FIELD STUDY ON CHANGING GRID REQUIREMENTS DUE TO HIGH PV PENETRATION

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ABSTRACT: The low voltage grid has to be designed, to handle the maximum occurring load. Decentralized power production has no impact on the grid as long as this power is locally consumed. Efficient planning of the low voltage grid demands for indicators of the simultaneity of the feed in and the nominal power of a PV system. The E.ON Bayern AG project "Netz der Zukunft", which is a cooperation of the E.ON Bayern AG, the Technische Universität München and the University of Applied Sciences Munich, analyzes these new load patterns on the grid. A limiting factor for the maximum power output of the PV system is the inverter design. Considering the weather conditions two competing Scenarios arise for the maximum feed in power. With clear skies in summer the irradiation reaches values around 950 W/m² in Southern Germany. The generated power of distributed PV systems shows due to the homogeneous weather situation a high simultaneity. The high radiation levels come along with high module temperatures. Cloudy skies lead to reflections, causing increases of the global radiation up to values above the standard test conditions (STC). These irradiation enhancements meet low cell temperatures. The simultaneity of this phenomenon is due to the cloud movement lower as the one of clear skies. This paper shows that typical PV systems only need to be considered in grid calculations with 85 % of their rated STC Power

Keywords: see enclosed list of keywords

1. Interaction of Photovoltaic Systems with the Low Voltage Grid

The low voltage grid has to be designed, to handle the occurring maximum Load. Considering the demand, this load is not the sum of every household's maximum load as there is a temporal fluctuation of these loads. If more than 100 households are considered, the operating experience shows a resulting load per house connection of 1 kW.

Decentralized power production has no impact on the grid as long this power is locally consumed. The load flow in the grid, however, shows that especially on sunny weekend there is very little remaining local consumption and new load patterns occur on the grid. Therefore the ongoing installation of photovoltaic (PV) systems leads to new requirements. It turns out that in grids with a high PV penetration not the consuming households, but the in feeding households are decisive for the grid reinforcement.

Efficient planning of the low voltage grid therefore demands for indicators of the simultaneity of the feed in and the nominal power of a PV system. The maximum power in the grid is limited both by the limits of safety devices and equipment, as well as their thermal stability. Furthermore, each load flow results in a voltage drop at the grid impedance. Thus power consumption leads to a lower voltage at the house connection. The reversed power flow, however, increases the voltage at the grid connection points of the local generation systems. This causes problems for the grid operator since he must comply with normative limits of the voltage range, in Germany specified by the DIN EN 50160.

2. Scenario for the occurrence of the maximum load

The E.ON Bayern project "The Grid of the Future" (Netz der Zukunft), which is a cooperation of the E.ON Bayern AG, the Technische Universität München and the University of Applied Science Munich, analyzes these new load patterns on the grid [EBY-10]. A investigation of the load profiles of 150 distributed PV systems throughout Bavaria showed clear differences in the distribution of the respective maximum system performance in the years 2009 and 2010 [Bu-10]. Figure 1 illustrates that the day with the maximum feed in power occurs mostly in the summer months, but not necessarily at the sun´s zenith in the end of June.

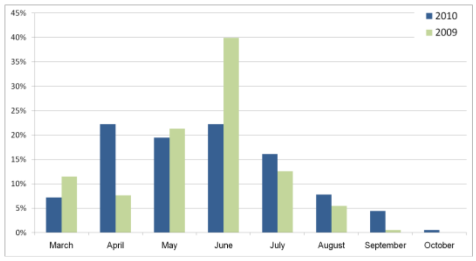

Figure 1: Relative occurrence of the day with the maximum feed in power of 150 distributed PV systems in Bavaria.

This shows that the maximum power of the PV system depends on different system immanent and meteorological parameters. The highest performance results at high irradiance and low module temperatures at the same time. Nameplate ratings of the modules (STC performance) is determined at a global radiation of 1000 W / m² and a cell temperature of 25 ° C. This case is a rare operating point in Germany. With increasing temperature, the efficiency of crystalline modules decreases by approximately 0.4 %/K. Considering the prevailing weather conditions on this background two competing Scenario arise for the maximum feed in power.

• With clear skies in summer the irradiation reaches values around 950 W / m² in Southern Germany. In this case the diurnal cycle of solar radiation has the shape of a bell curve. The generated power of distributed PV systems shows due to the homogeneous weather situation a high simultaneity, which means that all plants in a region feed high power to the grid. Due to the slowly increasing irradiation and high ambient temperature, the high irradiation levels come along with high module temperatures and the plant output remains well below the STC performance.

• The second scenario arises on days with changing cloud cover. Cloud reflections cause increases of the global radiation up to values above the solar constant. These irradiation enhancements meet low cell temperatures due to the thermal time constant of the PV module. The resulting power peaks are limited by the maximum inverter output power. Considering a whole low voltage grid, the simultaneity of the feed in power is due to the cloud movement lower as the one of clear skies.

3. Limitation of the Output Power through the Inverter Dimensioning

A limiting factor for the maximum power output of the PV system is the inverter design. Besides a large number of technical reasons also financial aspects have to be considered. The optimum sizing of the inverter depends on site and system specific parameters. The meteorological ratings, irradiation and ambient temperature can be seen as site specific, whereas the tilt angle, the orientation and the ventilation are system specific. The system designer has to choose the optimal sizing for each system considering all this parameters. Various articles and books, supply instructions and advice on this topic. In summary, however, most authors recommend a sizing factor below the STC power of the modules. A study within the project should show the variability and the final sizing of PV systems in the South of Germany [EBY 2010, Butz 2010], in order to determine the limitation of the PV power output. For the survey 934 systems in four communities in Lower Bavaria were analyzed. The sizing factor is defined by the continuous output power rating of the inverter (PWR_AC_NOM) over the rated power of the generator (P_PV_STC).

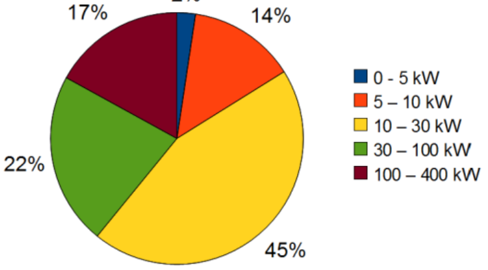

Figure 2: Distribution of the analyzed PV systems in the different classes according to the rated power.

The analyzed data is part of the E.ON Bayern AG database storing both the generator size in kW, and the nominal inverter output in kVA. The plants are divided into classes according to their size, to examine a dependency on the plants size. Figure 2 gives an overview of the distribution of the systems in the different classes according to rated power. It is noticeable that almost half of the rated power is provided by plants ranging from 10 kW to 30 kW..

System Size	Sizing Ratio
Up to 5 kW	0.88
5 kW to 10 kW	0.88
10 kW to 30 kW	0.90
30 kW to 100 kW	0.90
100 kW to 400 kW	0.93
Total	0.89

Table 1: Average sizing ratio ($P_{WR\text{-}AC\text{-}NOM}$ / $P_{PV\text{-}STC}$) of the analyzed PV systems.

The overall sizing ratio as shown in Table 1 is 0.89. It can also be seen, that the sizing ratio for smaller systems is with 0.88 below the overall value and shows a rising trend towards taller PV systems with 0.93. The maximum of the sizing ratios distribution as shown in Figure 3 is between 0.85 and 0.95 for all system sizes and shows a very equal distribution. The systems above 100 kW are shown with a broken line, as there are only 12 systems in this class.

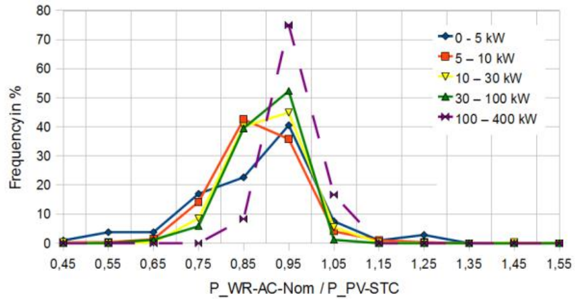

Figure 3: Distribution of the sizing ratio for the different system sizes.

The maximum power of a typical photovoltaic system in Germany is limited by the inverter with a factor of 0.89. For large PV systems this factor should be set slightly higher.

4. Calculation of the Maximum Power on a Clear Sky Day

The maximal feed in power on a clear sky day is calculated with a simulation model representing a typical south oriented PV system. The calculation is done for the whole of Germany so the different local conditions can be considered. The maximum global radiation has a strong dependency on latitude and altitude. The temperature at the suns zenith has various dependencies and is therefore very difficult to model. A long term dataset is used for this parameter.

Figure 4 shows a block diagram of the simulation algorithms. The simulation itself follows an efficiency-based model for the PV system and the inverter [Bey-04, Sch-96]. The calculated feed in power should be representative for the maximum power of a typical PV system with a high yield. Therefore the orientation and inclination of the system is set to optimal values faceing "South" with an inclination of 28°. To build a model for the typical system performance the system losses and the ventilation of the system are set to common parameters [Lor-10, Sol-11]. The temperature dependency of a represented module was determined by using a large module database. The Average of 7958 modules shows a typical efficiency of 12.7 % and a power temperature coefficient of -0.43 %/K.

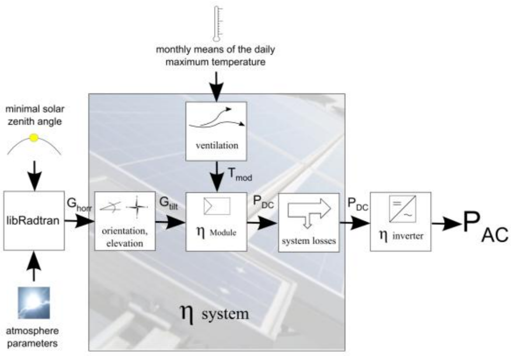

Figure 4: Block diagram of the simulation model.

The ambient temperature is taken from long term data series (2000 – 2011) of the German Weather Service [DWD]. The temperature at the sun´s zenith is not available, but the mean daily maximum temperature is a good approximation.

The maximum global radiation is calculated between the wavelengths 250nm to 2500nm with the radiative transfer library "libRadtran" according to the correlated-k method [May-05, Kat-99]. Furthermore, a standard atmosphere and a standard aerosol with a visibility of 50 km are assumed. The calculation of the global radiation is always the 25th of the month at the sun´s zenith. The calculations assume a perfectly south oriented system on a clear day. Therefore, the increase of the global radiation due to the inclination of the generator is transferred to a two-dimensional problem and solved according to the law of sines.

The results of the simulation show that the highest feed in power on clear sky days appears in June. Figure 5 shows the power output of a typical south oriented PV system in W per kWp. The maximum power in southern Germany stays below 850 W per kWp and therefore below the typical inverter limitation.

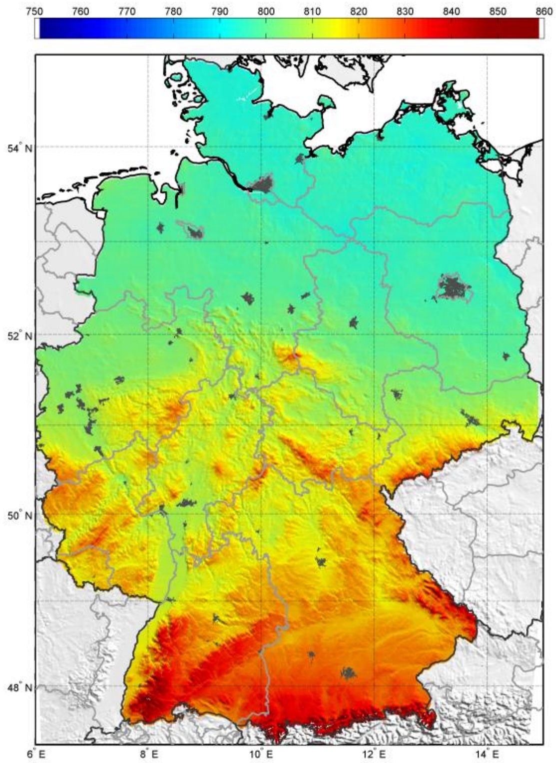

Figure 5: Maximal feed in power of a typical south orientated PV system for Germany in W per kWp installed STC power.

5. Calculation of the Maximum Power on a Cloudy Sky Day

The simultaneity of the feed in power on days with strong fluctuating cloudiness is examined more closely in a low voltage grid. Therefore detailed operating data of a large-scale photovoltaic power plant are taken and transferred according to Figure 6 to the low voltage grid which spreads out over the equal area of roughly two by two kilometers.

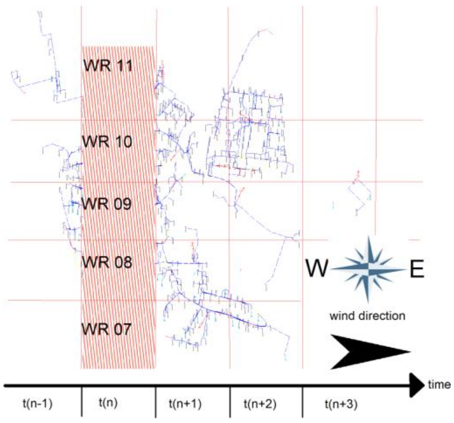

Figure 6: The analyzed low voltage grid with the allocated load profile and its movement.

In the simulation a slow west drift was adopted. All the PV systems are facing south with an optimal inclination and the size of the inverters is set to typical values depending on their size according to Table 1.

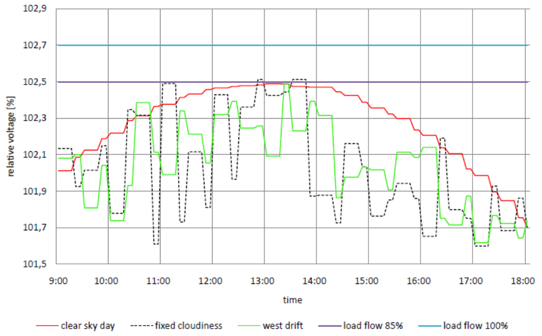

Figure 7: Relative voltage on a critical node on a representative cloudy day (green), a theoretic day without smoothing (broken black), and a maximum clear sky day (red). The light blue line indicates a simulation with the nominal power and the purple line indicates 85 % of the nominal power.

The results of the simulation, as required by DIN 50160, are 10 minute average values of the relative voltage on all nodes. Figure 7 shows the relative voltage of a load curve calculation for different representative cloud conditions. The green graph represents the west drift with the distributed profiles. The black curve describes a rigid state without a time shift of the profiles. So every PV system is assigned the same data set. In addition there are the curves for a clear sky day (red) and two static load flows, one for 85 % and the other one for 100 % of the PV systems STC power (blue, purple).

The curve of the distributed data set is much more even than the rigid curve and never exceeds the 85 % load curve. At the same time, it is shown that cloudy days show slightly higher values than clear sky days. The analysis of other days and different situations shows that these statements could be transferred to any cloudy day. Especially accumulated installations at the end of feeders show more critical vales on clear sky days.

6. Conclusion

The maximum feed in power of a typical photovoltaic system is limited by the inverter by a factor of 0.89. For large PV plants this factor is slightly higher. On a clear sky day in Southern Germany a typical optimally oriented PV system feeds less than 0.85 times it's installed STC power to the grid. Cloud reflections cause peaks of the global radiation up to values above the solar constant. The maximum feed in power of the PV system and the impact on the grid is higher on these days, but for DIN EN 50160 relevant time periods still a reduction factor of 0.85 can be applied. Therefore it is recommended to consider small PV systems with 85 % of the installed STC power in grid calculations.

Reverences

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