NEW LOAD AND INFEED APPROACHES FOR COST-EFFICIENT LOW-VOLTAGE GRID DESIGN

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ABSTRACT

The paper covers the derivation and application of new load approaches of private households for low-voltage power calculations especially in rural areas. In these areas private households have an over-average amount on consumption and a relatively high penetration of dispersed generation. That is why private households have a high relevance for an innovative and smart low voltage grid design. Therefore especially this group of consumer drives the transformation process of distribution grids founded on the rising development of dispersed generation, especially photovoltaics, and additional load patterns such as heat pumps and electric cars.

INTRODUCTION

Grid design is a long term task. Historically it was based on maximal-load-scenarios. In Future, it will be based on the consideration of two worst-case-scenarios: The load situation with maximum demand and minimal generation on one hand and the load situation with minimum demand and maximum generation on the other hand. Since anticipated changes in household technologies are not considered to their full extent, today´s assumptions about household load and infeed patterns for low-voltage power calculations are no longer compliant. This makes it necessary to question assumptions as current load patterns and adapt them to future developments. The significant technologies, determining household load patterns beside the basic equipment, have been identified. These technologies are heat pumps, electric cars and photovoltaic systems.

METHOLOGY

Concerning the new situation a calculation model for simultaneity factor curves has been developed. It considers infeed and consumption in its entirety. 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 previous specified in [1]:

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

with

g_∞ .. limit value (n=∞) n .. number of households.

In a first step this well-known simultaneity factor for maximum load situations has been improved, generalized and a second simultaneity factor for minimal load situations has been introduced (figure 1).

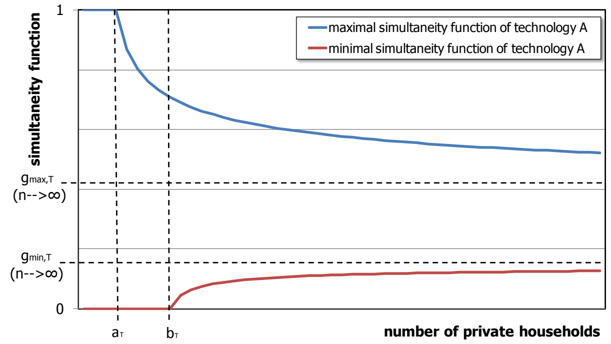

Figure 1: Schematic courses of minimal and maximal simultaneity factor

The analytical formulae can be defined as (cf. [2]):

a) maximal simultaneity factor

$$g_{\max,T}(n) = \begin{cases} 1 & \text{für } n \le a_T \\ g_{\max,T,\infty} + \dfrac{1 - g_{\max,T,\infty}}{(n+1-a_T)^{x_T}} & \text{für } n > a_T \end{cases} \qquad (2)$$

g_∞ .. limit value (n=∞)
n .. number of households
a_T.. decay limit
x_T.. decay factor

b) minimal simultaneity factor

$$g_{\min,T}(n) = \begin{cases} 0 & \text{für } n \le b_T \\ g_{\min,T,\infty} - \dfrac{g_{\min,T,\infty}}{(n+1-b_T)^{y_T}} & \text{für } n > b_T \end{cases} \qquad (3).$$

g_∞ .. limit value (n=∞)
n .. number of households
b_T.. echo limit
y_T.. echo factor.

In the next step the different functions of the single technologies are superposed on an aggregated load approach by analytical formula. Suchlike analysis could principally be explored by time series analysis. The here presented model makes two valid simplifications, which may be made under certain circumstances.

For sake of simplicity, it is assumed, that the events of technologies maximal or minimal demand occur simultaneously. First analysis approves this assumption as shown in [2] for electric cars and private households load patterns. The correlation in case of superimposing demand and infeed cannot be simplified as easy, because the point of maximal infeed (about noon) cannot sure be seen as the point of minimal demand (actually at night, but in this case the minimum about noon is searched). For this reason a time range has been defined, in which the event of minimal demand surely is included. This fact is modeled by the use of contingency analysis.

Disregarding a possible correlation between the technologies, the aggregated load approach can be described in the following way:

a) for superposition of maximal demand at the time of minimal infeed ("winter-case")

$$P_{\max}(n) = -g_{\min,T_{PV}}(n) \cdot P_{inst,T_{PV}} + \sum_{i=1}^{3} g_{\max,T_i}(n) \cdot P_{inst,T_i} \qquad (4)$$

b) for superposition of minimal demand at the time of maximal infeed ("summer-case")

$$P_{\min}(n) = -g_{\max,T_{PV}}(n) \cdot P_{inst,T_{PV}} + \sum_{i=1}^{3} g_{\min,T_i}(n) \cdot P_{inst,T_i} \qquad (5).$$

Figure 2 shows the principal scheme of the superposition of two technologies A and B to an aggregated load.

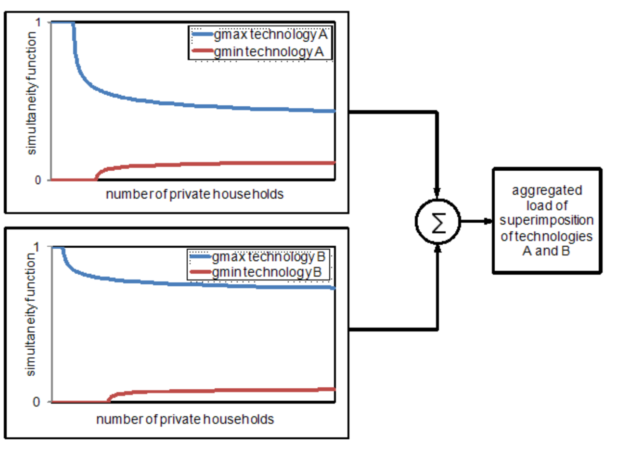

Figure 2: Superposition of technology A and technology B to an aggregated load

Fundamental assumption of the presented model is, that simultaneity factor functions are probability mass functions. They map maximal or minimal household load patterns considering the different possible load conditions and their probability. Improbable conditions up to a defined valid limit are not considered in the model. As a result high, but very short-term occurring load values are disregarded. An illustrated example based on households basic equipment load patterns is imaged below.

The result of superposition delivers the two mentioned new load situations, which are relevant for cost-efficient low voltage grid design.

SIMULTANEITY FACTOR OF FUTURE TECHNOLOGIES

Technologies with the largest impact on a households load and infeed pattern, such as heat pumps, electric cars, photovoltaic power plants and the basic technical equipment of households, have been analyzed concerning their simultaneity factor curves. This paper focus´ the demand-sided simultaneity factor functions.

Electric cars and heat pumps

The technology specifically simultaneity factor functions are performed by modeling load profiles. Due to missing detailed data about sufficient load profiles, synthetic load profiles are generated. Input parameter for the different simulation steps are e. g. load, utilization time, user group and random starting time. Figure 3 shows the maximal and minimal simultaneity factor functions for heat pumps.

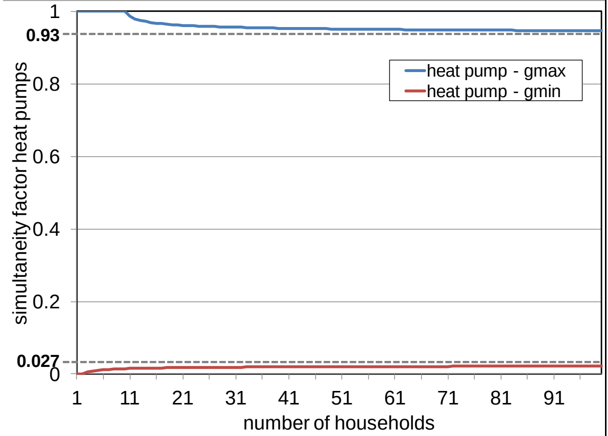

Figure 3: Maximal and minimal simultaneity factor of heat pumps

The analysis for electric cars and heat pumps delivered the following results, shown in table 1.

Table 1: Simulation results for simultaneity factor parameters corresponding to equations (2) and (3)

parameter	elektric cars	heat pumps
$g_{\infty,max}$	≈ 0.4	≈ 0.93
a_T	4	10
x_T	0.30	0.32
$g_{\infty,min}$	≈0.04	0.027
b_T	189	2
y_T	0.21	0.35

According to that the maximal simultaneity factor of electric cars with charging load of 3.6 kW is

$g_{max,\infty,EKFZ} = 0.4$. The rather small limit value is apparent to the fact that electric cars are charged chaotically circadian. Incidentally it is added, that the limit value further decreases, if the charging load rises.
By contrast heat pumps exhibit a high simultaneity factor with $g_{max,\infty,HP} = 0.93$ based on their long utilization time.

At this point should be exposed, that electric cars are often figured as the future technology with the biggest demand-sided impact on low-voltage grids. These results show that heat pumps, with a significant larger simultaneity factor than electric cars, will have a much higher impact.

Basic Equipment

The study delivers simultaneity factor functions respectively load approaches for rural areas. Regarding this the simultaneity factor of households basic equipment (like television, light etc.) has been examined and completes the demand-sided simulstaneity factor functions.
Approximately the general worst-case-determining influencing factors have been identified:

- household size and their combination on examination of a number of households
- high-powered electrical appliances and their penetration level
- utilization probability with utilization time and - frequency.

The combination of household sizes has been identified by reference to a 95 %-bound. At this a rural percentage distribution of household sizes was consulted (e. g. [3]). For small numbers of households the worst-case-determining combination is presented in table 2.

Table 2: Calculation parameters for combination of household sizes

number of households	**average household size (50%)**	**average household size 95 %-value (g_{max})**	**Average household size 5 %-value (g_{min})**
1	2.45	5	1
2	2.45	4	1
3	2.45	4	1.33
4	2.45	3.8	1.5
5	2.45	3.8	1.6
10	2.45	3.5	2

Concerning further analysis these results can be simplified. For g_{max}-calculation one household is committed to the size of 5 persons. Two households or more are combined as always four-person households. The determination of g_{min} follows by use of the combination of one-person-households up to three households. Four or more households are combined as two times table.

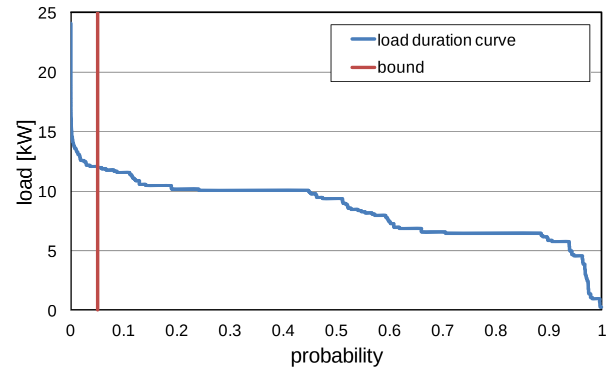

Figure 4: Maximal load conditions and 95 % bound in an exemplary household with electric car

In [4] is demonstrated, that electricity demand depends on a few electrical appliances. In the presented model the following high-powered electrical appliances were specified: stove and oven, washing machine, dryer, dishwasher, fridge, freezer as well as lighting and entertainment electronics. The utilization time and – frequency of each appliance result in the utilization probability. On this basis the different possible load conditions of households can be generated. Figure 4 shows the different possible maximal load conditions in an exemplary household with electric car.

As mentioned earlier, simultaneity factor functions are probability mass functions. They map the worst-case scenario for specific household load patterns up to a defined probability of occurrence. In this case the valid limit was determined to 95 %. In other words the five percent most improbable load conditions are disregarded. In this example load conditions of significant larger than 12,5 kW are too improbable concerning the defined 95 % - bound and not regarded.

On this basis the different load conditions and the related probability for one and more household can be generated and deliver the maximal and minimal simultaneity factor resp. load approach for households basic equipment. Figure 5 shows the maximal load approach for households basic equipment. In comparison to a general today´s used load approach the curve of the new calculated load approach of households basic equipment has a smaller starting value as well as a smaller gradient. This diversification can among others be justified by changes in the households equipment and the efficiency development of electrical appliances.

Photovoltaics

In a last step the simultaneity factor functions of the single technologies are completed with the photovoltaic simultaneity factor functions.

Up next the determined single technology functions are superposed to an aggregated load approach as earlier methodological described. The demand-sided superposition is shown in the next chapter.

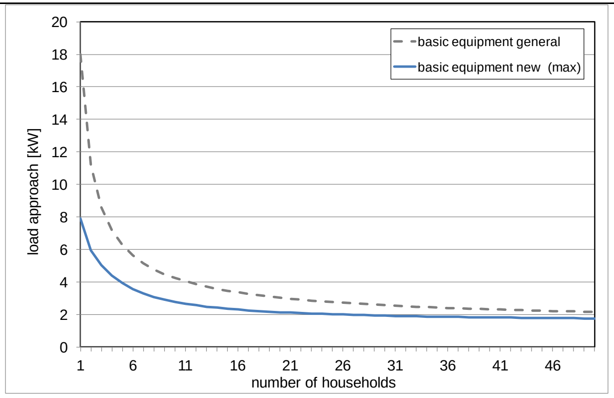

Figure 5: Maximal load approach for households basic equipment compared to a typical general today´s load approach

SUPERPOSITION OF LOAD APPROACHES FOR FUTURE TECHNOLOGIES

According to the household equipment the results offer an array of maximal and minimal simultaneity factor curves of the superposition of basic equipment, heat pumps (hp), electric cars (ev) and photovoltaic power plants.
The curves of new assumptions of household load patterns are represented in figure 6. This exemplary case shows the demand-sided load approaches, which are determined by adaptation of equation (4).

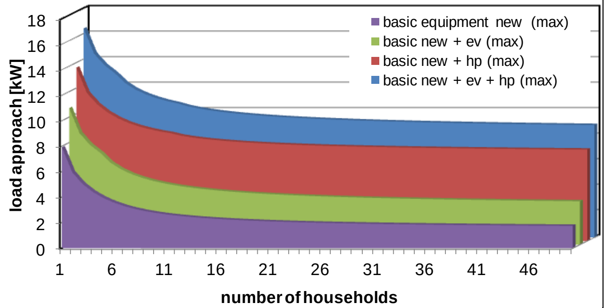

Figure 6: Curves of new assumptions of household load patterns (penetration level 100 %)

As easily can be seen, new technologies like electric cars and heat pumps could have a significant impact on private households load approaches. This also applies for lower penetration levels than 100 %. For a number up to 50 households the load approach can increase on multiple values. As already named the smaller gradients of the curves are also identifiable after superposition. In conclusion the implementation of low-voltage grid calculations might be simplified. There is no need to differentiate between separate grid calculations for capacity utilization of transformers and lines, then. This study will be presented in a later publication.

As these load approaches result on the supposition that the penetration level amounts to 100 % and the development of today´s ordinarily negligible penetration level of the new technologies is unknown, the implementation of a technology-sided variably penetration level is required. Four scenarios for penetration levels of future technologies are considered:

- low-level development
- moderate mid-level development
- dynamic mid-level development
- high-level development.

This model diversification enables a more precise model setting concerning the different possible future developments.

CONCLUSIONS

The main results presented in the paper are:

1. The changes in private household technologies necessitate urgently new assumptions of household load patterns and their simultaneity factors.

2. The rising impact of photovoltaic power plants requires the additional implementation of a minimal simultaneity factor.

3. Heat pumps have to be regarded in low-voltage grid design as the new technology with the demand-sided highest impact on low-voltage grids.

The new method introduced is the basis for a much more cost efficient LV-grid design than the simultaneity factors used in the past.

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