SIMULTANEITY OF PV- AND WINDPOWER-GENERATION FROM DISTRIBUTION GRID PERSPECTIVE

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ABSTRACT

Solar and wind power are volatile resources. Therefore the simultaneity of solar power feed-in and the combination from solar and wind power feed-in is analysed. The aim is to provide basic parameters for planning specifications, which lead to economic and technically sufficient distribution grids in low and medium voltage levels. Recommendations are given for the peak power from renewable feed-in at different grid nodes, because the simultaneity decreases with higher numbers of power plants and more spacious regions covered. Finally all the results are summarized in an simultaneity factor G, whose definition is presented.

INTRODUCTION

The sun shines coevally, but does the renewable feed-in from solar power into the electricity distribution grid do the same? And what is the correlation between solar and wind power or do they exclude each other? To analyse the effects at different grid nodes, measurements have been made within the project “Grids for Future Electricity Supply”. The project was partly funded by the German Ministry of Economics and Technology and should provide solutions for efficient grid adaption to realize energy transition to renewable sources in Germany [1]. The aim of the presented analysis in this contribution is to reduce assumptions for photovoltaic (PV) and wind feed-in concerning grid planning.

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DISCRIPTION OF THE TEST AREA

The consideration of a simultaneity factor on the load side is state of the art grid planning. While a grid connection capacity of 30 kW at service connection points is possible, only 2-3 kW on average remain at the local substation. On the other hand the simultaneity, of renewable generation is assumed as nearly 100 %. To achieve well based results about the simultaneity a complete 20-kV-line was equipped with smart meters to observe load flows at service connections, all secondary substations and the primary substation. The grid scheme is shown in Figure 1.

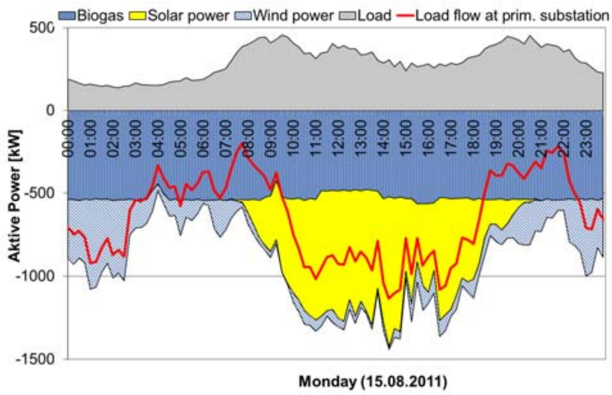


Figure 2: Load and renewable feed-in

An area of ca. 30 km² is supplied by this medium voltage line. There are 1.4 MW of solar power, 1.0 MW of biogas cogeneration units and 4.4 MW of wind power installed.

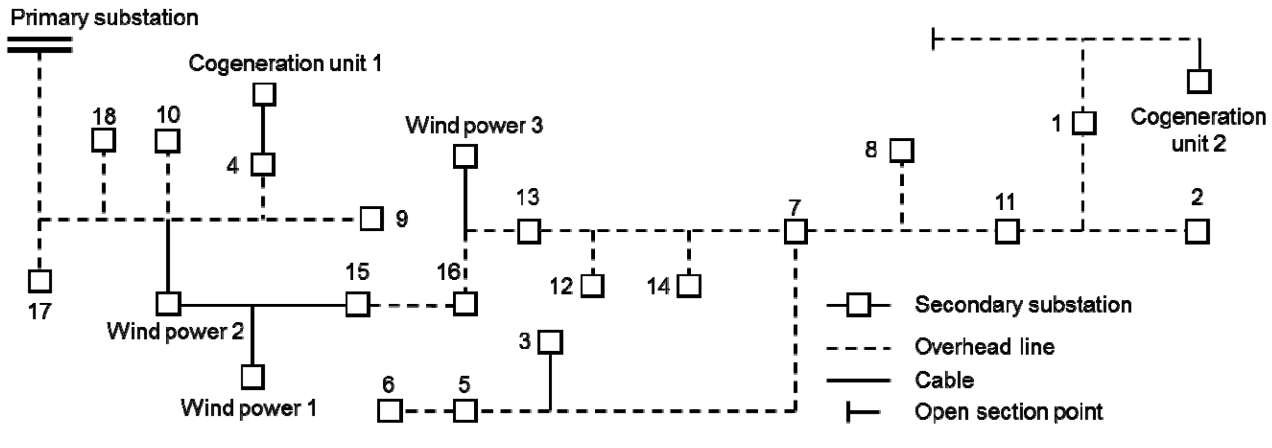
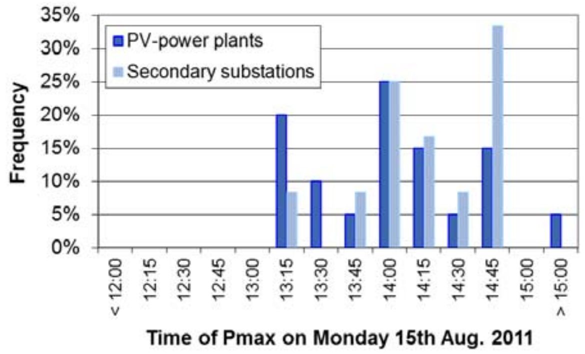


Figure 1: Grid scheme of medium voltage level inside the test area

Figure 2 shows a sunny day with light wind and low cloud cover. Although there is less wind power the direction of the resulting load flow is to upstream voltage levels due to electricity feed-in of biogas fired cogeneration units.
Global radiation is dependent on the season and decreases in the analysed region from e.g. August to November by ca. 85 % [2]. In contrast the measured values of maximum feed-in from solar power decreases only by 28.6 % during this period. Thus high peaks of PV-generation can occur over a couple of months and must be handled by the grid.

LOCAL DEPENDENCE OF PV-SIMUTANEITY

For the detailed analysis two typical days are selected. In addition to Monday 15th August, Thursday 25th September was a sunny, windless day without clouds and a perfect bell-shaped PV feed-in curve. On both days the time of P_{max} at PV-power plant connections is spread over about 3 hours based on different orientations (Figure 3). In order to achieve these results the PV-power outputs have been added, based on which PV-power plant belongs to which secondary substation. In this manner the load has no effect on the results.



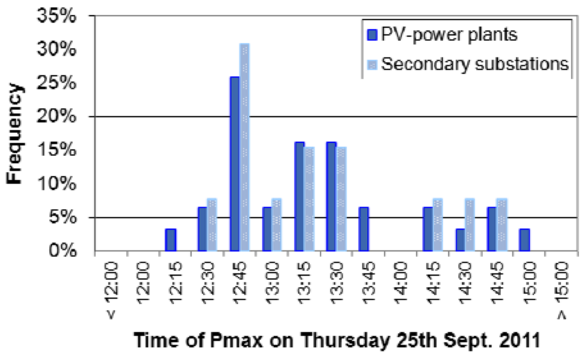


Figure 3: Times of maximum PV-power feed-in

The maximum power peak of a PV-power plant during a single quarter of an hour was measured in September with a maximum $P_{max}/P_{N(PV)}$ of 99.6 %. September 2011 was a cold and sunny month in Germany so that the result is comprehensible. Because of the time spread (Figure 3) the maximum power peak measured at the secondary substations was 9 % lower, standing at 90.9 %. Well below these values was the maximum power feed-in from PV at the primary substation with a $P_{max}/P_{N(PV)}$ of 69.5 %. Thus, without any further analysis the assumptions for grid planning can be reduced to these values. In reference [3] even lower values for PV feed-in assumptions at secondary substations with 85 % $P_{N(PV)}$ are recommended for grid planning.

The results for the whole area are given in Figure 4. The highest peak feed-ins are at PV-power plants in the low-voltage level. But the peaks at secondary substations are slightly lower. This means, the supplied area of a secondary substation is not large enough that there are other weather conditions and there is not an effectual number of power plants for a bigger statistical spread. Over the whole area of ca. 30 km² the differences rise and the simultaneity decreases. In addition to a lower maximum power peak itself the probability of high maximum power peaks also decreases.

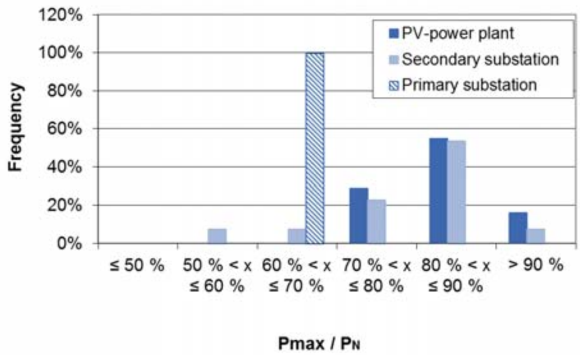


Figure 4: Frequency of high PV-power peaks at different points in the test area

This leads to a further aspect of volatile renewable generation. The electrical power levels, on which the majority of the PV-generation takes place, are interesting for analyses regarding thermal aspects.

THERMAL EFFECTS OF PV-GENERATION

In order to open further efficiency potential for grid planning defaults, the view of the maximum power peaks is however insufficient. The energy provided at power peaks has to be also taken into account. Figure 5 shows that the most energy is delivered below 50 % of the installed PV-power. Even at peak times the largest part of the energy is also fed with regard to low power values. The question being, if a grid should be designed for the last quarter of an hour or if the power feed-in for e. g. the last 1 – 3 % of the time of a year (Figure 6) is not relevant for grid design. To support this grid planning optimization, the legislator in Germany added a paragraph to the renewable energies law [4] to allow peak cutting from renewable generation. Another possibility is to analyse which thermal load the PV-generation represents for the grid equipment. Therefore the delivered energy is analysed as a function of momentary PV-power feed-in. The results are illustrated in Figure 5.

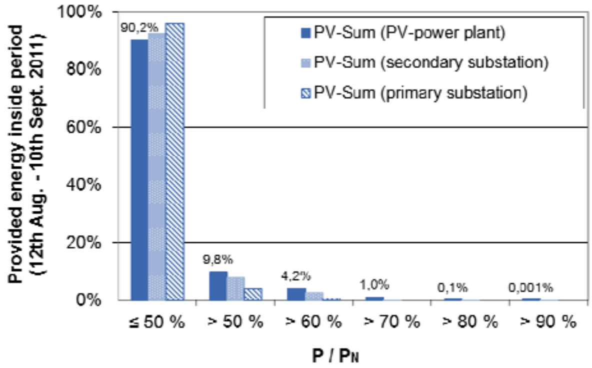


Figure 5: Part of provided energy in dependence of momentary PV-power feed-in

Only 1.0 % of the supplied energy is provided with a $P/P_{N(PV)}$ of > 70 % by PV-power plants. If only feed-ins below this value are considered while grid planning, 43 % more PV-power can be connected to the existing grid, corresponding to the following equation (1):

$$0{,}7 \cdot \sum_{i=1}^{n} P_{N(PV),\,i} = P_{N(E)} \Leftrightarrow \sum_{i=1}^{n} P_{N(PV),\,i} = 1{,}43 \cdot P_{N(E)}$$

$P_{N(PV)}$: Nominal installed PV-power (1)
$P_{N(E)}$: Nominal power of equipment

This is valid under the condition that renewable generation is not connected with n-1 reliability to low and medium voltage grids in Germany [5] and voltage fluctuations do not work restrictively with reference to EN 50160. Concerning this however, different grid concepts are regarded in reference [1], so that we can act on this assumption here. During times of higher PV-power peaks than 70 % $P_{N(PV)}$ (Figure 5) equipment load will exceed 100 % $P_{N(E)}$ but they could be handled according to reference [4]. Thus, no unacceptable equipment load will occur.

These analyses are based on ¼-hour-average values as it is usual for the load side. In reference [6] gradients of solar radiation up to 30 % in 5 s are indicated so that these effects are not shown by ¼-hour sliding average values. This leads to the question, which sliding average value is relevant for thermal load and life time usage of equipment under PV feed-in conditions? In Table 1 the parts of provided energy are exemplary given for secondary substation No. 7 and indicated for different average value calculations. The evaluation of the measurements for secondary substations shows that with a sliding average value over 2 hours there is nearly no energy delivery above $P/P_{N(PV)}$ of > 70 %. The PV-power peak decreases from 82.2 % to 73.5 % in order to the average calculation from ¼ to 2 hours. With consideration of 8-hour average values no relevant energy will be provided with $P/P_{N(PV)}$ of > 60 % from solar power. Thus, the use of the temporary overload ability of primary grid equipment can help to postpone or avoid grid expansion for the connection of a higher amount of PV-generation.

Secondary substation No. 7	Sliding average value		
	0.25 h	2 h	8 h
Sum of delivered Energy (W_{PV})	100,0%	100,0%	100,0%
Part W_{PV} with a $P/P_{N(PV)}$ of > 90 %	0,0%	0,0%	0,0%
Part W_{PV} with a $P/P_{N(PV)}$ of > 80 %	0,0%	0,0%	0,0%
Part W_{PV} with a $P/P_{N(PV)}$ of > 70 %	0,2%	0,0%	0,0%
Part W_{PV} with a $P/P_{N(PV)}$ of > 60 %	1,9%	1,0%	0,0%
Part W_{PV} with a $P/P_{N(PV)}$ of > 50 %	7,0%	5,1%	0,3%
Part W_{PV} with a $P/P_{N(PV)}$ of ≤ 50 %	93,0%	94,9%	99,7%

Table 1: Renewable feed-in from solar power at secondary substation No. 7 for instance

Additionally a minimum load, which is unconsidered here, works against high load flows and provides additional security against feed-in conditioned overloading. Before the planning specifications can be however strongly lowered, further analyses are necessary.

CORRELATION BETWEEN SOLAR AND WIND POWER

As shown in Figure 5 the simultaneity of PV-power feed-in to a medium voltage line rarely exceeds 70 % of the rated total power of the PV-equipment in the test area.
The correlation between solar and wind power is analysed from power measurement for a complete year from 1st January to 31st December. The study covers 5 PV-power plants with a total power installed of 7.5 MW and 4 wind power plants with a total power installed of 5.8 MW close to the test area.
35,039 measurement values (1/4-h-kWh) are put into a scheme showing the instantaneous power in relation to the maximum power value for PV-, wind- and combined PV-wind-power generation. As shown in Figure 6 the total PV-power feed-in exceeds 70 % of the rated total power for less than 190 hours a year, which is 2.2 % of the time period and only 1.2 % of PV energy supplied to the grid.

Power feed-in from wind power plants to the medium voltage grid in the test area rarely exceeds 90 %. A value lower than 90 % for simultaneity of wind energy has been considered for onshore wind farms. Since strong winds might blow for several days the thermal effects to electrical equipment of distribution grids have to be considered. Power generation from wind engines exceeds 90 % of the rated total power for less than 145 hours a year, which is 1.6 % of the time period and only 0.3 % of wind energy supplied to the grid.

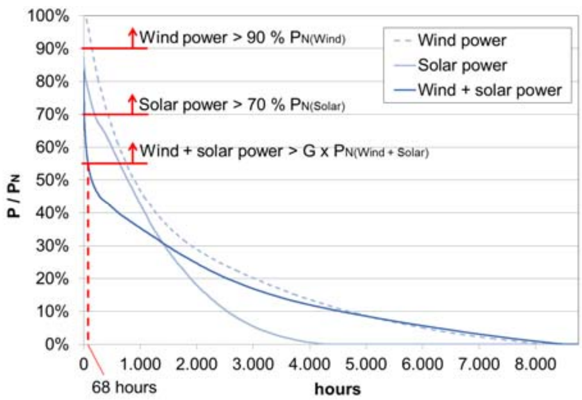


Figure 6: Annual duration of Renewable feed-in from PV and Wind power generation

To answer the question whether the existing medium voltage grid is able to transport more and more energy from renewables the correlation between PV- and wind-power generation has to be considered. The study done in the test area proposes to use a simultaneity factor G for grid planning purposes as follows :

$$G = \sqrt{\left(0{,}7 \cdot \sum_{i=1}^{n} P_{N(solar),i}\right)^2 + \left(0{,}9 \cdot \sum_{i=1}^{m} P_{N(wind),i}\right)^2} \quad (2)$$

In the test area mixed power generation from PV and wind exceeds G = 56 % for less than 70 hours a year, which is 0.8 % of the time periods and only 0.4 % of PV and wind energy supplied to the grid.
With the exception of coastal regions the above mentioned simultaneity factor G will help to give a good forecast for the thermal load from renewables to Central European medium voltage grids.

CONCLUSIONS

The integration of renewable energy from solar and wind power into existing distribution grids need to be analysed carefully, because comprehensive grid expansion will solve all technical challenges but may overtax the economy. Therefore the simultaneity of solar and wind power was analysed in a test area in the southwest of Germany. With a higher penetration of renewable power plants the simultaneity of PV-power feed-in can be reduced to a $P_{max}/P_{N(PV)}$ of 90 % at secondary substations and a $P_{max}/P_{N(PV)}$ of 70 % at primary substations. If there are additional feed-ins from wind power in the considered region the simultaneity factor is even lower. Depending on the total number of PV- and wind-power plants, the calculation of the renewable simultaneity factor G is given, which is valid for medium voltage lines. Stronger values have to be considered for connecting lines of single PV- or wind-power plants [5]. Thus, the planning specifications can be updated with these results.

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