POWER QUALITY ASPECTS OF RURAL GRIDS WITH HIGH PENETRATION OF MICROGENERATION, MAINLY PV-INSTALLATIONS

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ABSTRACT

This paper focuses on the influence of the harmonic emissions of power inverters of photovoltaic installations connected to the low voltage grids on the power quality in these grids. A method is developed to define optimal locations of power quality measurement sites in this type of LV grids, to analyze the influence of the harmonic emissions. In this process consumer, network and generation topologies of the grids are analyzed and compared, because these are the main factors that contribute to power quality. In the first project state three measurement locations in a rural German LV grid were selected. The results of these first measurements are analyzed with a focus on the harmonic emissions of the PV units. They serve for optimization of the measurement campaign.

Abbreviations

LV	low voltage	MV	medium voltage
S_{SC}	short circuit power	PV	photovoltaic
POS	point of supply	NSP	number of supply points

INTRODUCTION

The number of smaller generating units (especially PV installations) connected to LV networks have increased significantly during the last years in Germany. This ongoing development is mainly caused by the present political framework that actively promotes such smaller installations. In many cases profitable locations for PV generation can be found in rural areas, where surfaces on top of houses or farm buildings are available. Rural grids are usually weaker compared to the urban networks of larger cities, which means the short circuit power S_{SC} at the supply points is smaller. Consequently a higher risk exists for significant network disturbances.

The main intention of this paper is to analyze the relation between power quality (voltage and current quality) and network conditions in rural LV networks with a high penetration of distributed generation. Long term measurements at selected points will give an inside view to present quality levels and possible negative long term trends. A medium voltage ring in a rural region was selected for the project. For the connected LV networks, a detailed simulation model is available. The measurements started at the beginning of June 2010. This project is still in a very early stage and more extensive evaluations will follow in future publications.

MEASUREMENT SITE SELECTION

The LV grids are located in a rural zone in Germany in the federal state of Baden-Württemberg. There are 51 grids connected to the same 20 kV medium voltage grid and each grid is identified with a number. The loads are made up of single family houses or rarely small apartment buildings and few small businesses. More than 180 PV installations with rated power values from 5 kVA to 130 kVA are connected to these LV networks. The total peak power of PV installations is more than 2 MW.

Due to the high number of available LV networks compared to the low number of three measurement devices, a method had to be developed which allows an efficient choice of measurement locations.

Power quality is influenced by three factors: generation aspects, consumer aspects and network aspects. Generation aspects cover the quality of the voltage that is generated, while consumer aspects deal with current quality. Network aspects discuss how current quality and voltage quality are related. To find optimal measurement locations, all of these aspects need to be considered.

Network topology

For power quality, the most important aspect of a grid is the short circuit power. In the first step the short circuit powers of the networks were examined. This is the crucial indicator for the influence on the voltage disturbance caused by the load. The maximum short circuit power at the secondary side of the transformer and the weakest point in the grid is shown in Figure 1. The reference short circuit power for the evaluation of emissions given in IEC 60725 [2] is included in this figure. It can be seen from this figure that in many networks POSs with a short circuit power lower than the reference value exist.

It can also be seen in Figure 1 that the upper limits of the short circuit power of the networks appear stepped. This means, that in grids with the same maximum short circuit power the transformers have the same rated power and short circuit voltages, while the impedance of the MV grid can be neglected for the impedance.

For further distinction the type of network, whether radial or meshed, should be considered, since it also may have an

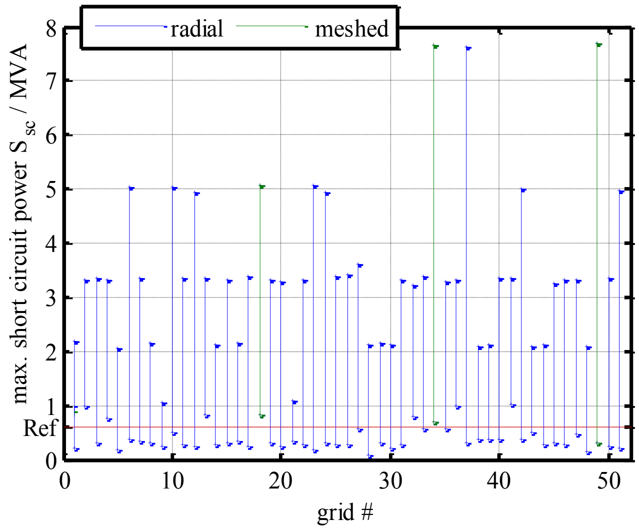

Figure 1: Range of the maximum short circuit power in the analyzed networks, reference short circuit power marked red

influence on the effective network impedance. It should be noted, that the grids are operated as normally open rings. The rings are closed in cases like high PV generation, to keep the voltage level within the limits of EN 50160 [1].

For the selection of measurement sites, the criterion is to perform measurements in grids with a large variety of short circuit power.

Consumer topology

In the second step, the consumer structure was analyzed. The types of customers are similar for all available grids. An important criterion for the comparison of networks is the short circuit power per customer. To also take the weakest points in the grid into consideration, the grid extent parameter is introduced. It is the variation of the short circuit power $\Delta S_{SC} = S_{SCmax} - S_{SCmin}$ divided by the maximum short circuit power S_{SCmax}. It is a suitable quantity to evaluate the size of a network, if no detailed information is available. Figure 2 shows the calculated results for all networks.

Highest levels of voltage distortion are expected in grids with a low power per customer and a high grid extent. The criterion for the selection of measurement sites is to receive a wide range of power per customer and grid extent values.

Generation topology

The main target of this project is to analyze the influence of PV units on power quality. Therefore, the generation topology is the most important part in the process of measurement site selection.

Three different variants of influences shall be examined, that are shown in Figure 3:

1. The difference between grids with a different number of PV systems and the same total PV power (blue)
2. The difference between grids with the same number of PV systems and different total PV power (magenta)
3. The difference between grids with a different number of PV systems and with the same PV power per PV unit (green)

Figure 3 shows parameters for all grids with PV installations, possible lines to identify potential measurement locations and the selected grids.

Selected grids

A reference grid with no PV installation and high short circuit power grid #27 was chosen.

Furthermore, two grids with similar PV power, but different short circuit power and different number of PV units were chosen. These are the grids #34 and #41. Table 2 shows the detailed grid characteristics for the selected grids. The results will be used in the analysis of the criteria mentioned in the section Generation topology.

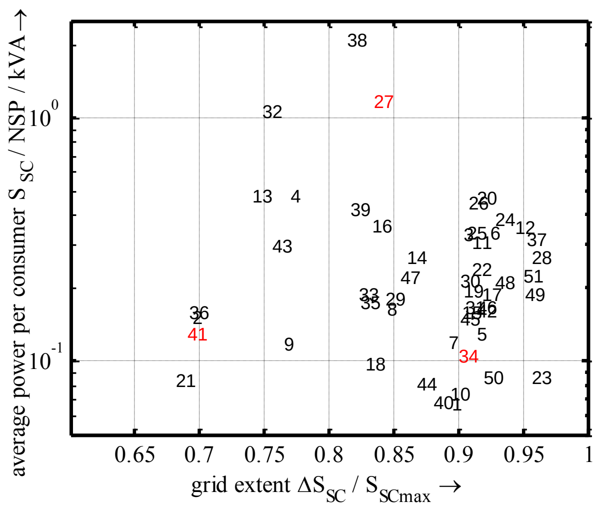

Figure 2: Short circuit power per consumer and grid extent, measured grids marked red

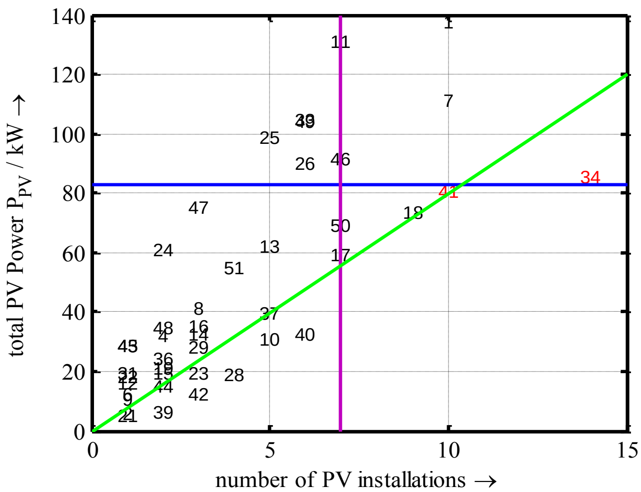

Figure 3: Installed PV power and number of PV installations, measured grids marked red, see section Generation topology for details

#	max line length	# supply points	total PV power	# of PV units
27	0.346 km	3	0/25 kW	0/1
34	0.459 km	72	85.64 kW	14
41	0.430 km	26	80.76 kW	10
S1	0.130 km	1	82.00 kW	1

Table 1: Consumer and PV details for measured LV grids

#	type	transformer rated power	max. short circuit power
27	radial	160 kVA	3.52 MVA
34	meshed	400 kVA	7.65 MVA
41	radial	160 kVA	3.36 MVA

Table 2: Grid details for measured LV grids

MEASUREMENT ANALYSES

With and without PV installation

During the measurements a new PV system was installed and commissioned in grid #27. Due to this circumstance, an evaluation of the same grid with and without a PV installation is possible. The active and reactive (inductive) power consumption is shown in Figure 4.

For the comparison, two Tuesdays with similar loads where chosen, June 1st and July 8th 2010, of which the later was a sunny day.

In Figure 4 the active power generation of the PV installation during daylight hours from 7 AM to 7 PM can be seen. The peak active power generation is reached at noon, as it would be expected. An active power demand only exists in the morning and evening hours, therefore it can be assumed that between 12:30 PM and 1:30 PM the PV system would the most significant impact on power quality.

The comparison of the harmonic current and voltage levels with and without the PV installation is shown in Figure 5. It

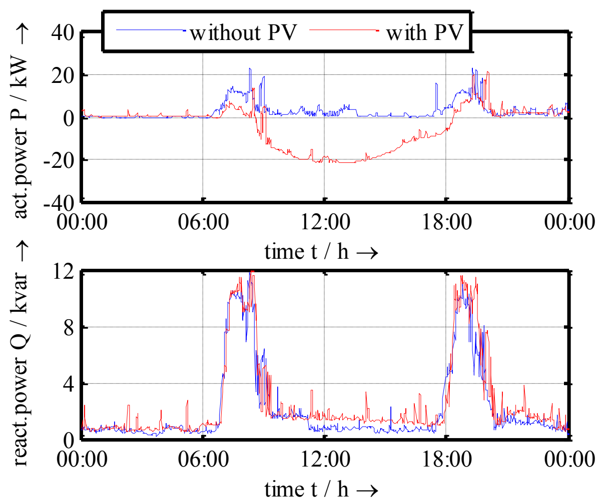

Figure 4: 3phase active and reactive power consumption with and without PV installation, grid #27

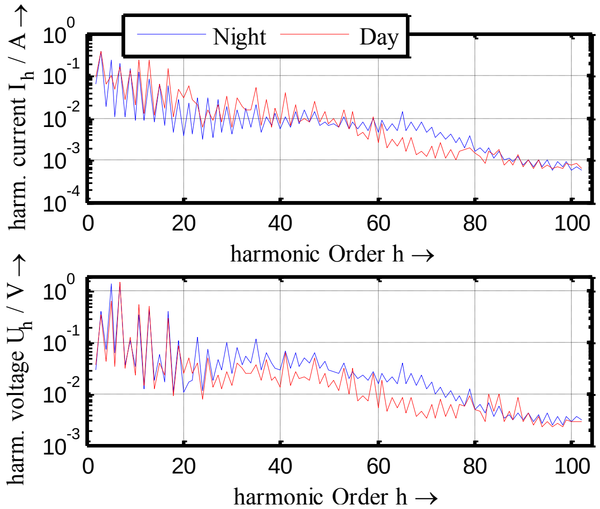

Figure 5: Harmonic levels at noon, 1 min values averaged over 1 h, L1, with and without PV, grid #27

can be realized from Figure 5 that the PV system seems to have increased the harmonic current levels slightly up to the 60th harmonic. However, very little influence can be seen in the harmonic voltage levels in this frequency range. Above the 80th harmonic, the levels even seem to have decreased. However, the LV distortion is a combination of impacts from the upstream MV and the LV grid, so explicit conclusions cannot be drawn.

To evaluate the difference between high and low generation periods, measurements from 12:30 AM to 1:30 AM (night) and 12:30 PM to 1:30 PM (day) on July 8th 2010 are compared in Figure 6. Since the differences in the harmonic current levels are lower between the periods of generation and no generation, the inverter appears to emit harmonic currents even during times of no sunlight.

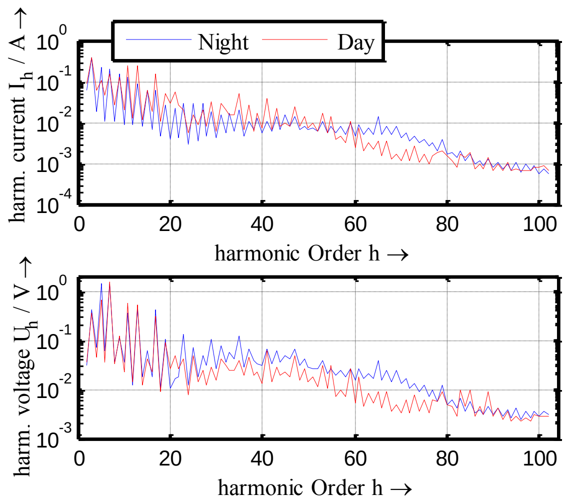

Figure 6: Harmonic levels at noon and midnight, 1 min values averaged over 1 h, L1, with PV, 8th of July 2010, grid #27

#	date	THDi	THDu	Unbalance
27	Jul8	2.75 %	0.82 %	0,06 %
34	Jul8	11.17 %	1.68 %	0,45 %
41	Jun5	9.09 %	2.36 %	0,50 %

Table 3: THD and unbalance values for analyzed grids, 1 min values averaged over 1 h

Comparison of grids

In Table 3 the THDi, THDu and unbalance values are given for all grids that were measured. For comparability, these values were taken from a 1 h period at noon on sunny days, so they show the maximum impact of the power inverters on the low voltage grid. The spectrum is shown in Figure 7 for the same time periods. In Figure 7 can be seen, that the harmonic voltages overall are highest in grid #41. The same grid also shows elevated harmonic voltage content around 2 kHz and 4 kHz, which is not visible in the current. The reason for this is yet unknown and subject to further investigation. It may have been caused by the upstream grid. The harmonic current emissions are highest for grid #34, which also has the highest number of consumers connected. This is a proof for the initial assumption that the power quality depends on the consumer behavior, which the grid selection is also based on. In the considered frequency range, all measurements show inconspicuous results. No significantly elevated harmonic emission levels up to 5 kHz are visible.

Higher frequency range

Based on these results, emissions at higher frequencies were expected and therefore the measurable frequency range of one measurement device was increased up to 40 kHz for just one line in grid #27. The results of this measurement for day and night on the same day are shown in Figure 8. It can be seen that emissions exist up to 40 kHz. The current and

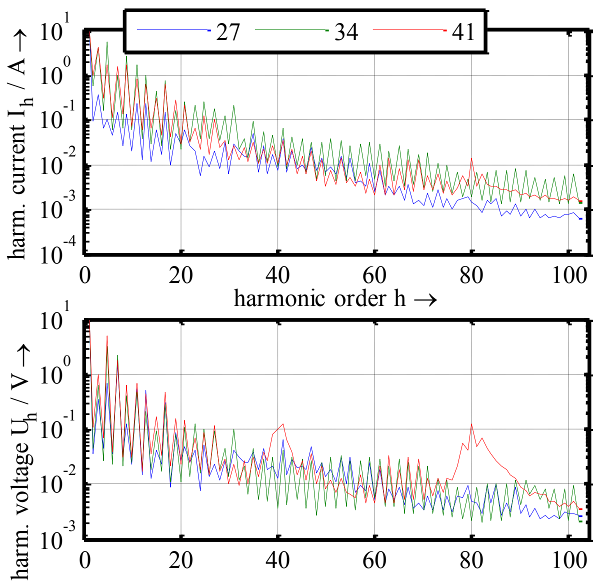

Figure 7: Harmonic levels in line 1 in all grids at noon, 1 min values averaged over 1 h, see Table 3 for details

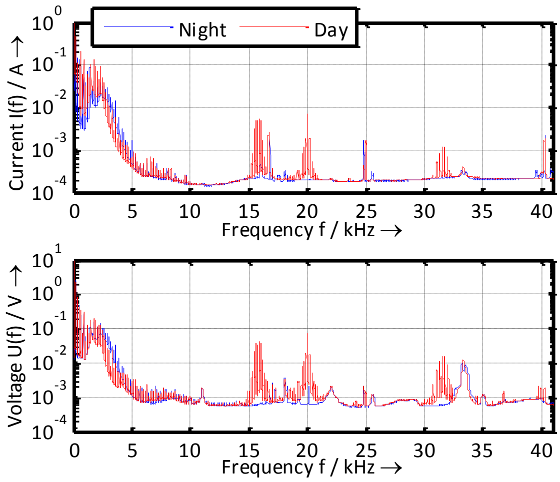

Figure 8: Spectrum measured in line 1 in grid #27, up to 40 kHz, 95% quantiles over one hour

voltage levels are increased at 16 kHz, 20 kHz and 32 kHz during the day, as compared to the night. Based on these results, all devices are upgraded to measure up to 40 kHz on all channels.

SUMMARY

In this paper a methodology for the selection of measurement sites is introduced. The method includes the evaluation of network, consumer and generation topology. Based on this evaluation, the first three sites were selected for measurement.

The initial results are analyzed in detail. All grids comply with EN 50160. Emissions caused by the PV systems were found above 10 kHz. These may cause interference with other equipment in the grid. Since emissions seem to occur at frequencies higher than 10 kHz, all devices are upgraded to cover the frequency range up to 40 kHz.

Such high frequencies are not yet covered by the EN 50160. Therefore, standardization and research activities at frequencies above 2 kHz need to be intensified. Future standards should include such higher frequencies.

In the course of this project, more sites will be selected and measured in the next years.

REFERENCES

[1] EN 50160: Voltage characteristics of electricity supplied by public distribution networks

[2] IEC 60725: Consideration of reference impedances and public supply network impedances for use in determining disturbance characteristics of electrical equipment having a rated current ≤ 75 A per phase