Methodology for Simulation of Large Distribution Grids with Dynamic Generation of Load Profiles

Mathias Müller, Janis Reinhard, Thomas Estermann
Forschungsstelle für Energiewirtschaft e.V. (FfE)
Research Center for Energy Economics
Munich, Germany
mmueller@ffe.de

***Abstract* — The energy transition, which is taking place both on the generation and on the consumption side through increased electrification, leads to new challenges in the distribution grids. This paper shows how medium- and low-voltage grids can be analyzed in detail and effectively. The focus is on the consideration of controllable flexibility options for which there are no standard load profiles. The developed method is described using the example of two charging strategies for electric vehicles on the basis of a real distribution network.**

Keywords: flexibility, distribution grid, medium voltage, low voltage, electric vehicle, heat pump, smart grid, simulation, energy system, charging strategy, load profile

I. Introduction and Motivation

In recent years, the energy transition has massively changed the requirements on distribution grids in Germany. Not only have many renewable energy systems, e.g. photovoltaic systems, been installed, but load has also risen and is expected to rise further due to the progressive electrification of the heating and mobility sectors. Both developments are mainly taking place in the distribution grid, and in low voltage grids in particular. In combination with digitalization, which makes it possible to control new producers and consumers, new challenges and opportunities for electricity grids arise. The focus of this paper is on electric vehicles (EVs), which due to their high maximum power can cause grid overloads, but can also be used to prevent grid overloads via load shifting, thanks to their large storage capacities. The effects of these new consumers on low voltage grids as well as on the superimposed medium voltage grid shall be investigated. [1]

Detailed simulations are to be carried out for different operating modes of each system. To evaluate the influence on the low voltage grid, all loads at each grid connection point are to be considered in detail. However, the effects on the medium/voltage grid will also be investigated. In this case, a detailed consideration of all households and components is not absolutely necessary, and would in fact lead to a disproportionate computing effort. Therefore, it is necessary to create models that represent the questions to be investigated with sufficient accuracy, but without excessively increasing computing time.

Low voltage grid areas within a medium voltage grid can be modeled with a residual load placed at the node of the transformer substation. The common practice for this type of modeling includes the utilization of standard load profiles, which are used by the grid operators for billing and energy procurement [2]. Thus, each household customer is described by an identical profile, which is scaled with the corresponding energy quantity per annum. This method shows an acceptable accuracy for a high number of household entities, e.g. at least 150 [3], [4]. However, it is not possible to determine the impact of new components like electric vehicles or their operating behavior using currently available standard load profiles.

For this reason, a methodology was developed to dynamically calculate standard load profiles per component, depending on their mode of operation and other parameters, within the simulation of a medium voltage grid. These load profiles are based on detailed, bottom-up models of each entity of the components.

The following questions are to be analyzed in the context of this paper: How many detailed systems, e.g. individual load profiles, need to be calculated to achieve a valid and suitable result for a medium voltage simulation? What do the generated load profiles of electric vehicles, heat pumps and battery storages look like for different operating modes? How high are the resulting simultaneity factors and the resulting peak power of all systems?

This methodology shall be implemented in a simulation model to determine if future scenarios lead to congestions in the distribution grid of the field test area of the FfE in C/sells in Altdorf, which is close to Landshut in Bavaria, Germany. In C/sells the FfE is developing and testing a smart market platform to integrate small-scale-flexibility in the congestion management. Part of the FfE activities is to forecast the flexibility demand for the following day in the medium voltage level. [5]

The research of FfE in the project C/sells is funded by the Federal Ministry of Economics and Energy (BMWi) as part of the "Schaufenster intelligente Energie - Digitale Agenda für die Energiewende" (SINTEG) funding program (funding code: 03SIN121)

II. The Simulation Model GridSim

To investigate the effects of future developments on distribution grids the simulation model GridSim has been developed at FfE in recent years. The simulation model gives a detailed depiction of distribution grids based on load flow calculations. A comprehensive representation of the electrical energy system on the distribution grid level allows determining impacts of various systems of decentralized generation and consumption on the distribution grid. [6], [7], [8]

The combination of an energy system model for distribution grids with a focus on the low voltage side and the three-phase load flow calculation of the associated grid area allows a detailed energy analysis of the components connected to the grid. Moreover, the inclusion of different modes of operation and charging controls makes it possible to comprehensively analyze the above questions. By running daily or yearly simulations with temporal resolutions of minutes to hours, these complex analyses and evaluations can be realized.

A broad parameter selection (more than 350 parameters), which are pre-determined by default values, enables a simple and efficient way to create and define scenarios. Parameters are defined via a neat graphical user interface. Case distinctions can be used to vary parameters and for sensitivity analyses. Additionally, parameters or scenarios that include energy consumptions for every grid connection can be defined in a database to simulate real grids with their grid load. Based on these scenarios new components like electric vehicles, heat pumps, storages or decentral producers can be added and analyzed.

After choosing between a real grid, a reference grid derived from a clustering process, or a synthetic grid, buildings with one or more residential units are assigned to the nodes of the grid based on parameters or settlement structure. An exemplary low voltage grid is shown in Fig. 1. A three-phase electrical load curve and a heating demand curve are assigned to each residential unit.

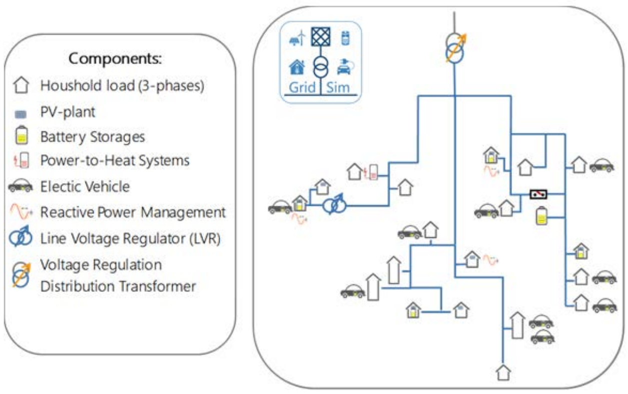

Fig. 1: Exemplary grid region including modeled, electrical components

Additionally, components such as electric vehicles, PV plants, electrical storages, or heat pumps can be allocated to each building. These components are assigned to the buildings and parameterized at random or via look-up tables. Each component is connected with a certain driving profile, generation curve or heating demand curve. For all of these additional components, scenarios can be defined and a variety of control strategies can be selected. Control strategies include, for example, the increase of self-consumption via an electric storage or a voltage-controlled control to avoid voltage band violations at the grid connection point.

Through the coupling of GridSim to the FfE regionalized energy system model (FREM), numerous data about the energy system with high spatial resolution can be used to distribute and parametrize the components. [9], [10]

In the subsequent simulation, the residual load per building is calculated for every time step, taking control strategies of the individual components into account. Based on the residual load matrix, the current grid status is determined by means of a load flow calculation. Therefore, all voltages, currents and equipment loadings are calculated. Depending on the selected control mode, these results directly influence the control of the components or are simply stored.

Within the analysis of the simulation, locations in the grid where critical conditions occur can be detected. The critical power (generation or consumption) at which grid optimizing measures should be used can be identified. Regardless of the condition of the grid, load curves of all components, as well as the state of charge of storages, are calculated and saved. Based on this data, energy balances of the whole grid, loading of the grid components, or equivalent full cycles of storages can be calculated after completion of the load flow calculations. Furthermore, typical, statistical load curves depending on the chosen control strategy as well as CO_2 emission balances of the grid can be calculated.

Since the distribution of the components in the grid has a very large influence on the results of the simulation (e.g. in the worst case all generators are placed at the end of one feeder), all scenarios can be calculated several times with different distributions of components, like a Monte Carlo simulation. At a certain number of different random distributions, a statistically sound evaluation of impacts on the grid for a certain penetration of components can be made.

Following the simulation, an automated multi-level evaluation of the simulation results takes place, in which both statistics are calculated and plots are created. These evaluations are calculated separately for every random distribution and then summarized to calculate statistically significant results for the considered scenario.

III. Methodology for Simulation of Detailed and Aggregated Grids.

This chapter describes the methodology for the simulation of detailed and aggregated low voltage grids in one simulation. This is done to simulate larger medium voltage grids within an acceptable time. First, the initialization and assignment of the detailed grids is described and then the aggregated grids. In the next step, the procedure for creating load profiles during the simulation and their scaling is explained.

As previously described, each grid connection point (gc) is modeled in detail and can have different components. In Table 1, the different components and the input data for the model are described.

Since electric vehicles are the focus of this paper, the different modes of operation that can be selected and are used for the following simulations, are described next. In this paper only charging procedures at home are considered, and it is assumed that the vehicles are always plugged in while at home.

TABLE 1: COMPONENTS AT EACH GRID CONNECTION POINT

Component	***optional***	***Source***
Household	(x)	Load Profile Generator, 3 phases [6]
Trade and Commerce	(x)	standard load profiles [2]
PV Plant	x	measured PV profiles
Heat Pump	x	Heating demand generator [11] based on [12], [13], [14]
Electric Storage Heating	x	
Battery Storage	x	-
Electric Vehicle	x	driving profile generator [15] based on [16]

(x): At least one household or commerce profile, or a combination of several of these profiles, must be assigned to each grid connection point.

Uncontrolled Charging: This mode is set as default. The EV is charged immediately on arrival at home with the maximum charging capacity possible, limited by the charging station and EV itself, until the battery is full or the EV leaves. [17]

Self-consumption optimized: In this mode, the EV is charged immediately after arriving at home until it reaches a definable minimum state of charge (SoC; in this case 40 %). Afterwards, the EV is only charged if surplus energy is produced by the PV system. If the vehicle cannot be charged to a desired SoC (in this case 70 %) with surplus energy, it will be charged in the period before departure. So, in this case, the dominating parameter is PV-generation. [18], [7]

The methodology to integrate these charge procedures and other new operation modes and components into a medium voltage simulation the following methodology was evolved. Fig. 2 shows the initialization of the grid.

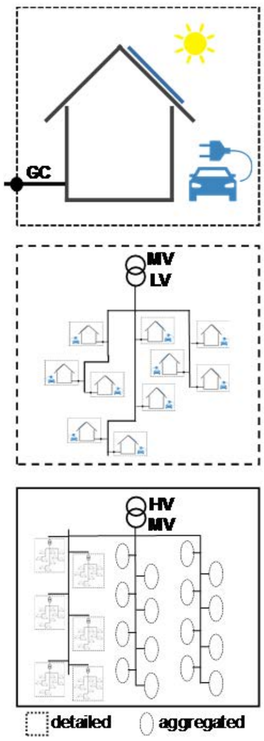

Fig. 2: Initialising and modeling the medium voltage grid with both detailed and aggregated low voltage grids. First: modeling one house; second: assigning the detailed houses to the low voltage grid; third: assigning the detailed and aggregated low voltage grids to the superimposed medium voltage grid.

First each house is initialized with its components and the corresponding demands. In the next step the houses are assigned to the nodes of the detailed low voltage grids. Then the detailed low voltage grids are connected to the medium voltage grid. Next, additional loads, e.g. industrial loads, or larger PV plants or conventional generators and the aggregated low voltage grids are assigned to the nodes of the medium voltage grid. The aggregated low voltage grids are modeled with load profiles representing the load of the individual components. The used load profiles are H0, G0-G6, L0-2 [2] and also profiles for heating demand (TLP) [19]. These profiles are scaled with the corresponding annual energy consumption and summed to obtain the residual load at each node. The use of standard load profiles is only valid if there are at least 150 instances of each component [3], [4].

The procedure described up until this point is a state-of-the-art grid simulation. But so far there are no electric vehicles, no storages, and newer operation modes for e.g. heat pumps taken into account. The obstacle to simply building new load profiles for these new loads and their different control strategies is that, depending on the control strategy, additional parameters must be taken into account. The calculation of the actual standard load profiles is based on the yearly amount of energy, with only differences between types of days (weekday, Saturday and Sunday) and the seasons considered. Heating profiles rely solely on temperature. For electric vehicles with uncontrolled charging this procedure could be used as well, but as soon as the EVs are charged using some sort of smart charging technique (self-consumption optimized, tariff optimized) it is not possible any longer, since neither the PV production nor the prices are taken into account for calculating the standard load profiles. If all potential variability of numerous parameters such as type of day, season, PV, temperature, and variable tariffs were taken into account the number of different profiles would combinatorically explode.

Therefore, a standard load profile, including all the mentioned parameters is calculated during the simulation for each time step and directly applied to the aggregated grids. This is done by considering all loads of the EVs modeled in detail (1).

$$\emptyset P_{EV}(t) = \frac{\sum_{i=1}^{n} P_{EV,i}(t,)}{n_{EV}} \qquad (1)$$

$\emptyset P_{EV}$	*mean charging power of all EVs*
$P_{EV,i}$	*charging power of electric vehicle i*
n_{EV}	*number of EVs*
t	*time*

This process is also shown in Fig. 3. In this case, more than 600 EVs, of which one half used a charging power of 3.7 kW (one phase) and the other 11 kW (three phases), were modeled with uncontrolled charging and a resolution of 15 minutes. The blue lines show the charging power of the individual EVs, which is 3.7 or 11 kW in most cases. The power is only reduced for the last 15 minutes if the EV is almost full.

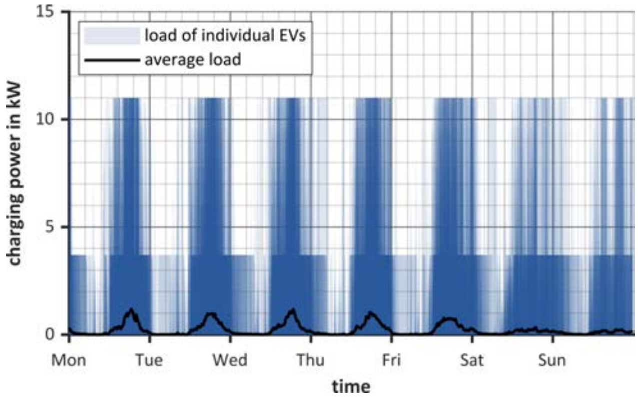

Fig. 3: Charging power of 600 individual EVs (blue) with and the mean charging power of all EVs

The density of the blue lines shows when many EVs are charging. The black line marks the average power and it can be seen that the highest mean power is around 1.2 kW per EV on weekdays in the evening. The highest mean power on weekends is around 0.35 kW. During the early morning hours almost no EV is charging.

In the next step, this resulting mean power is scaled for each aggregated low voltage grid with the number of connected EVs (2).

$$P_{EV\_agg,i}(t) = \emptyset P_{EV}(t) * n_{EV,i} \quad (2)$$

$P_{EV\_agg,i}$	*charging power of EVs in the aggreg. lv grid i*
$\emptyset P_{EV}$	*mean charging power of all EVs*
$n_{EV,i}$	*number of EVs in aggreg. lv grid i*
t	*time*

Two exemplary resulting load profiles for one week for two different aggregated low voltage grids with 7 and 18 EVs are shown in Fig. 4. The profiles are not as smooth as expected, therefore a statistical analysis is performed in the next section to determine the possible error and to verify that this method is valid.

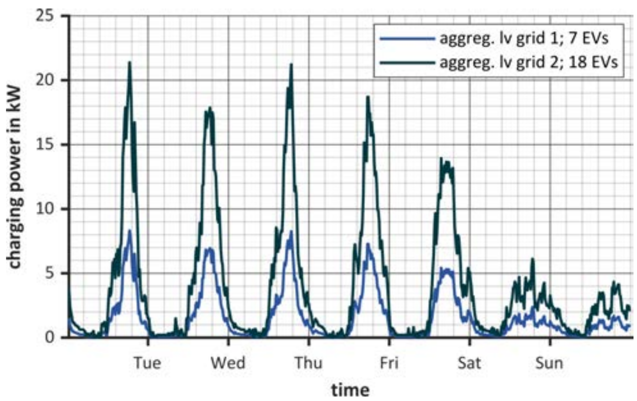

Fig. 4: Resulting load profile for one week in two exemplary grids with 7 and 18 EVs

IV. LOAD PROFILES FOR ELECTRIC VEHICLES

Before creating load profiles for different scenarios, the method has to be validated and evaluated for different numbers of electric vehicles. In Fig. 5 the resulting load profile for 1900 electric vehicles and the corresponding standard deviation (std) for 10, 50, 100 and 500 EVs resulting from a yearly simulation on a typical workday are depicted. To calculate the standard deviations 100 random samples of the 1900 profiles were picked. The used control strategy is uncontrolled charging and all EVs have a 40 kWh battery and a maximum charging power of 11 kW. The highest power occurs during the 6:00 pm and is 0.9 kW per EV, which corresponds to a simultaneity factor of 8 % on a typical workday.

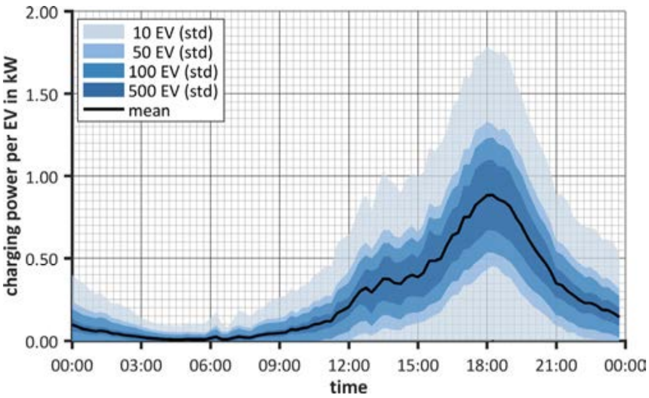

Fig. 5: Resulting load profile for uncontrolled charging of electric vehicles at workdays and the corresponding standard deviation for different numbers of EVs

The standard deviation decreases with increasing numbers of EVs. For calculating these values for every number one hundred samples were made. So the shown standard deviation represents the 100 samples of all working days of one year, which makes in total a number of 26,100 profiles.

The standard deviations for these profiles are shown in table 1. For 10 EVs the average standard deviation is 0.415 kW while for 50 EVs it is already decreased to 0.2 kW. Furthermore, the maximum standard deviation per day is approximately two times the average standard deviation in most cases.

TABLE I. TANDARD DEVIATIONS FOR UNCONTROLLED CHARGING AT A WORKDAY

number of EVs	*minimum std in kW*	*average std in kW*	*maximum std in kW*
10	0.073	0.415	0.907
25	0.050	0.273	0.603
50	0.038	0.200	0.456
100	0.027	0.149	0.351
500	0.012	0.089	0.236
1000	0.009	0.077	0.224

Thus, on an average workday 100 EVs have a total standard deviation of 14.9 kW on average or 35.1 kW at maximum, which is not very much compared with a typical transformer power of 630 kVA.

V. Case Study

This methodology was developed to simulate the distribution grid in Altdorf, which is close to Landshut in Bavaria, Germany. The grid area is shown in Fig. 6. The grid consists of eight medium voltage feeders, which supply 173 low voltage grids. One of these eight feeders, containing 10 low voltage grids, is modeled in detail. For this part of the grid, the type of load and yearly consumption at each grid connection point are known. The LV grids supply between four and 152 buildings. In total 320 buildings with 547 households are modeled in detail. The whole grid area contains 4,200 buildings with almost 8,000 households

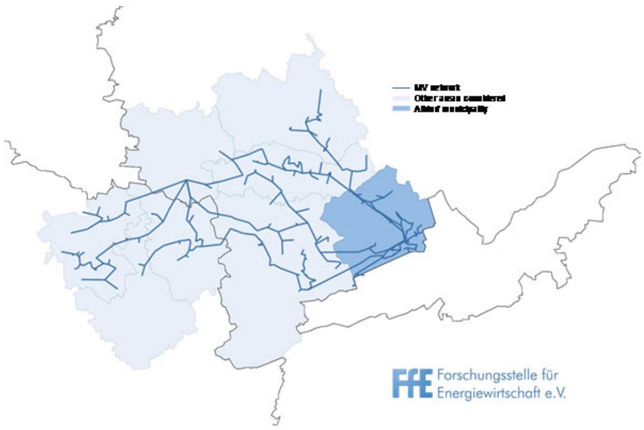

Fig. 6: Medium voltage grid of the project area (based on [20])

Based on the scenarios which are described in [21] and [22], every second household will have an EV in the future. This means that the detailed grids will be penetrated with 0 to 135 EVs. In total 274 EVs are simulated in detail. The amount of EVs in the aggregated grids is 4,032. Fig. 7 shows the resulting typical daily profile for the different charging strategies (uncontrolled and self-consumption optimized).

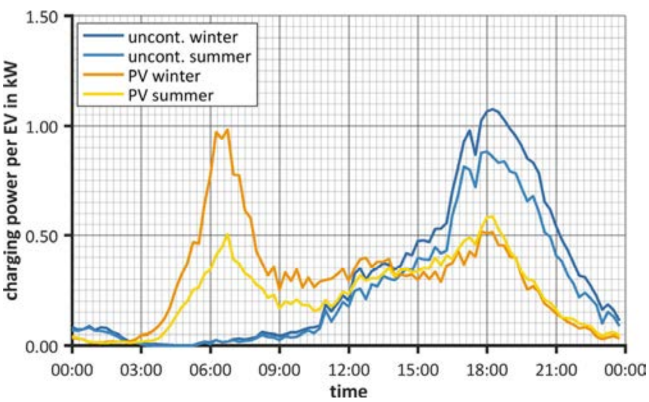

Fig. 7: Typical profiles on weekdays for different seasons and charging strategies

For both charging strategies the overall energy consumption in summer is lower than in winter. The highest peak for uncontrolled charging is in the evening, after most of the people arrive at home and plug in their car. The influence of the seasons on uncontrolled charging is rather low. In contrast, the seasonal influence can clearly be seen in the profile for self-consumption optimized charging with PV energy: In winter the highest peak occurs in the early morning hours since there is often not enough surplus PV energy the day before to reach the desired SoC of 70 % so that the EVs have to be charged to the desired SoC in the morning, before departure. In contrast, in summer the highest peak is during the evening hours, when there is still PV production and many EV are plugged in. In total the average peak power per EV is around 1.1 kW, which corresponds to a simultaneity of 10 %. Of course on single days the simultaneity can be much higher.

In addition, due to the self-consumption optimized charging strategy the weekly average SoC of the EV fleet are lower than in uncontrolled mode and the average SoC of the fleet is slightly decreasing towards the weekend and rises again at the weekend, where many EVs are at home during the day. This effect can be seen in Fig. 8.

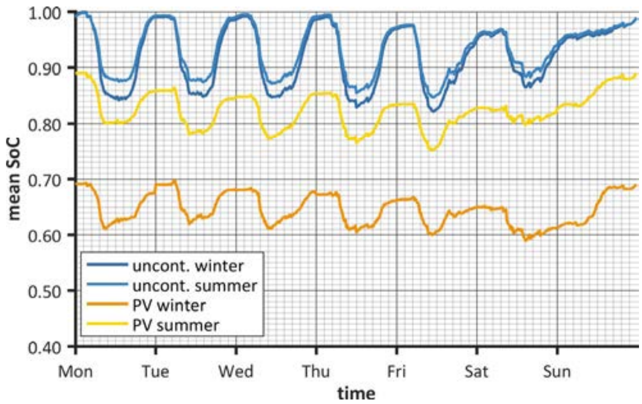

Fig. 8: Mean SoC of all EVs during the mean week for different seasons and charging strategies

The average SoC of the EV fleet decreases during the day and increases again at night when the cars are charged. As mentioned before with self-consumption optimization the average SoC of the fleet over time is lower. Especially during the winter, when the EVs often need to be charged before departure to reach the desired SoC of 70 %. It can also be seen that in summer and winter the SoC is rising on Sundays.

Overall it can be said that the resulting charge profiles are not only dependent on the applied charging strategy, but are also very sensitive to parameters like PV production, surplus energy, temperature, type of day and so on. This makes it hard to generalize them.

Despite the high number of simulations and averaged EVs, the profiles presented are not as smooth as we expected them to be. This results on the one hand from the method of creating the driving profiles, which are repeated weekly, but with different energy consumptions due to temperatures. On the other hand, it looks like that the people that took part in the survey for [14] tended to use full or half hours to start journeys, which results in higher simultaneities.

VI. Critical Review

First of all, this section will deal with alternative methods. The objective of considering different modes of operation in aggregated grids requires a dynamic determination of the loads to be applied.

In addition to the averaging procedure for all units considered in detail, which works well for large numbers as described, the errors become larger for a few units. Here it must be differentiated whether only a few units are considered in detail or in aggregation.

In case that only a limited number are simulated in detail, it can happen that the averaged load profile is very strongly dominated by individual plants and therefore has high gradients. In this case, it can be useful to calculate the power for the aggregated loads not only from the current power of the detailed plants but also from the past time steps and to weight these with various factors. In addition to the challenge of a suitable determination of the weighting factors, this method results in a temporal shift, since only the past values are available. Thus, in the case of electric vehicles, for example, the charging times would be slightly delayed. Likewise, averaging could lead to individual peaks being cut too sharply. A distinction would have to be made between these peaks from the insufficient database and from the desired simulated behavior, which could be the case, for example, with tariff control.

In the second case, with very few aggregated components, the use of averaged loads leads to significant deviations from the loads in reality, as in this case there would be insufficient averaging and the peak loads would, therefore, be higher than average. In this case, as an alternative to averaging, individual, detailed loads could be selected and assigned to the aggregated networks. The disadvantage here is that exactly the same loads are used and therefore the simultaneity is too high.

Thus the choice of a suitable method is always strongly dependent on which scenarios are to be examined and whether sufficiently detailed and aggregated facilities are considered.

The methodology presented in this paper should be further validated. It is important to analyze the resulting load profiles for the aggregated grids. Depending on the components and the mode of operation, these can also have very high gradients in many systems (e.g. storage heaters or externally switched controls). Thus the result of the load curve aggregation should always be checked and interpreted before the simulation results of the distribution network simulation and the load flows from this are evaluated and analyzed.

The presented method has a weak spot due to the required high number of entities of each component. It should be noted, however, that the focus of the concept is on the analysis of a medium voltage network and that individual components are therefore only relevant from a high level of penetration, as their performance would otherwise have no significant influence on the simulation results. For example, in a medium voltage grid, which, as in the region under consideration, is supplied by a transformer station with transformers with an output of 40 or 50 MW, it is irrelevant whether, for example, 50 electric vehicles with a charging power of 11 kW are available. Even in the very unrealistic case that all 50 vehicles would charge at maximum power simultaneously, these 50 vehicles reach a power of only 550 kW i.e. a power in the percentage range of the transformer station capacity.

REFERENCES

[1] Navigant, Kompetenzzentrum Elektromobilität und RE-xpertise: Verteilnetzausbau für die Energiewende - Elektromobilität im Fokus: Studie im Auftrag von Agora Verkehrswende, Agora Energiewende und The Regulatory Assistance Project (RAP), 2019.

[2] VDEW et al.: Repräsentative VDEW-Lastprofile. Cottbus: VDEW, 1999.

[3] Esslinger, Peter; Witzmann, Rolf: Entwicklung und Verifikation eines stochastischen Verbraucherlastmodells für Haushalte in: Symposium Energieinnovation. Graz, Österreich: Technische Universität München, Fachgebiet Elektrische Energieversorgungsnetze, 2012

[4] Sterner, Michael et al.: Energiespeicher - Bedarf, Technologien, Integration. Regensburg, Köln: Springer Vieweg, 2017. ISBN 978-3-662-48892-8

[5] Köppl, Simon; Estermann, Thomas; Zeiselmair, Andreas: Laufendes Projekt: C/sells – Großflächiges Schaufenster im Solarbogen Süddeutschlands in: www.ffe.de/csells. München: Forschungsstelle für Energiewirtschaft e.V. (FfE), 2017

[6] Nobis, Philipp: Entwicklung und Anwendung eines Modells zur Analyse der Netzstabilität in Wohngebieten mit Elektrofahrzeugen, Hausspeichersystemen und PV-Anlagen. Dissertation. München: Technische Universität München - Fakultät für Elektrotechnik und Informationstechnik, 2016

[7] Köppl, Simon; Samweber, Florian; Bruckmeier, Andreas; Böing, Felix; Hinterstocker, Michael; Kleinertz, Britta; Konetschny, Claudia; Müller, Mathias; Schmid, Tobias; Zeiselmair, Andreas: Projekt MONA 2030: Grundlage für die Bewertung von Netzoptimierenden Maßnahmen - Teilbericht Basisdaten. München: Forschungsstelle für Energiewirtschaft e.V. (FfE), 2017

[8] Samweber, Florian: Systematischer Vergleich Netzoptimierender Maßnahmen zur Integration elektrischer Wärmeerzeuger und Fahrzeuge in Niederspannungsnetze. München: Fakultät für Elektrotechnik und Informationstechnik der TU München, 2017

[9] Schmid, Tobias: Dynamische und kleinräumige Modellierung der aktuellen und zukünftigen Energienachfrage und Stromerzeugung aus Erneuerbaren Energien. Dissertation. Herausgegeben durch Technische Universität München, geprüft von Prof. Wagner, Ulrich und Prof. Kolbe, Thomas H.: München, 2018.

[10] Corradini, Roger; Konetschny, Claudia; Schmid, Tobias: FREM - Ein regionalisiertes Energiesystemmodell in: et - Energiewirtschaftliche Tagesfragen Heft 1/2 2017. München: Forschungsstelle für Energiewirtschaft, 2017

[11] Schröder, Lutz: Modellierung der Energienachfrage privater Haushalte auf Basis individueller Zeitverwendung - Modelling the energy demand of private households based on individual time use. Masterarbeit. Herausgegeben durch die Hochschule Trier, betreut durch die Forschungsstelle für Energiewirtschaft e.V.: München, 2016

[12] Bundesverband der Energie- und Wasserwirtschaft: BDEW/VKU/GEODE Leitfaden - Abwicklung von Standardlastprofilen Gas. Berlin: BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., 2015

[13] Michael, Hinterstocker; Benedikt, Eberl; Von Roon, Serafin: Weiterentwicklung des Standardlastprofilverfahrens Gas. München: Forschungsgesellschaft für Energiewirtschaft mbH, 2015

[14] Hellwig, Mark: Entwicklung und Anwendung parametrisierter Standard-Lastprofile - Dissertation. München: Lehrstuhl für Energiewirtschaft und Anwendungstechnik (IfE), TU München, 2003

[15] Müller, Mathias; Samweber, Florian; Leidl, Peter: Impact of Different Charging Strategies for Electric Vehicles on their Grid Integration - Einfluss der Ladesteuerung von Elektrofahrzeugen auf deren Netzintegration in: 2. Internationale ATZ Konferenz Netzintegration der Elektromobilität. Wiesbaden: ATZ Live, 2017

[16] Follmer, Robert; Gruschwitz, Dana; Jesske, Birgit; Quandt, Sylvia; Lenz, Barbara; Nobis, Claudia; Köhler, Katja; Mehlin, Markus: Mobilität in Deutschland 2008 - Struktur – Aufkommen – Emissionen – Trends. Bonn: infas Institut für angewandte Sozialwissenschaft GmbH, 2010

[17] Wen, Chao-Kai et al.: Decentralized Plug-in Electric Vehicle Charging Selection Algorithm in Power Systems. Kaohsiung, Taiwan: IEEE, 2012.

[18] Kaschub, Thomas et al.: Intelligentes Laden von batterieelektrischen Fahrzeugen im Kontext eines Stadtviertels - VDE-Kongress E-Mobility. Karlsruhe: Karlsruher Institut für Technologie, 2010.

[19] Fünfgeld, Christian et al.: Bestimmung von Lastprofilen für unterbrechbare Verbrauchseinrichtungen. Cottbus: Energieressourcen-Institut e.V., 2002.

[20] Data provided for the project region Altdorf und Umgebung; Regensburg: Bayernwerk AG, 2018 (confidential).

[21] Wohlschlager, Daniela et al.: Bottom-up-Szenarien am Beispiel des Altdorfer Flexmarkts. In: ew - Magazin für Energiewirtschaft 3/2019. Berlin: EW Medien und Kongresse GmbH, 2019.

[22] Schulze, Yannic: Szenariobasierte Analyse des Flexibilitätspotenzials eines realen Verteilnetzes im Engpassfall mithilfe eines Verteilnetzsimulationsmodells. Masterarbeit. Herausgegeben durch RWTH Aachen University, betreut durch die Forschungsstelle für Energiewirtschaft e.V.: Aachen, 2019.