DETAILED ANALYSIS OF NETWORK LOSSES IN A MILLION CUSTOMER DISTRIBUTION GRID WITH HIGH PENETRATION OF DISTRIBUTED GENERATION

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ABSTRACT

Understanding network losses is important regarding energy efficiency and grid regulation. A method was developed to determine grid losses for each voltage level of a distribution grid and to investigate the influence of distributed generation and reactive power. The losses in an actual distribution grid in northern Germany with a high share of PV and wind energy are calculated.

Keywords: grid losses, grid regulation, distributed generation, reactive power provision

LOSSES, EFFICIENCY AND REGULATION

Understanding grid losses, their origin and determination, is important considering energy efficiency and grid regulation. Grid losses are divided in technical and non-technical losses. A categorization is shown in Figure 1.

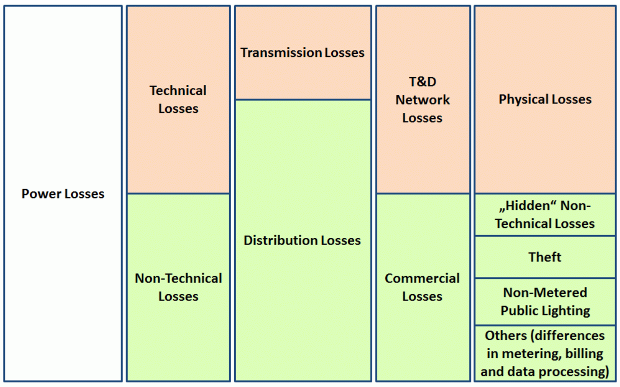

Figure 1: Categorization of losses [1]

The main part occurs in the distribution system and its amount is ranging from 2.3 to 11.8% in European countries [1]. But these figures have to be examined carefully as the definition is not harmonized. Nevertheless the grid itself is one of the biggest energy consumers and the regulating authorities have in mind that the losses are one lever to reach European energy efficiency targets. Accordingly the grid losses are more and more considered in the frame work of yardstick regulation. For example in Germany [2] and Sweden [3], first a fixed amount of losses will be set for each grid operator. Costs exceeding this fixed amount are not covered. In the next regulating period it is planned to summarize losses under "in the long run" controllable costs.

THE INVESTIGATED DISTRIBUTION GRID IN NORTHERN GERMANY

In the investigated distribution grid on LV level there are about 1.4 million residents with approx. 0.8 million end consumer connections to the LV grid, about 3000 customer connections to the MV grid and a few connections on substation and secondary substation level. On MV level the supply with electrical energy is realized on different voltage levels. The electric system consists of about two thirds of 20 kV and one third of 10/11 kV grids. Few of the MV grids are not directly connected with an own HV/MV substation to the HV grid. Instead their connections to the HV grid are realized by 30 kV or 60 kV MV grids, which are connected to an own HV/MV substation. More than 80% of the lines are cable, whereas the rest consist of overhead lines. By the end of 2011 3500 MW of distributed generation (DG) power is installed in the investigated distribution grid. This is approx. 150 % of 2008's installed DG power. With about 70 %, wind energy has the major share. About 20 % of the DG is contributed by PV and about 8 % by biomass. With the engineering progress in the wind industry the rated power per wind turbine increased and the newer installed turbines and wind farms are mostly connected to the HV/MV substations directly or by a single line, just rarely directly in the MV grid with an own transmission station. Therefore in the past few years the distribution grid operator has built several HV/MV substations and HV/MV transformers in already existing HV/MV substations exclusively connecting wind farms.

The federal state government declared that by the end of 2012 there are new suitable areas for the operation of wind turbines available. With this decision the effective surface for the operation of wind turbines nearly doubles. The grid operator expects about 7000 MW additional wind power on the new areas and repowering on already existing areas up to 2020. Due to the amount of additional wind energy, the required grid expansion and the described direct grid connection types of wind farms, the grid operator anticipates increasing grid losses in the distribution grid, particularly in the MV grid and on the level of HV/MV substations.

COMBINED METHOD FOR THE DETERMINATION OF GRID LOSSES FOR EACH GRID LEVEL

Loss calculation is based on the technical data of grid components and the profiles of energy demand and generation. These data are normally used for different purposes (e.g. planning, maintenance and service, reporting, billing) and stored in different and heterogeneous data bases. Profiles could be available as measured profiles or as yearly consumption to be combined with standardized profiles. Especially for the LV grid the data are rarely ready to be used in load flow calculations. Therefore we have developed a model for the LV grid with categorized building blocks based on the approach presented in [4] and combined them with load flow calculations over one year in 15-min-intervals on MV level. The model followed a bottom-up approach from the LV grid to the substations and was validated with the measured energy profiles of the substations.

LV grid

From GIS data the location, length and type of the lines and the number and type of consumers were retrieved. The components were allocated to a secondary substation using an especially developed automatic grid sectioning algorithm. The grid losses are proportional to the impedance and the square of the current. We mapped these parameters with the line length and the demand and defined three network classes, with expected losses being low, middle and high (blue, red and green area in Figure 2). Each point in the scatter diagram of Figure 2 is representing one local grid.

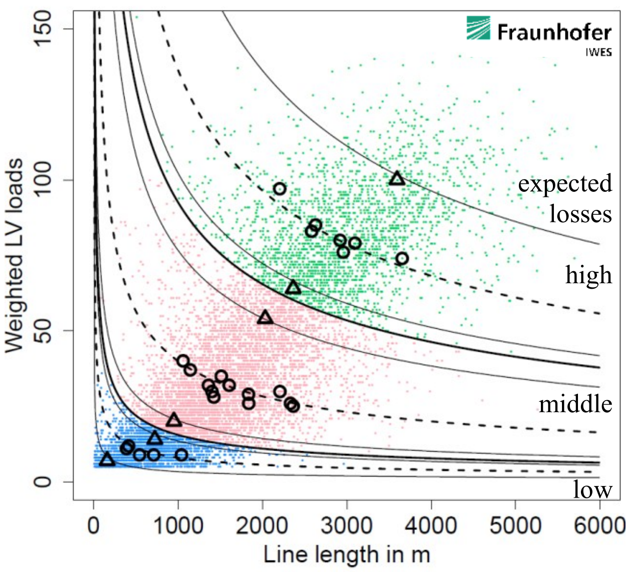

Figure 2: LV grid classification

The lines in Figure 2 are level curves of expected losses, the dashed lines showing the median of a grid class. Along these medians reference grids (circles) were chosen. For each grid the network impedance and then the average for each grid class was calculated. For validation the average of each class was compared to a test grid chosen from the 0,125- and 0,875-quantile (triangles in Figure 2).
In a similar way the average load profile for a grid class was identified and, using the building block approach described in [4], applied to the concentrated network impedance of its class. Furthermore, the local grids were assorted to three classes of DG coverage and combined with the grid classes. For each of the resulting nine building blocks the losses were calculated and multiplied by the number of LV grids represented by it.

MV grid

The losses in the MV grid were calculated in a load flow calculation. All MV customers, DG installations and MV/ LV substations were represented by a 15-min-profile and the losses were cumulated over one year. For the investigated distribution grid about 18000 profiles had to be implemented in the load flow calculation.

Losses per grid level

With the developed method the losses can be calculated per grid level. These separate figures can be used for detailed benchmarking and the allocation of efficiency efforts. The distribution of the overall losses on the grid levels is shown in Table 1. It differs significantly from the distribution identified for a grid area in France by ERDF [6]. Such differences emphasize the importance of an individually and detailed analysis as basis for grid planning.

Grid levels	northern Germany	France [6]
HV/MV substations	10%	17%
MV grid level	34%	28%
MV/LV substations	14%	36%
LV grid level	42%	14%

Table 1: Distribution of the losses on the grid levels

Losses in transformer stations

Transformer losses are divided in load dependent copper losses and load independent iron losses. The transformer rating in respect to the expected load and the type of the core determine the iron losses. These two parameters should be carefully considered regarding loss reduction. The iron losses in the investigated grid account for 58% of the losses in the HV/MV and 79% in the MV/LV substations.

LOSSES AND YARDSTICK REGULATION

The yardstick regulation is becoming more and more detailed for each regulating period. Losses are one of the issues to be developed. In Germany this development starts with losses treated as a fix amount of costs. Reducing these costs during the regulating period is for the benefit of the network operators. In the following regulating period losses could be treated as “controllable costs in the long run” [2]. Therefore understanding and influencing losses is gaining importance for the grid operators. And for the benchmark the regulation authorities have to define losses and their controllability in a proper way.

General influence of DG

In the beginning grid losses in a specific area will be reduced with DG installed. Some regulating authorities are referring explicitly to this fact [3]. But with growing DG penetration or coverage, and depending on the synchronism of demand and generation this effect could fade out and be reversed. The qualitative development of grid losses with DG is shown in Figure 4 with DG penetration being the installed DG power in reference to the power demand in a network area and the DG coverage calculated on a yearly basis as DG feed-in energy over the total energy demand.

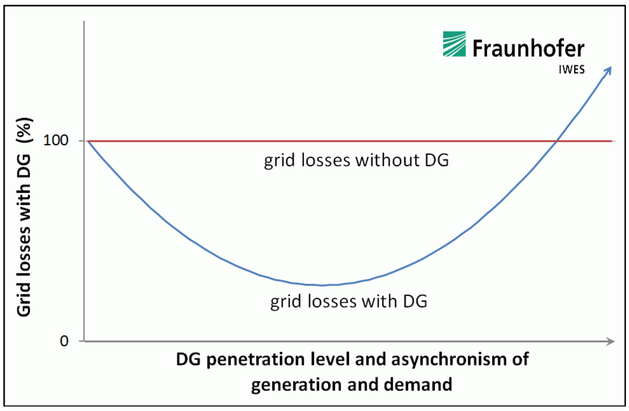

Figure 4: Qualitative development of grid losses with DG

DG, DSM and loss reduction

Demand side management (DSM) in grid operation is used to synchronize generation and demand. If demand and generation can be synchronized locally, transportation losses can be avoided twice. At full asynchronism losses occur first for transporting DG power to neighbored grid areas or higher grid levels and second for bulk power supplying local consumers, e.g. off-peak heating systems loaded at night in local grids with PV surplus [5]. These losses could be avoided by smart grid operation.

Definition of grid losses

For yardstick regulation a benchmark has to be defined. Regarding losses this is likely to be a percentage of the total energy with input or output of the grid as reference. The actual reference differs from country to country [1]. But as described above the evaluation of DG penetration or coverage is also important especially regarding the reference. The benchmark for grid losses should not only refer to the energy input or output of the grid, but also to the DG coverage, thus influencing the efficient and smart system operation involving DG.

INFLUENCE OF DG FEED-IN AND OF THE CONCEPT OF REACTIVE POWER PROVISION

A sensitivity analysis was performed for two MV grid areas that are comparable by size but with a considerable difference regarding the DG coverage. Interconnected local LV grids are represented by their load/ feed-back profile. In grid area 1 the actual DG coverage for 2011 reaches 46%, and 141% in grid area 2. Table 2 comprises structural data of the investigated grid areas.

	Area 1	Area 2
DG feed-in (MWh)	28970	103989
Demand (MWh)	63608	73956
No. of MV connected DG	11	50
No. of MV connected customers	33	30
No. of secondary substations	146	134
MV line length (km)	155	229

Table 2: Structural data of grid area 1 and 2

Grid losses and DG penetration

The development of grid losses regarding DG penetration was investigated for the LV grid using the nine building blocks and for the MV grid using load flow calculation for the two described grid areas. The status of 2011 is set as reference for the grid losses. The bars in Figure 5 and 6 show the development of the losses and the line the expected grid losses without any DG installations.

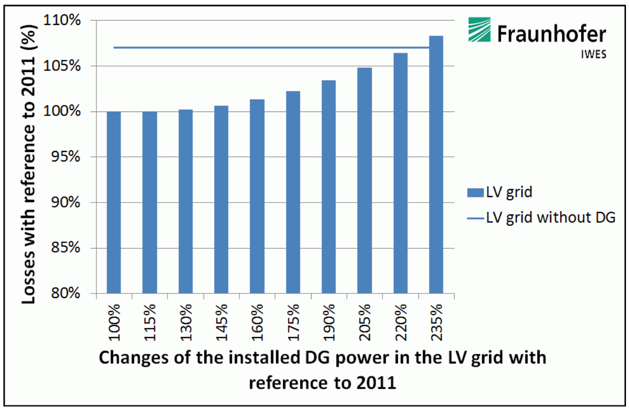

Figure 5: Installed DG power and LV grid losses

For the LV grid the actual losses are well under the one for the case without any DG, but the loss minimum is already reached and with further DG installations the losses will increase.

In MV grid area 2 significantly more energy is produced than consumed. The actual losses are higher than in the case without DG. Even with a reduction of DG by 30%

the losses are still higher. In grid area 1 the loss minimum is almost reached with the actual DG installation. The slope of the loss curve for the reduction of DG power is very small. Up to 30% it is not changing the amount of losses visibly.

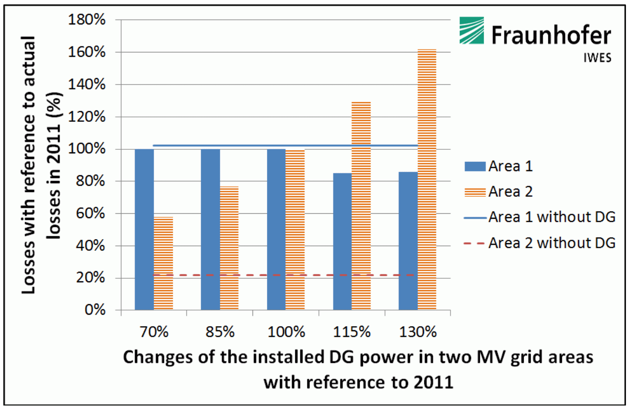

Figure 6: Installed DG power and MV grid losses

Grid losses and reactive power provision

According to the interconnection guidelines in Germany the grid operator can request reactive power by the DG. Four kinds of reactive power provision are possible [7]: cosφ = const., cosφ (P), reactive power Q = const., and voltage dependent reactive power Q(U). These concepts can be used to enhance the DG hosting capacity of the grid [8]. The actual concept in use by the grid operator is cosφ = const. For each DG installation an individual value is set according to the grid planning. The sensitivity of grid losses for changing the concept to cosφ (P) was calculated following the example of the guideline depicted in Figure 7.

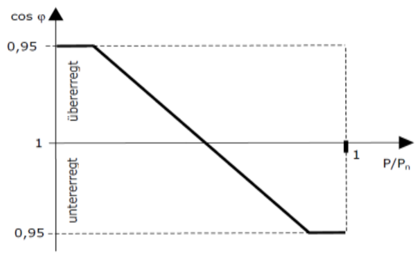

Figure 7: Example for cosφ (P) [7] (untererregt = under-excited; übererregt = over-excited)

The influence of the power provision concept is clearly visible but does not follow the same direction (Table 3). It depends on the grid topology, the actual DG penetration and the set points for cosφ = const. of the different DG installations in the reference case.

Reactive power provision concept	Area 1	Area 2
cosφ = const.	100%	100%
cosφ (P)	85%	103%

Table 3: Grid losses for different reactive power provision concepts in grid area 1 and 2

CONCLUSIONS AND OUTLOOK

A combined method was developed to determine the grid losses of a distribution grid modeling the LV grid and integrating it into the MV grid load flow calculation. The distribution of the losses on the grid levels was determined allowing for the definition of benchmarks and the allocation of efficiency efforts.

The DG coverage and its reactive power provision play a major role regarding grid losses. For yardstick regulation a harmonized definition of losses and a benchmark definition are necessary considering the actual DG coverage. This could also provide incentives for utilizing the potential of DG installations in smart grid operation.

Further investigations will include improved validated models of low voltage grids.

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