LOSS CALCULATION AND OPTIMISATION IN LOW-VOLTAGE NETWORKS

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ABSTRACT

Technical energy losses in low voltage networks are usually estimated by balancing feeded and delivered energy of the analysed grid area, but generally it is not possible to derive information for loss reduction opportunities out of these data. The proposed method calculates grid losses in low voltage networks and takes the effect of short time load peaks as well as unbalanced loads into consideration by using standard load profiles in connection with an obtained loss correction function. It provides the option to point out high loss areas or equipment owning a high potential for loss reduction, to allow optimised investments in development and maintenance of the system.

INTRODUCTION

In general grid losses are determined by balancing the infeed and outfeed of an analysed grid area, respectively losses are calculated by load and loss factors but both methods have their specific drawbacks. The balancing method does not distinguish between technical- and non-technical losses whereas the loss factor method is based on assumptions that are not generally valid for nowadays distribution networks [1] [2]. To optimise the losses in low voltage systems consisting of various assets it is necessary to work out the amount and the localisation where the losses occur. Due to the fact that the DSO's are faced with an extensive change in their distribution networks (decentralised generation, increasing load demand, rural depopulation…) it is necessary to utilise existing data and new available information for optimising network efficiency for future tasks.

Data of existing load profile meters combined with new available data from smart meters allow a real load data series based loss calculation. Therefore it is elementary to have detailed asset data bases to point out high loss areas or equipment. To use these specific data several dependencies must be known. For example by converting metered data to 15-minutes-energy values, information about short duration load peaks loads gets lost. Furthermore the metering data will often be only available as a total power of the three-phase energy supply system, but the devices are primarily single-phase loads, effects of unbalanced loads are usually not calculated. These specific factors as well as an application example using data of a genuine low voltage distribution grid are shown at the following pages.

EFFECTS OF SIMPLIFICATIONS

By calculating grid losses using 15-minutes-energy values from smart meter databases several inaccuracies occur because of the simplification of using balanced loads and metering mean values. For this reason a comprehensive inquiry based on high resolution measurement data was carried out to determine the influence of measurement value averaging time and load unbalance on loss calculation results in different low voltage network areas.

Influence of averaging time

The high amount of individual loads in low voltage systems, their individual cycle time as well as their different starting currents are resulting in a high level of short term load fluctuation (Figure 1). If 15-minutes-measurement-values from metered data (Figure 2) are used for loss calculation the effect of typical short term load fluctuations should be known.

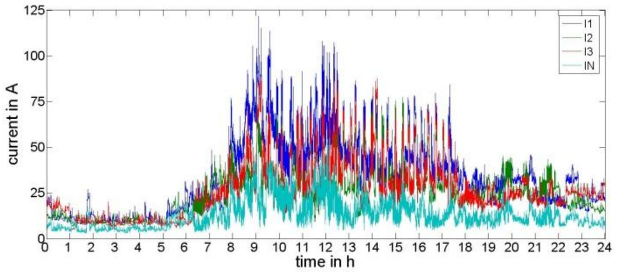


Figure 1: Measured load profile over 24 hours - measurement mean value of 1 second

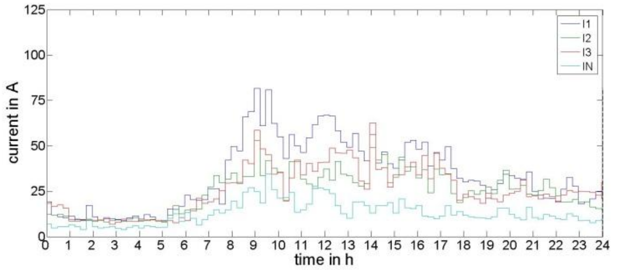


Figure 2: Measured load profile over 24 hours - measurement mean value of 15 minutes

Due to the active-power-losses quadratic dependency from the according current and the consideration of short term load peaks, the calculated losses yield to higher values, as can be seen in Figure 3, calculated based on one-week measurements, performed on 50 low voltage branches. It is evident that especially for lower loads and higher demand fluctuation (outer grid branches) the results of a loss calculation based on one second mean values differ by up to more than 20 percent in comparison to a loss calculation based on 15 minutes mean values.

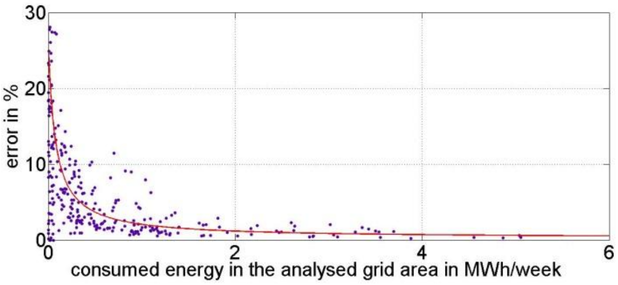


Figure 3: Error in loss calculation using 15-minutes-average values instead of using one-second-average-values

Figure 3 illustrates that a factor taking the measurement averaging time into consideration is only necessary in very detailed analysis.

Influence of unbalanced loading

Due to the fact, that low voltage systems consist of numerous amounts of single phase devices and an increasing number of installed generators, unbalance is also a factor for the increase of losses. Based on the same measurement data, the impact of unbalanced loads for loss calculation is analysed and expressed as load unbalance factor (LUF).

$$LUF = \frac{W_{V(unbalanced\ load)}}{W_{V(balanced\ load)}} \qquad (1)$$

The following Figure 4 shows the difference in the result of a loss calculation using true measurements (unbalanced loads) in comparison to calculated balanced loads.

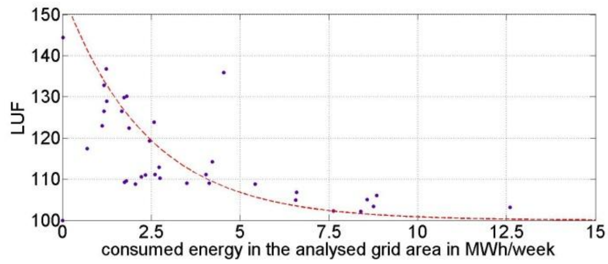


Figure 4: Loss calculation results considering unbalance in comparison to the result of a balanced calculation

The major differences between balanced and unbalanced calculation occur as expected in areas with a low superposition of loads. In this area the unbalanced power losses can reach up to 6 times the balanced ones.

Because of the actual low penetration of load-profile-meters in ordinary low voltage grids a loss calculation can be done by using the knowledge of the assigned standard load profiles and the yearly energy consumption of a customer. For these cases a factor was calculated from the performed measurements taking into consideration the effect of averaging short term load peaks and unbalance in relation to the annual energy consumption.

Calculated loss correction function

The loss correction function was calculated out of 50 single measurements mostly carried out in urban residential areas with a share of commercial demand up to 20 percent. It demonstrates the difference in the result of a loss calculation between the use of real measurement data and synthetically generated load profiles based on standard load profiles [3] and the amount of transmitted energy. In the following Figure 5 the result of the measurement analysis is displayed by the loss correction function. The function shows the results of loss calculations using standard load profiles and transmitted energy in ratio to the calculation results based on real measurement data.

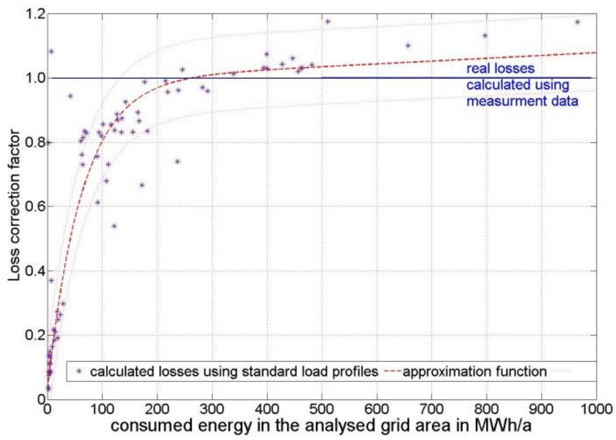


Figure 5: Loss correction function to take account of unbalance and short term load peaks by using standard load profiles for loss calculation (100 percent corresponds with losses calculated on measured load data)

The losses can be calculated according to the following formula 2.

$$W_V = \frac{W_{V(standard\ load\ profile)}}{LCF} \qquad (2)$$

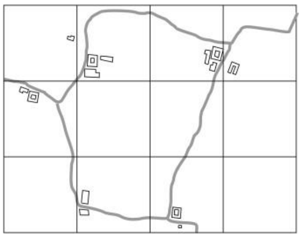
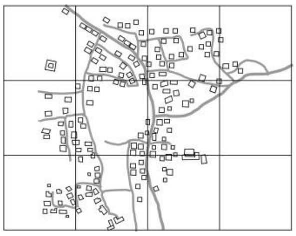
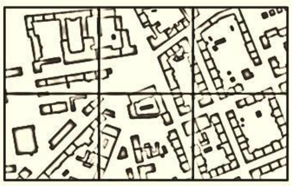
With a consumption of about 250 MWh/a (~70 households) the losses calculated using standard load profiles (including short time load peaks and unbalanced loads) equals to the losses calculated based on measurement values. Below 250 MWh/a the losses calculated on standard load profiles are underestimated, above 250 MWh/a the losses are overestimated.

INVESTIGATED LOW VOLTAGE GRIDS

A real distribution network was digitalised to accomplish load flow calculations using the generated loss correction function. For this reason single stations were categorised into the following settlement areas (Table 1) to show the impact of unbalance and short term load peaks on line losses in various grid areas.

Settlement areas

Table 1: Studied settlement areas

Area	Top view	Nr. of branches
Rural		46
Village		98
Provincial suburban		90
Provincial urban		115

Loss calculation

A key task of the implemented loss calculation routine was to join various databases. So the asset databases (conductor data, meter data, connection status, fuse data) were combined with the geographical information system (topology) and the customer database (producer, consumer, available metered load profiles, associated standard load profiles, transmitted energy).

Afterwards every low voltage station is divided into its single feeder branches. In a first step the impedance matrix for each feeder of the investigated local network station is formed. If available, a measured load profile is assigned to each measuring point. In cases in which no measured load profile is available the assigned standard load profiles are adjusted corresponding to the annual energy demand. Thereafter the loss correction factor is calculated for every line. Using this data the algorithm calculates the losses, for every quarter of an hour per year, based on simple load flow calculation.

RESULTS OF LOSS DETERMINATION

The following evaluation shows only the line losses (excluding fuses, transformers, measurement losses...). The power factor of the load was assumed according to the type of load profile and remained constant over the whole calculation period, if there were no measured values available.

Deviation within a settlement area

The calculation results of a single settlement area show that the deviation within an area is large and ranges up to about 3 percent per branch, as shown in the following Figure 5 using the settlement area provincial urban. This deviation results mainly from the large variety of topologies and load composition at the single grid branches in the low voltage grid.

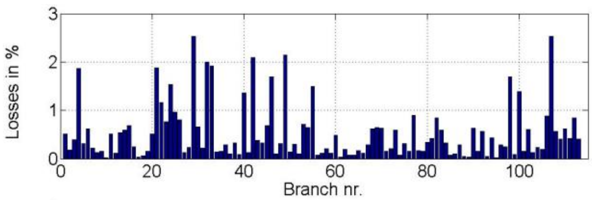


Figure 5: Calculated energy losses in percent referenced to the transmitted energy on the branches of the settlement area provincial urban

Effect of loss correction function

The developed loss correction function is an important part of the performed investigations; the effect is graphically shown in the following Figure 6 using the example of settlement area village. The first bar chart shows the energy losses calculated per low voltage branch per year.

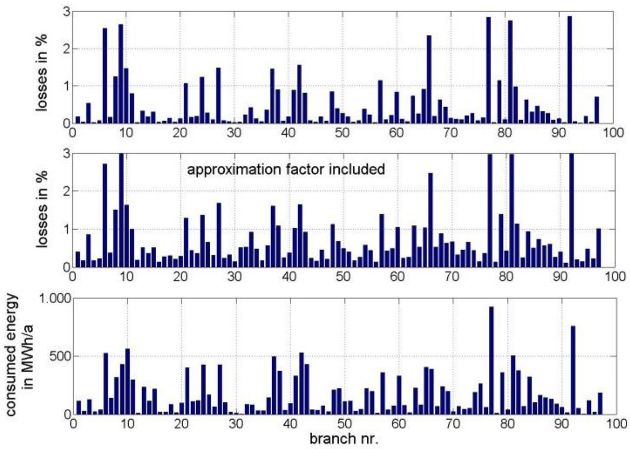


Figure 5: Calculated energy losses in percent (1+2) referenced to the transmitted energy (3) on the branches of the settlement area village.

The second bar chart additionally includes the loss correction function. Especially branches with small amounts of transmitted energy now show a higher share of the losses.
A closer look at the single settlement areas shows that the effect of the loss correction function has an especially strong impact in rural areas, which can be explained by the often long transmission lines and the comparatively low load densities as shown in table 2. In provincial urban areas is effect of the loss correction function is substantially less marked, so the result of the energy loss calculation rises in the selected grid area by an average of about 10 percent.

Table 2: Calculated line losses in percent of annually transmitted energy with and without loss correction function

Area	Average energy loss in percent of transmitted energy	
Loss correction function	NO	YES
Rural	0,97	1,28
Village	1,13	1,34
Provincial suburban	0,77	0,86
Provincial urban	0,88	0,94

CONCLUSIONS

By evaluating the high resolution measurements, the impact of unbalance and short term load peaks on energy loss calculation in low voltage grids is shown, depending on the annual transmitted energy and a derived loss correction function. These effects are especially relevant in areas with a low level of load superposition (Figures 3 and 4, Table 2).
The application of the developed loss correction function on different settlement areas of a real low voltage grid points out that the loss calculation based on standard load profiles leads to high differences especially in rural areas with a low load density. This effect is much smaller in provincial urban and suburban areas.
Furthermore the topology of low voltage distribution grids varies in a wide range. This fact can be especially seen in the transmitted energy per low voltage branch. To point out assets with major losses, a detailed calculation as shown in this paper is necessary. Because of the fact that a main part of the costs for loss optimisation in cable networks originates from the underground works it is usually not economically attractive for system operators to realise loss affected changes in the system topology. For this reason a processed algorithm can be an option to point out economical and efficient possibilities for loss reduction.

OUTLOOK

In a next step the additional losses of fuses, meters and transformers will be integrated into the existing grid model to analyse the share of total losses in mid and low voltage distribution grids.
In the future additionally available metering data from smart meters will also allow to point out high loss areas or equipment owning a high potential for loss reduction.

ACKNOWLEDGEMENTS

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[4]