OPTIMAL INTEGRATION OF RENEWABLE ENERGY SOURCES BY LIMITING PEAK GENERATION

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ABSTRACT

According to the current German Renewable Energy Law the distribution networks have to be enforced such that all the power produced by decentralized generation units can be absorbed. Since the generation units produce the maximum power only for a short period in the year this constraint inevitably leads to a low usage of the network equipment.

In the paper it is found that a large reduction in peak power (e.g. to 70 %) only leads to a small reduction in delivered energy (e.g. 4 %). The influences on this relation are evaluated.

Different methods are investigated how to allocate the peak shaving, if there are several generation units in a part of the network.

It is derived that for practical planning of the network the best way is to allow a certain not used energy to all generation units but to actually restrict the infeed only for the units which cause a voltage problem or an overloading of a line in the network.

INTRODUCTION

According to the current German Renewable Energy Law (EEG) the distribution network operators are obligated to extend their network in such a way that all the power produced by decentralized generation units can be absorbed by the network.

By analysing the yearly generation curves of wind power plants and photovoltaic power plants it can be seen that most of the time the generated power is much lower than the installed power. A power in the range of the installed power is generated only a few quarters of an hour a year. Since most of the energy is generated with partial power, cutting the few generation peaks does not lead to a considerable amount of not used energy for the power plant. Overloading of the network and increase of voltage can be reduced significantly by cutting the peaks. In this paper it is evaluated how much energy will not be used, if the peaks are cut to a certain value for wind and photovoltaic power plants. Influencing factors are identified and assessed.

In the second part of the paper it is investigated how the planning of distribution networks can be optimised if peak shaving would be applied to the generation units. There are different possibilities to allocate the not used energy onto the generation units in a network section. These possibilities are assessed taking the requirements of the practical network operation and the uncertainties in knowledge about the actual network condition and future development of renewable energy use in a certain network area into consideration.

PEAK SHAVING AND NOT USED ENERGY

Principle

In figure 1 a typical yearly generation curve of a wind power plant in Central Europe (the example is from Saxony in Germany) is displayed. The values are the average generation values for each quarter of an hour and they are normalised to the installed power of the wind turbines.

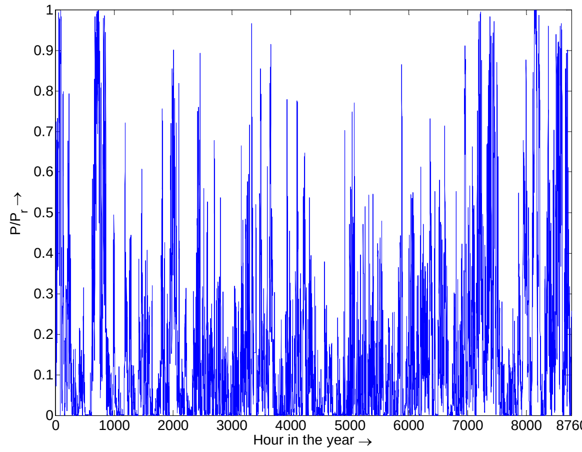

Figure 1: Example of yearly generation curve of a wind power plant

If the values are sorted according to their size a yearly generation duration curve is produced, see figure 2.

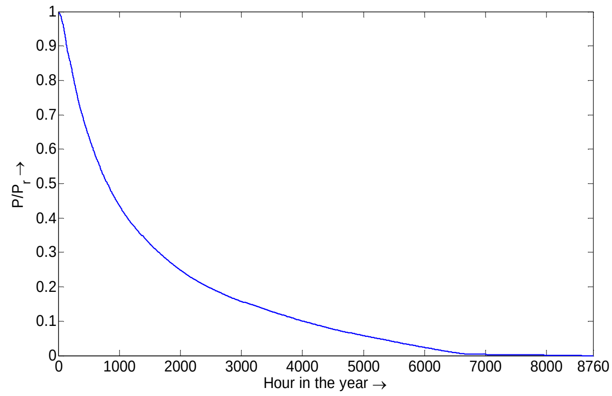

Figure 2: Example of yearly generation duration curve of a wind power plant

It can be seen that only few values are higher than 70 % of the installed power of the wind turbines. This means that only few energy will be lost if the generation power is limited to 70 %, for example. The principle of limiting the peak power is illustrated in figure 3 and figure 4 for a daily generation curve and figure 5 for the yearly generation duration curve.

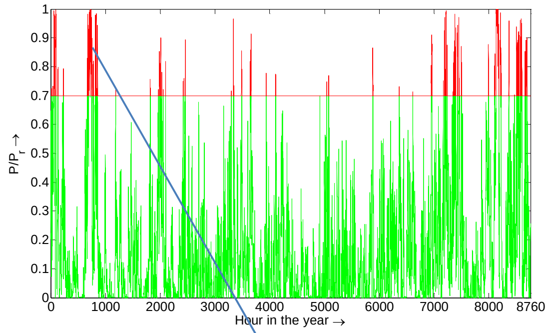

Figure 3: Example of yearly generation curve of a wind power plant with peak power limited to 70 %

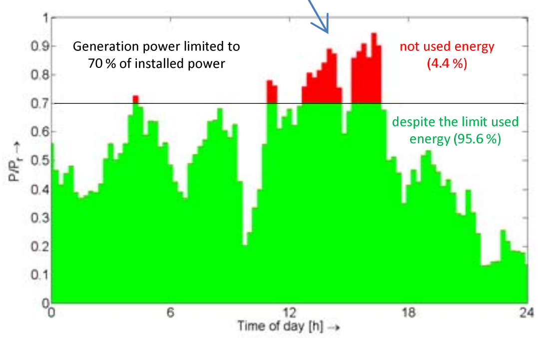

Figure 4: Example of daily generation curve of a wind power plant with peak power limited to 70 % in February 2013

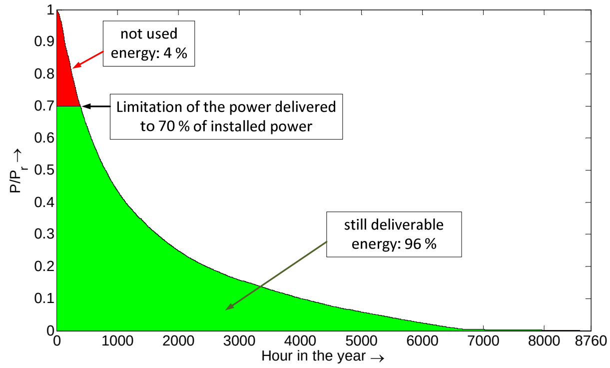

Figure 5: Example of yearly generation duration curve of a wind power plant with peak power limited to 70 %

If the value of the limit is varied a different amount of energy cannot be used. The relationship between the value of the limit and the amount of not used energy for the example wind park is shown in the energy loss curve in figure 6.

Energy loss curve

In the previous section the principle of the energy loss curve was explained at an example of a wind park in Saxony, Germany, see figure 6. In this section it is investigated which factors influence the energy loss curve and how large is their influence.

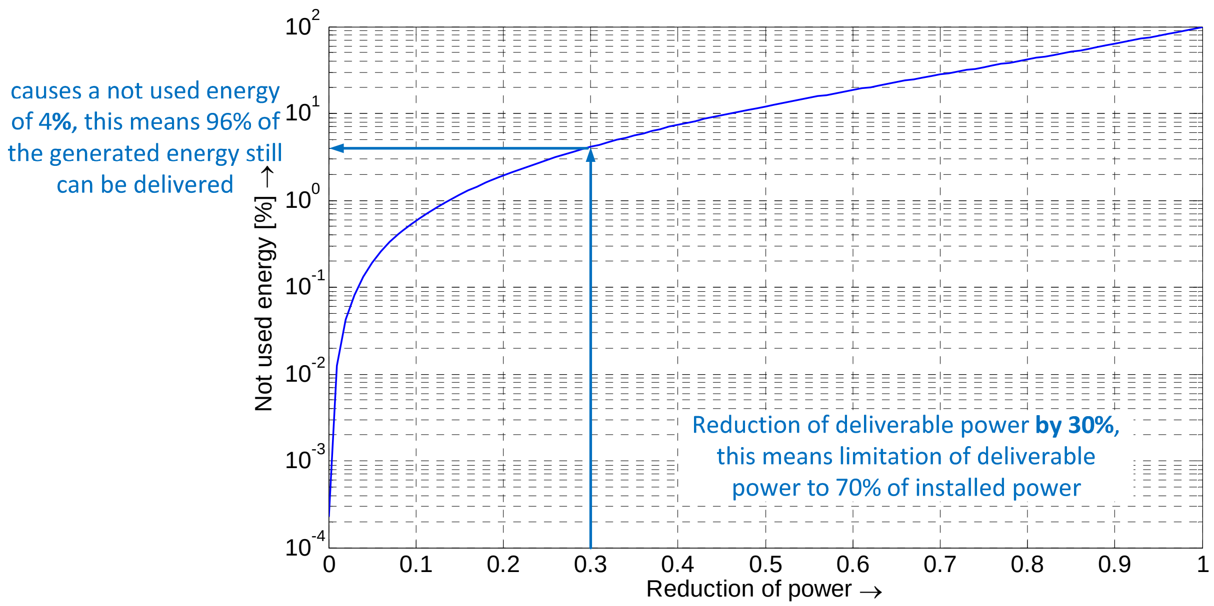

Figure 6: Evaluation of energy loss by limitation of power (example)

For the energy loss curves the 15-min-average-values of power generation were evaluated. The 1-min-average-values contain short peaks which are relevant, if the network bottleneck is caused by voltage problems. The additional amount of not used energy if these short peaks are cut is minimal (less than 1 %). Hence for all evaluations in this paper the 15-min-average-values are used.

As main parameters were assessed:

- location of power plant,
- variation of availability of wind and solar radiation from year to year,
- dimensioning of inverter rating in relation to rating of solar panels.

According to the available data wind parks and solar parks at different onshore locations in the eastern part of Germany were compared. As the availability of wind energy resources heavily depends on the location it can be expected, that the variations will be larger if more locations are evaluated. Since the full load hours of offshore wind power plants are considerably higher than those of onshore plants their energy loss curves will differ from the ones under consideration for this paper. For such regions detailed investigations are required before using reduced power values for network planning purposes.

The variation of the different locations is shown in figure 7 and figure 8 in the yearly generation duration curve and in figure 9 in the energy loss curve.

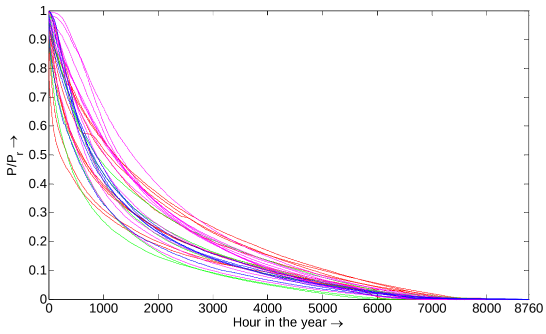

Figure 7: Dependency of wind generation duration curve on location

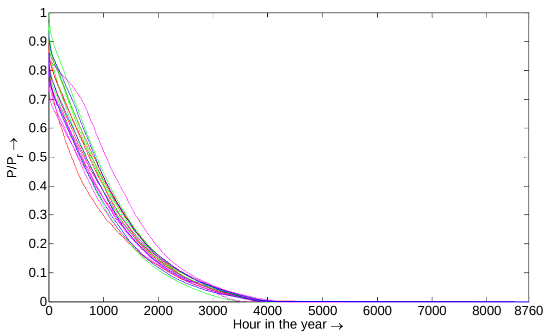

Figure 8: Dependency of photovoltaic generation duration curve on location

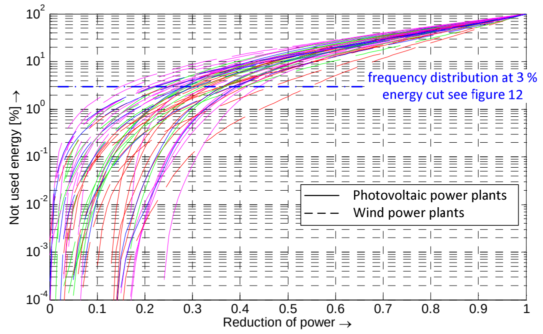

Figure 9: Dependency of energy loss curves on location and energy source

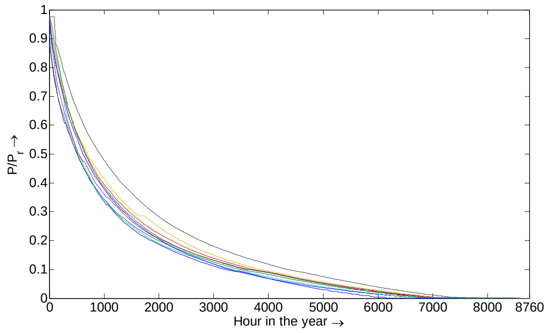

Figure 10: Variation of wind generation duration curves over the years 2005 – 2013

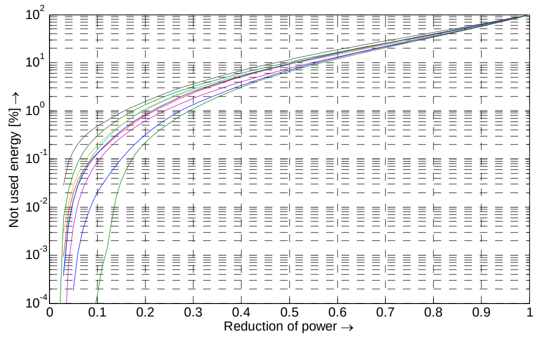

Figure 11: Variation of energy loss curve of wind power plant over the years 2005 – 2013

The comparison of the above figures reveals the following:

- The variation of yearly generation duration curves is the highest between different locations of wind parks, see figure 7.
- The variation over the years is smaller, see figure 10 and figure 11.
- Between solar power plants the variation is comparably small regarding locations and years.

This means that in a given area it can be assumed that the effects of cutting peak power to the energy not used is similar to all plants in this region, provided that there are no special geographic characteristics for certain plants.

There is still a wide range of reductions of power that result from the same value of energy not used depending on the location of the power plant and the energy source in a given year, see figure 12.

Therefore a somewhat probabilistic approach is needed, leading to a higher amount of energy not used in one year which is compensated by a lower amount in another year, depending on the actual weather conditions.

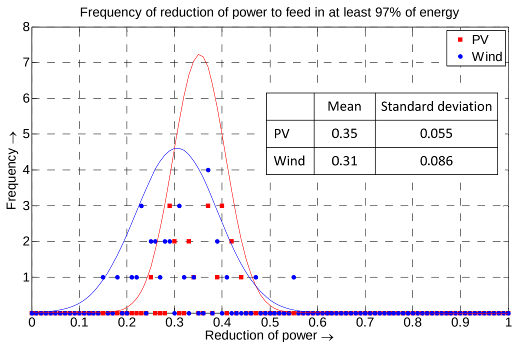

Figure 12: Frequency of reduction of power to feed in at least 97% of energy, see also figure 9

The solar power plants under consideration are dimensioned with a typical relation between panel rating and inverter rating:

- panel rating – 100 %,
- maximum power of inverters – 90 – 95 %,
- rated power of inverters – app. 90 % of maximum inverter power, 80 – 88 % of panel rating.

The curves of the solar power plants in this paper are based on the measurements of the actual infed power but are normalized to the solar panel rating to make it comparable. Therefore they contain already the energy loss which is caused by the smaller rating of the inverters compared to the panels. But the fact that the yearly generation duration curves are steep and not flat around zero hours proves that no energy is lost by the used dimensioning of the inverters.

If the maximum power of inverters is smaller than 90 % of the panel rating theoretically the peaks in the yearly generation duration curves have to be cut accordingly. But the experience shows that usually the inverters are dimensioned such as to use most of the power. Smaller inverter ratings usually will be found only if the orientation of the solar panels does not allow the generation of the rated power anyway (e.g. if they are oriented in east-west-direction).

EFFECT AT NETWORK BOTTLENECKS

The intended effect of the peak shaving is to increase the amount of installed power of renewable sources in the networks and therefore to deliver a higher energy from renewable sources into the networks without costly network enforcements or extensions.

For an example medium voltage network the effect was investigated. The network consists of a 20 kV feeder with generation units connected in a distance of 3.7 km, 7.5 km, and 11.2 km. For the example it is assumed that all the generation units have the same installed power.

With a power factor of $\cos(\varphi)=0.95_{underexcited}$ the limit of voltage rise (ΔU_{max}=2 %) by the generation units is reached, if 3 units with 3.5 MW each are connected, giving 10.5 MW installed power in total. Based on the yearly generation duration curve these 3 units deliver about 15 GWh per year to the network.

Assuming 3 % of the generated energy are allowed not to be used, the generation units in this example can be limited to 70 % of the installed power.

As the maximum power fed into the network cannot increase because there is a limit caused by the voltage rise, generation units can be connected which produce 3.5 MW each, if limited to 70 % of the installed power. This means generation units with a rated power of 5 MW (=3.5/0.7) can be installed. These deliver about 21 GWh per year to the network, see figure 13.

This means that by limiting the infed power the amount of delivered energy of renewable sources can be increased by a factor of 140 % (21 GWh/15 GWh) without any network enforcement.

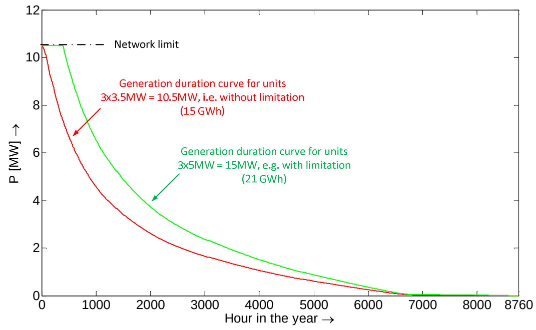

Figure 13: Comparison of yearly generation curves with and without limitation of power infed

OPTIMAL DISTRIBUTION OF NOT USED ENERGY

In the previous sections it was found, that a considerable cut of the generated power of wind and solar power plants only leads to a small amount of energy not used. To reduce or avoid network enforcement this power cut has to be allocated onto the generation units in a way that they do not overload lines or violate voltage limits. Under the assumption that the total maximum energy not used for the network is defined, there are different ways to realize this, see also figure 14:

1. No power cut at all

The strategy currently required by law in Germany. All generated energy is used.

2. Limit all the power plants to the same value

Simple strategy but as there are power plants limited which do not cause an overload of the network or a violation of voltage limits, the amount of energy not used is too high.

3. Optimise distribution of cut power

The amount of energy cut is allocated among the generation units in such a way that, keeping the network conditions under consideration, the most possible power

is connected. This means for example that generation units located at places in the network with a strong connection can feed in all their energy. Generation units located at places with a weaker connection are reduced higher in power, feeding in less energy. The total amount of energy not used is kept constant in the network.
This strategy allows the maximum generation power installed in the network but distributing the power limits to the individual units is a difficult optimisation problem. It is non-convex and non-linear. As the yearly generation duration curves cannot be described with analytical formulas there is no analytical solution to the optimisation problem. Calculations using a simplex algorithm lead to computation times of several days not delivering satisfactory results.
This strategy can be used if there are network areas that do not influence each other (e.g. because they are in different regions). If there is one strong network that can take all the installed power the energy can be taken and equally applied to the units that are in the weak network.

4. Cut power where necessary

For each generation unit the same limit of allowed not used energy is set (P_{max}). The power is actually cut only for these units where network conditions require a power reduction. It is only cut as low as it is actually needed, e.g. taking load curves into consideration (P_{cut}). The limit of allowed not used energy is observed for each generation unit.
This strategy is considerably simple to handle but the amount of possibly installed generation power is lower than for the strategy number 3. As there is the same limit of not used energy for all units the possible amount of not used energy for the units with a strong network connection is not fully exploited. In locations with a weak network connection the amount of power to be installed is limited by the limit of allowed not used energy.
From a network planning and operating point this strategy is considerably easy to handle. Based on the yearly generation duration curve of the generation unit (or a similar one, if the unit is in planning state only) the limit of allowed not used energy can be used to calculate the maximum allowed power reduction. The reduced power then can be compared to the network capacity at the planned connection point. If it is lower the unit can be connected. The actual reduction in power is then determined by the control centre depending on the current network conditions. This requires a communication infrastructure which often still has to be installed.

Therefore the strategy 4 (Cut power where necessary) was found to be the one that can be recommended.

CONCLUSION

Limiting peak power of generation units based on the resources wind and solar power does allow the integration of a considerable higher installed power into a given network by not using only a small amount of the yearly producible energy.
By evaluating historical generation curves from different regions in Germany and different years it was found that there is a wide variation of the amount of possible power cut for the same energy not used between regions but a small variation over time.
If for a given network region the total amount of energy that is allowed not to be used is defined, the optimal distribution of this energy is a very difficult task even for simple network structures. A suboptimal but in practice feasible procedure could be determining an identical limit of allowed not used energy for all generation units in a network but cut the power where necessary. This cut can be determined either operationally or as a fixed limit for each unit.
Although the implementation of this principle has to be discussed and regulated for the network operators, the principle of limiting peak generation can lead to a reasonable balance of the value of not used energy of the generation units on the one side and cost of network enforcement or extension on the other side.

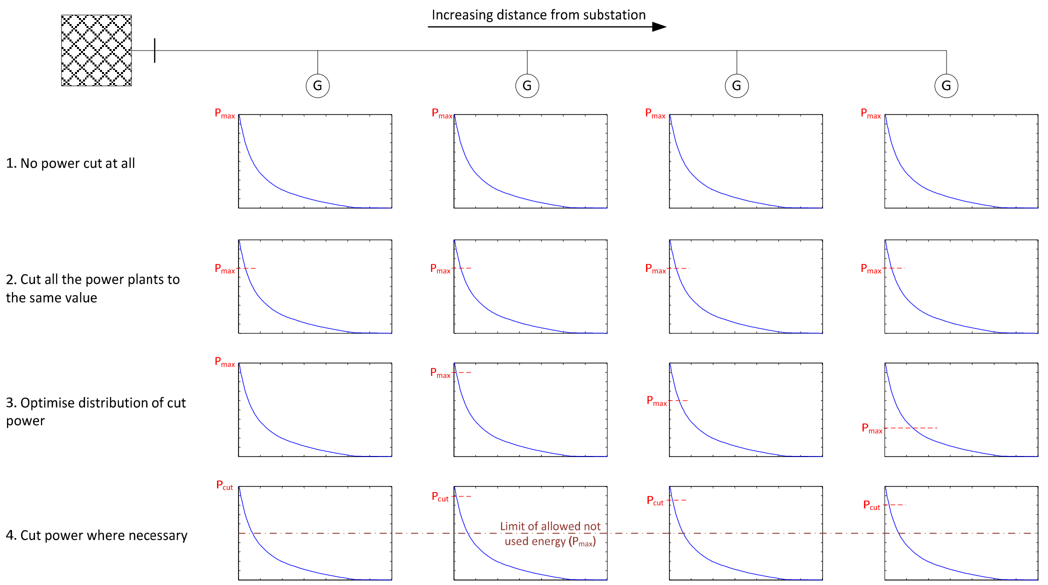

Figure 14: Power cut strategies