electric mobility penetration scenario shown here, the increase in the energy demand is about 30% compared to the status-quo. This increase causes overloads in three cables for the selected charging powers of 3.7 kW and 11 kW in scenario 2.

In addition, the project "move2grid" takes scenarios with charging powers of 11 kW / 22 kW and 22 kW / 350 kW into account in order to estimate the influence of controlled and regulated charging on the medium-voltage level. Furthermore, the implementation of storage units and their impact to the power grid in combination with PV potentials and electric mobility is checked to avoid grid instability.

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REFERENCES

[1] VDE, „Der zellulare Ansatz. Grundlage einer erfolgreichen regionenübergreifenden Energiewende", 2015

[2] B. Böckl, L. Kriechbaum and T. Kienberger, „Analysemethode für kommunale Energiesysteme unter Anwendung des zellularen Ansatzes". In 14. Symposium Energieinnovation. Energie für unser Europa, 2016.

[3] BDEW – Budesverband der Energie- und Wasserwirtschaft e.V., „Standardlastprofile", https://www.bdew.de/internet.nsf/id/DE_Standartlastprofile, 26.01.2016

[4] E-Control, „Sonstige Marktregeln Strom – Kapitel 6: Zählwerte, Datenformate und standardisierte Lastprofile", https://www.e-control.at/recht/marktregeln/sonstige-marktregeln-strom#p_p_id_56_INSTANCE_10318A20066_, 26.01.2016

[5] Neplan AG, http://www.neplan.ch/; 13.01.2017

[6] J. Vopava, B. Thormann and T. Kienberger, "Development of a Model for Power Grids Based on the Cellular Approach for an Optimum Integration of Electric Charging Infrastructure", 1tst E_mobility power System Integration Symposium, 2017.

[7] Amt der Steiermärkischen Landesregierung, „Solardachkataster Steiermark", http://www.gis.steiermark.at/cms/beitrag/11864478/73081691/, 26.01.2016.

[8] ZAMG, Einstrahlungsmessdaten und Temperaturmesswerte des Jahres 2014 für Kapfenberg.

[9] B. Böckl, J.Vopava, L. Kriechbaum and T. Kienberger, "Limitations of integrating photovoltaic energy into municipal grids excluding and including storage systems", 6th Solar Integration Workshop, 2016.

[10] MATLAB, The MathWorks Inc., 2017.

[11] A. Probst, M. Braun and S. Tenbohlen, „Erstellung und Simulation probabilistischer Lastmodelle von Haushalten und Elektrofahrzeugen zur Spannungsbandanalyse"

[12] T. Wieland, M. Reiter, E. Schmautzer, L. Fickert, J. Fabian and R. Schmied, „Probabilistische Methode zur Modellierung des Ladeverhaltens von Elektroautos anhand gemessener Daten elektrischer Ladestationen – Auslastungsanalysen von Ladestationen unter Berücksichtigung des Standorts zur Planung von elektrischen Stromnetzen",e & i Elektrotechnik und Informationstechnik, April 2015, pp. 160-167.

[13] A. Schuster, „Batterie- bzw. Wasserstoffspeicher bei elektrischen Fahrzeugen", Diplomarbeit, Wien, 2008.