Sebastian Palm, Marco Weisenstein

Grid Operation and Planning with Modern Loads: Comparison of Low-Voltage Analysis with Yearly Energy and Coincidence Curves

1 Motivation

The composition of electrical loads in low-voltage grids is undergoing rapid change. New types of electrical consumers such as electric vehicles (EV) and heat pumps (HP) are replacing other energy sources and lead to a greater utilisation of the existing power system. Existing grids have to be re-evaluated taking these new consumers into account and weak points have to be remedied in a forward-looking manner.

Although the availability of concrete measured values is increasing in the context of digitalization with smart meters, it is not to be expected that grid operators will have the active and reactive power of all individual connections available as time series in the future for reasons of data protection and the need for data storage and communication. Therefore, it will still be necessary to execute load flow calculations to evaluate the network utilisation with the use of as little data as possible, only by categorizing the types of load.

Often, the grid operator knows the annual energy demand of the metering points as well as the highest current or power over a year (e.g. via drag indicator) at the MV/LV-transformer. With this method, however, there is also the problem of taking new loads into account appropriately. Another way to find suitable load settings for the load flow calculation are coincidence curves.

This contribution aims to show how the grid utilisation and voltage profiles can be estimated as accurately as possible with as little information as possible. At the same time, critical cases must not be overlooked. For this purpose, the methods:

- Peak load assumption of the loads,
- Usage of the yearly energy consumption, and
- Low-voltage analysis with coincidence curves

are investigated. In all three methods, distributed generation can be considered, too. For the load case considered here, however, generation is neglected.

2 Benchmark Grid and Methods for the LV Load Modelling

2.1 Investigation Environment and Benchmark

To show the differences between the modelling methods, a simple example grid is used, see Fig. 1. The LV grid contains households (HH) as well as a high share of private charging stations for EV. The consideration of HP is also possible, but has been omitted in this example for the sake of simplicity.

For this grid, times series over the course of a year were created using synthetic load profiles based on a probabilistic method according to [1]. This enables an individual yearly energy demand of all HH loads as well as the identification of the peak load moment in the year. At the peak load moment, 80 % of all EV are charging. The load flow results at the peak load moment are used as a benchmark (BM) for the investigated methods. The yearly energy demand as well as the power demand of the loads in the benchmark case are given in Fig. 1.

2.2 Worst Case Peak-Load Assumption (WC)

In the peak-load assumption, the maximum active power is assumed for each metering point. The aim of this method is therefore to obtain the worst-case results. In this investigation, the following values are assumed:

- HH: S = 24 kVA (equal to the power capacity), $\cos\varphi = 0.95$
- EV: P = 11 kW, $\cos\varphi = 0.99$

2.3 Yearly Energy (YE)

In this method, the measured yearly energy is used to distribute the power measured by a drag indicator (highest value over a longer period of time) at the MV/LV transformer over all load elements. For this, eq. (1) is used.

$$S_{\text{load 1}} = \frac{E_{\text{load 1}}}{\sum_i E_i} \cdot S_{\text{drag indicator value}} \quad (1)$$

The yearly energy from the synthetic load profiles in the benchmark grid are used for the HH loads in this investigation.

- HH: according to benchmark grid (1786 kWh up to 7045 kWh), $\cos\varphi = 0.95$
- EV: E = 4373 kWh

2.4 Low-Voltage Analysis with Coincidence Curves (CC)

For the application of coincidence curves, the peak powers according to 2.2 are used as base values. The peak load can also be calculated from the yearly energy using different mathematical approaches like the Velanders equations [2], however, this is not part of this investigation.

Coincidence curves $g(n)$ take the stochastic consumption behaviour of low voltage loads into account. They depend on the number of customers n of a specific load type connected to the investigated node. Possible curves for coincidence curves of HP, EV and HH are shown in Fig. 2.

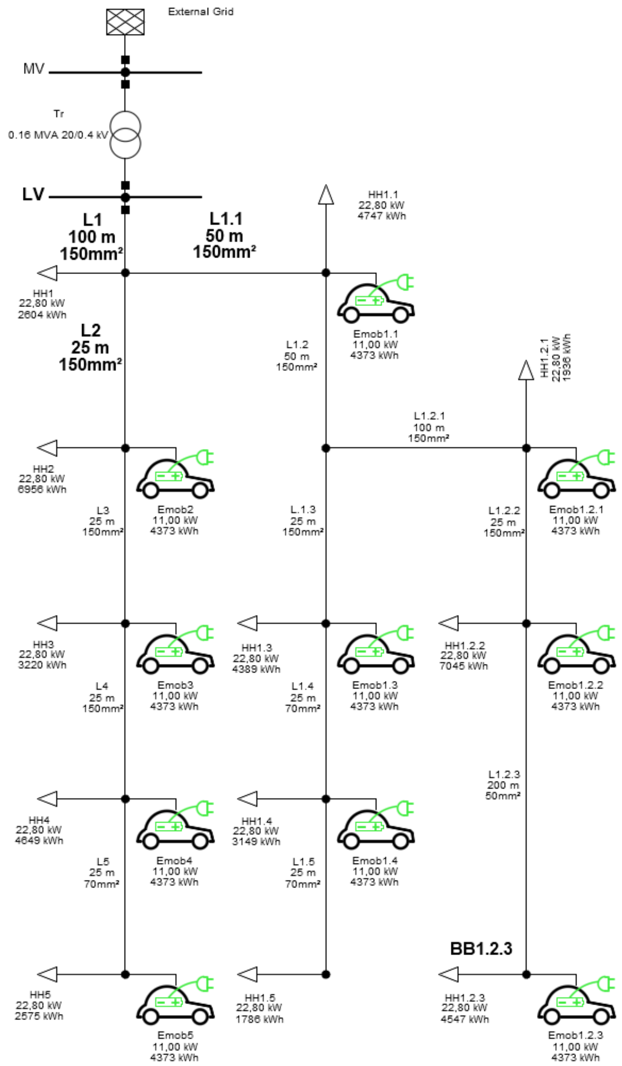

Figure 1: Single-line diagram of the analysed grid

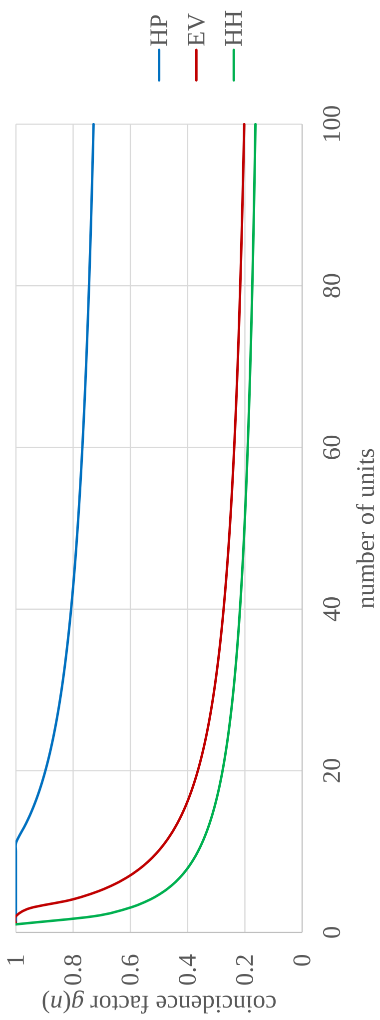

Figure 2: Coincidence Curves according to [2] and [3]

If all load types are treated independently from each other, the contribution of a load type at each point in the grid can be calculated with (2).

$$S_{\text{type 1}} = g_{\text{type 1}}(n_{\text{type 1}}) \cdot \sum_{i} S_{\text{peak type 1}\,i} \tag{2}$$

It should be noted that Kirchhoff's current law (the sum of all currents is zero at each node) is not valid in these calculations, as the coincidence factor can be different at each branch connected to the same node.

3 Simulation Results and Discussion

3.1 Results

Table 1 shows the load flow results of relevant grid elements with the different methods.

Table 1: Loading and voltages at relevant lines and busbars for the different methods

Variable	Element	BM	WC	YE	CC
Loading	Transformer	**104,3%**	**289,0%**	**104,9%**	**105,3%**
	L1	**85,2%**	**236,5%**	**85,6%**	**86,0%**
	L2	23,9%	**83,0%**	32,7%	48,0%
	L1.1	59,8%	**139,6%**	50,5%	63,5%
Voltage	LV	0,964 p.u.	**0,888 p.u.**	0,963 p.u.	0,959 p.u.
	BB1.2.3	**0,930 p.u.**	**0,839 p.u.**	0,945 p.u.	**0,921 p.u.**

The CC method provides the best results in terms of network planning and operation. Without requiring many input parameters, CC is able to identify critical points in the network. In contrast to YE, CC is always on the safe side without generating excessively extreme values like WC.

3.2 Conclusion

All three methods can be used to evaluate LV grids for possible loading and voltage issues. However, the WC method overestimates voltage deviations and the loading of lines and transformers by a large degree. Network planning based on these results would lead to a huge over dimensioning of the grid.

With the YE method, values are calculated that are closer to the benchmark case. In some cases, however, the loading and the voltage deviations are underestimated compared to BM. The addition of new load elements is problematic with this method because no values for the yearly energy of the new loads are known and the existing drag indicator value cannot be used because it was measured without the new loads.

With the CC method, much more precise results can be obtained. Since network branches with fewer network connections tend to be rated more critically, voltage problems can be predicted more easily. At the same time, the loading at the beginning of the feeder is not highly overestimated. The comparison with BM shows, that the extreme values are detected and that calculations are still on the safe side. Using a calculation with CC, it is easy to consider new additional load elements because only an estimated peak load value is needed. A forward-looking and moderate network expansion is thus possible.

Literature

[1] Nicolas N., "Synthesis of domestic load curves for low voltage grid simulations," *in 2017 IEEE Power and Energy Student Summit (PESS)*. Erlangen.

[2] Dickert J. and Schegner P., "Residential load models for network planning purposes," *in 2010 Modern Electric Power Systems*, 2010, pp. 1-6.

[3] Kippelt, S.; Wagner, S. and Rehtanz, C., "Consideration of new electricity applications in distribution grid expansion planning and the role of flexibility," *in 2017 International ETG Congress*. Bonn.