E-HOME ENERGIEPROJEKT 2020

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ABSTRACT

E.ON Avacon AG launched a three-year pilot project in 2011 to examine the future needs of low voltage grids. The project will be scientifically monitored by the Energie-Forschungszentrum Niedersachsen (EFZN). The aim of the supporting research is to investigate the impact of new components on the low voltage grids. One focus is on increasing the penetration of photovoltaic systems through the use of on-load tap-changing transformers. In addition thereto, a field test with a plurality of measurement campaigns is carried out. Previously, each participating household was equipped with electric vehicles, photovoltaic systems, air conditioner and smart meters. Also the measured values are recorded centrally and are available for evaluation. When using a few reference grids for representation of the entire low-voltage grid, high inaccuracies in the transmittance of the results on the entire grid can be expected. The creation of synthetic grid structures may be an alternative to the use of representative grids. The advancing change of the grid demand from a pure supply task to a mix of power demand and infeed has to be regarded in this context. This development demands the definition of new load approaches, which can be used in future grid calculations. In addition to the technical issues, economic, legal and sociologic themes are examined.

INTRODUCTION

For more than a decade Germany followed an accelerating path in developing its renewable power production capacities. The nuclear disaster of Fukushima encouraged German politics on this way, now commonly known as the "Energiewende", with the German government aiming at 80 % renewable share of the overall power consumption in 2050. With this ambitious goal at hand, a rather unattended part of the power infrastructure moves towards the center of attention: rural low voltage grids. The largest part of the 25 GW of PV-plants is connected to this part of the German distribution grid. As a result, distribution system operators (DSO) are confronted with great problems to keep the grid voltage within given constraints of 230 V +/- 10 %. The predominant although very costly method to deal with voltage rise due to decentral power infeed is substantial grid enforcement. Only recently new methods and technologies have been developed (see CIRED Paper 235 "*Voltage Control In Low Voltage Systems With Controlled-Low-Voltage-Transformer*").

In the context of the "Energiewende" decentral infeed is not the only change rural low voltage grids will have to cope with. Residential power demand has already undergone structural change for instance due to efficient lighting or rising number of electronic devices. In future devices such as electric vehicles, heat pumps and air conditioners for cooling and heating will influence rural and residential load profiles considerably. Whereas integration of large customers or infeeders such as windfarms or biomass CHP into the high or medium voltage grid can be achieved by planning case specifically, the above mentioned developments within low voltage grids lead to planning challenges a degree where a case by case approach is not possible.

On the one hand there is a pressing demand for theoretical research and practical testing of new innovative grid components such as tap-changing MV/LV-transformers, on the other hand new concepts and standards of planning and operation, which prove to be lasting despite of fast changing demands on the low voltage grid are needed.

E.ON Avacon AG, one of the largest German DSOs amongst other operating 18.000 LV grids in Germanys Lower Saxony and Saxony-Anhalt, and the EFZN combining the energy competences of all Lower Saxony universities, together search for these sustainable grid concepts in line with the E.ON Avacon run "E-Home Energieprojekt 2020" pilot project dealt with in this paper. Not only are concepts and innovate components being discussed theoretically or by simulation but the project enables the partners to test them within the project grids in an environment resembling future demands, with 32 households using air conditioning, full electric vehicles and producing electric power with roof mounted PV-panels. In contrast to many other "smart grid" pilot projects the E-Home Energieprojekt 2020 focuses on solutions within the scope of the grid itself, i.e. no control of household equipment and therefore no load management will be used to achieve project goals.

Next to the pure technical issues, there are many "soft" topics within scope of the project. One of those for instance is the customer acceptance for the new electric devices. Therefore, the project bridges the research gap

of a holistic view on the future low voltage grid as the backbone of the German "Energiewende".

1. FIELD TEST AND MEASURMENT SETUP

Field test environment and future households

A total number of 32 households were chosen to participate in the E-Home Energieprojekt 2020. They were equipped with photovoltaic systems, full electric cars, air conditioners and smart meters to represent a possible future household. To investigate the effects of electric mobility, the participants received an electric vehicle of the manufacturer Peugeot (Peugeot Ion). In addition thereto, photovoltaic systems with different capacities between 3 to 30 kWp were installed. The air conditioner resembling future heat pump systems represents the last component of the project. Each of these components has a separate smart meter to collect a large number of measurement values in a resolution of one second.

Design of the measuring technique

In addition to a variety of smart meters in the households, data recorders (Janitza®) are used in cable distribution boards and in the local grid station. Using these instruments, the analysis of power quality according to the DIN EN 50160 [1] standard is possible. The measured values of the smart meters and the data recorders are transmitted over a broadband powerline system (Power Plus Communication AG) with a frequency of 2 to 10 MHz to the grid control center. By using a web-based portal, participants can view an analysis of the measured values of the smart meter. In another web-based portal, all measurement values are provided for research purposes.
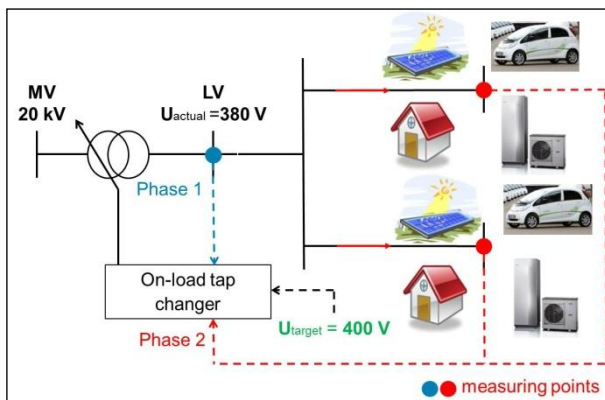
Applications of the measured values

Figure 1: Measuring points

The effects of the increasing decentralization of power generation and the integration of new components will lead to a strong voltage variation and a possible violation of the voltage range [1]. The measured values

of the household are used in studies of simulated load scenarios. Theoretical considerations will be validated with these data (see section 2.2.).

2. ACCOMPANYING RESEARCH

The following section describes the development of synthetic grid structures and new approaches of low-voltage power calculations. For this purpose field test results are used as a basis.

2.1 Simulation of Synthetic Low-Voltage-Grids

Distinction from representative grids

Studies on representative grids can help to identify present and future challenges at the distribution grid level [2], [3]. A typical classification of low-voltage grids is the distinction between rural, village and suburban grids [1]. In terms of integrating additional electrical loads and power generation systems the main challenges occur in rural grids [4].

The creation of synthetic grid structures may be an alternative to the use of representative grids. The main challenge for the development of representative grids is the often poor data base of the DSOs. Due to the sometimes widely varying low voltage distribution grid topologies is the classification of the entire grid inventory in just a few classes practically hardly possible. When using a few reference grids for the representation of the entire low-voltage grid, high inaccuracies in the transmittance of the results on the entire grid can be expected.

Databases

The starting point of the process for creating synthetic grid structures is the analysis of existing data. As known, the following parameters are assumed: number and type of transformers, number of cable distribution boards and house connections per grid area, the total cable and overhead line lengths and the sum of house connection cables and overhead line lengths. Unknown are the following relations: exact amounts of equipment and its distribution for each transformer and the number of house connections for each transformer.

Simplifications and Procedure

For the creation of synthetic grid structures typical parameters of low-voltage grids and equipment quantities are used. For this purpose an analysis of the available grid parameters is required. Individual parameters and parameter combinations can be assigned specific probabilities. In this way it is possible to determine probabilities for the occurrence of individual grid structures. By using these probabilities it is possible to infer the entirety of the grids.

Due to the large number of possible combinations, it is purposeful to make suitable simplifications. For

example, there is no need for the inclusion of overhead lines, if a dismount is planned in the near future in the investigated grid area. The grids are seen as decoupled supply areas, initially for three different sizes of transformers which means, each structure is assigned to a transformer and changes or improvements to the topology are neglected. The modeling is based on individual lines. Each transformer will be assigned to just one grid string; the influences of other strings can be simulated at the transformer bus bar with equivalent loads and generators.

The number of the investigated structures is limited to three different types; they differ by the number of cable distribution boards. The proportionate lengths of the respective line sections and the used cable types are determined for each structure. In addition to the number of cable distribution boards the parameters total cable length (TCL), length of house connection cables (HCC) and numbers of household connections (HHC) are varied. The definition of the limits, means, and the number of steps for each parameter variation is based on the determination of available grid data, equipment quantities and analyses of measurements on real grids. For structures without cable distribution boards Table 1 gives an overview. Studies on the effects of different enforcement levels of loads like heat pumps or generators such as photovoltaic systems can be performed on the created grid structures. For worst-case-scenarios of generation photovoltaic systems can be simulated with their rated power and households with a low load. New approaches for calculating low-voltage loads are introduced in the next section.

Table 1: parameters for grids without cable distribution boards

Parameter	Values	Number
TCL / m	100, 200, 500, 1000, 1500	5
HCC / m	10, 30, 50	3
HHC	1, 5, 15, 25, 35, 50	6
Topologies		**90**

2.2 New approaches of Low-Voltage Power calculations

Private households make up the largest class of customers in the field of low voltage grids and will be in focus of the analyses of the E-Home Energieprojekt 2020. Low voltage grid load approaches are determined from installed capacity and their simultaneity factor. The simultaneity factor g is the quotient of demand set up and installed capacity such as specified in [5]:

$$g(n) = g_\infty + (1 - g_\infty) \cdot n^{-3/4}$$

with

g_∞.. limit value n.. number of households.

In this connection it is considered, that electrical equipment is generally not simultaneously on grid with its maximum capacity. In classical comprehension the simultaneity factor is an average, but maximum existing capacity on grid. This is named maximum simultaneity factor below.

The expectable consumption- and supply-sided diversifications of the grid demand mainly take place in the field of households. This necessitates analyzing actual in low voltage applied load approaches and adapting them to the new situation.

Departing from the existing supposition of a pure consumption based load, the load of future households is a superposition of technologies existing in households and for this reason a collective consideration of power supply and consumption. For the E-Home Energieprojekt 2020 significant load determining technologies have been identified. These technologies are heat pumps, electric vehicles and photovoltaic systems.

Because of the future penetration of the named technologies the bi-directional grid demand of low voltage grids is increasing. It necessitates to add a minimal simultaneity factor to the conventional maximum simultaneity approach. The schematic run of both curves is exemplarily shown in figure 2.

Background of this consideration is the need to dimension future low voltage grids on the basis of two load situations. They are based on the corresponding worst-case-scenarios. The load situation with maximum demand and minimal infeed is shown on the one hand and the load situation with minimum demand and maximum infeed on the other hand.
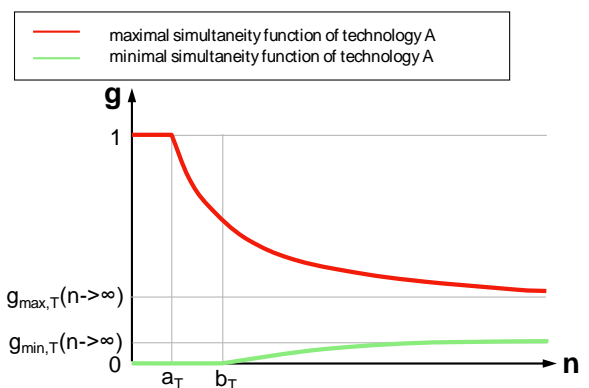
Figure 2: Schematic illustration of the courses of minimal and maximal simultaneity factor

Under these assumptions the two technologies heat pumps and electric vehicles have already been analyzed concerning their simultaneity functions. The definition of the functions was performed by modeling load profiles. According [5] the maximum simultaneity factor g_{max} for electric vehicles can exemplary be described by:

$$g_{\max,\mathrm{EFZ}}(n) = \begin{cases} 1 & \text{for } n \le 4 \\ g_{\max,\mathrm{EFZ},\infty} + \dfrac{1 - g_{\max,\mathrm{EFZ},\infty}}{(n+1-4)^{x_{\mathrm{EFZ}}}} & \text{for } n > 4 \end{cases}$$

With $g_{\max,\infty} = 0{,}33$ and $x_{\mathrm{EFZ}} = -0{,}3$ for 3,68 kW charging capacity.

Both researches show the result, that in the analysis of individual technologies the simultaneity factor can be determined to $g_{\max} = 1$ resp. $g_{\min} = 0$ for minor groups of households. Not until major groups of households $g_{\max}$ and $g_{\min}$ significantly decreases does resp. increases.

The simulation of synthetic low voltage grids just takes into account numbers of households up to 60 households per grid string. Due to this fact the installed capacity P_{inst} can approximately be adopted for the considered technology (for example 3,68 kW for electric vehicles). In the calculation of scenarios the penetration is then varied from low to high. So for each technology different penetration paths can be defined.

The photovoltaic systems technology will be analyzed in the same way and involved in the research. The calculation of a simultaneity factor for the basic technical equipment, that is to say the conventional techniques, of households, finishes the analysis.
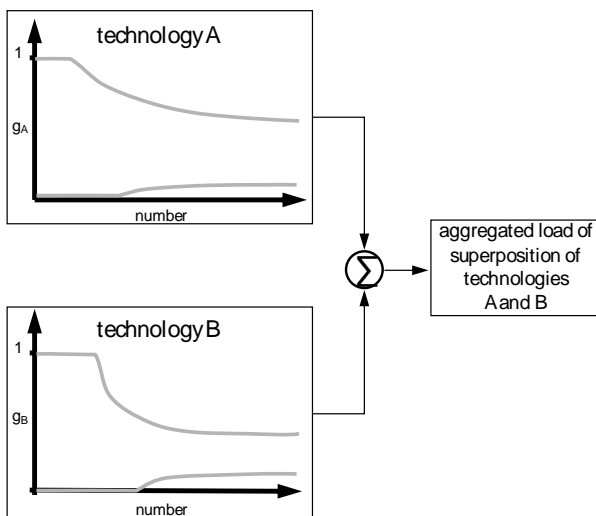
Figure 3: Schematic illustration of the superposition of technology A and technology B to an aggregated load

On the next step the measured functions of the individual technologies are superposed on an aggregated load approach by analytical formula. Figure 3 shows the principal scheme of the superposition of two technologies A and B to an aggregated load.

If a possible correlation between two technologies is disregarded, the aggregated load approach can be described in the following way:

    a) for superposition of maximal demand and minimal infeed

$$P_{\max,Bezug}(n) = -g_{\min,T_{PV}}(n) \cdot n \cdot P_{inst,T_{PV}} + \sum_{i=1}^{3} g_{\max,T_i}(n) \cdot n \cdot P_{inst,T_i}$$

    b) for superposition of minimal demand and maximal infeed

$$P_{\min,Bezug}(n) = -g_{\max,T_{PV}}(n) \cdot n \cdot P_{inst,T_{PV}} + \sum_{i=1}^{3} g_{\min,T_i}(n) \cdot n \cdot P_{inst,T_i}$$

The result delivers the two mentioned newload situations, which are relevant for the low voltage grid design. They serve as input parameter for future grid calculations.

3. SUMMARY AND FORECAST

The central element of the E-Home Energieproject 2020 is the on-load tap-changing transformer. To allow efficient use, a series of measured values is necessary. For this reason, an extensive measuring system has been implemented with a plurality of data recorders and smart meters.

The creation of synthetic grid structures can be used as an alternative to representative grids. By using typical grid parameters of distribution system operators for grid modeling and applying new approaches for electrical loads calculation, results with high accuracy can be generated.

Load approaches for future households constitute an essential part of future low voltage grid design. The obtained results are used as input parameters for further detailed grid calculations to define general future low voltage grid structures.

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