THE TRANSPARANT HOSTING-CAPACITY APPROACH – OVERVIEW, APPLICATIONS AND DEVELOPMENTS

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ABSTRACT

This paper summarizes the hosting capacity approach and gives some recent developments: including uncertainty in location and size of production units; curtailment to connect more production than according to the initial hosting capacity. For both developments it is shown that the transparency of the approach still holds but also that the results may be strongly location dependent. It is however also shown that the hosting-capacity approach can be used to obtain rough estimations, rules-of-thumbs, and to make a first assessment in case more detailed studies are not possible for example because insufficient data is available.

INTRODUCTION

The hosting capacity approach has been introduced as a method to quantify how much distributed generation can be connected to the power system. The approach is based on a transparent definition of performance indicators and appropriate limits. The choice of performance indicators and limits, including the way in which they are calculated, has been shown to have a huge impact on the hosting capacity of the grid.

The method was originally proposed by STRI in 2004 [1, 2] as part of the EU-DEEP project [3, 4] and developed further and applied by the authors of this paper [5, 6, 7, 8] and by many others as well (see [7] for an overview). The most prominent applications are at European level and in the regulations of a number of European countries [12, 13, 14, 15].

The term has also been used to quantify the amount of other equipment (like electric cars or heat pumps) that can be connected to the power system. Especially after 2010, the number of publications using the term "hosting capacity" has grown a lot, as is shown in Figure 1. The introduction of small production units on customer-side of the meter (mainly solar panels) makes the hosting capacity approach an essential tool in network planning. Also other customer-side developments, like the introduction of electric heat pumps, contribute to the necessity of the approach.

Existing planning methods consider the connection of individual production units, large consumer installations, or load growth, but without specifically quantifying the available margin and often without the transparency needed for an open discussion between the stakeholders.

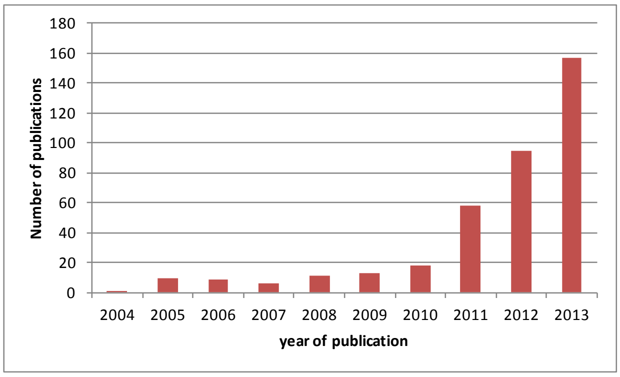

Figure 1. Number of publications, according to Google Scholar, using the term "hosting capacity" in the same meaning as in this paper [5].

OVERVIEW OF THE APPROACH

The maximum amount of distributed generation that can be connected to a certain location, to a feeder, to part of the power system or to the power system as a whole, without resulting in an unacceptable quality or reliability for other customers, is the so called hosting capacity [1, 5, 8]. The hosting capacity varies a lot between different locations in the grid. At some locations, the grid can accept almost no distributed generation without additional investments, whereas it can accept large amounts at other locations.

To know how much distributed generation can be connected it is important to define appropriate performance indicators. In a simplified way, the hosting capacity approach proceeds as follows:

- Choose a phenomenon and one or more performance indices;
- Determine a suitable limit or limits;
- Calculate the performance index or indices as a function of the amount of generation;
- Obtain the hosting capacity;

The basic principle is illustrated in Figure 2; a deterioration compared to the existing level of performance is acceptable up to a certain limit. Above that limit the deterioration becomes unacceptable and the hosting capacity has been exceeded.

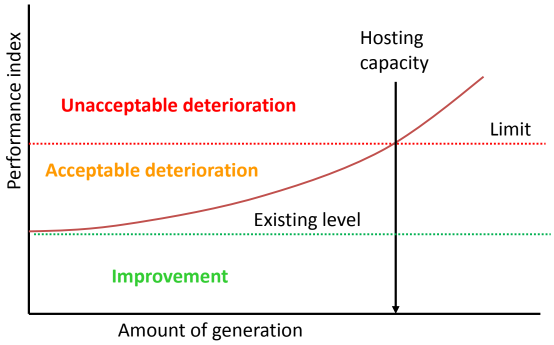

Figure 2. Basic principle of the hosting-capacity approach for one performance index [8].

The performance indices include those that are directly related to the quality or reliability (like the highest and lowest 10-minute rms voltage) but also indirect ones related to the operation of the system (like highest current through a transformer and the probability of unwanted operation of a protection relay).

The choice of index (e.g. 99% or 100% values of the 10-minute rms value) and limit (e.g. 108% or 110% of nominal voltage) will have a big influence on the amount of distributed generation that can be accepted [8]. Also the method used to calculate the performance index can have a significant impact. This was shown in [6] for the amount of wind power that can be connected to a subtransmission grid.

The above approach gives a hosting capacity for each phenomenon (voltage magnitude, overload, protection mal-trip, etc.) or even for each index (number of interruptions, duration of interruptions, etc). It is the lowest of these values that determines how much distributed generation can be connected before changes in the system (typically investments) are needed. This is illustrated in Figure 3, where the hosting capacity (H.C. in the figure) is the highest amount of generation for which none of the performance indices exceeds its limit.

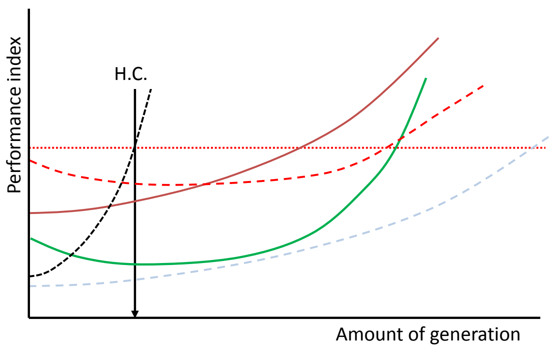

Figure 3. Including multiple performance indices in the hosting capacity approach

In practice, the different curves will rarely be plotted in one figure: different values will typically be used along the vertical axis and even along the horizontal axis (kW, kWh, kVA, percent of maximum, average of minimum consumption, percent of transformer size, percent of short-circuit capacity, etc).

Once the hosting capacity (as the lowest of the values obtained for each performance index) is found, mitigation methods can be discussed. In all cases it is recommended to take a close look at the calculation methods, at the performance indices and at the performance limits. When minor changes in any of these have a big impact on the resulting hosting capacity this may point to an easy mitigation method. However, any adverse impact of this will have to be considered as well. This is one of the examples where the transparency of the method becomes very important. It will allow an open discussion between the different stakeholders finding a solution that is acceptable to all stakeholders.

APPLICATIONS

Microgeneration on a Low-Voltage Feeder

The maximum-permissible voltage rise, with connection of a distributed generator, is the one that brings the maximum voltage magnitude exactly at the overvoltage limit. The "overvoltage margin" is the difference between the maximum voltage magnitude for a given customer and the overvoltage limit. When considering overvoltages, the hosting capacity is the amount of generation that gives a voltage rise equal to the overvoltage margin. Each customer has a different overvoltage margin. The connection of a generator to a distribution feeder gives the same relative voltage rise for every location downstream of the generator. What thus matters is the lowest value of the overvoltage margin downstream of the location at which the generator is connected. It is this overvoltage margin and hosting capacity we will consider here.

Calculating the hosting capacity for a specific feeder requires a large amount of data, on existing voltage variations, on variations in consumption of active and reactive power, on the locations of the production units, and on the variations in injected power. It is however possible to get an estimation of the order of magnitude, using the above-mentioned "overvoltage margin" as a base. A 1% overvoltage margin is reasonable to be expected for most feeders. A margin much less than 1% would point to a risky situation already without distributed generation. A margin much higher than 1% would imply an overdimensioned feeder or a feeder where the voltage drop is not the main concern. The latter is the case in many but not all urban networks.

The hosting capacity has been calculated for low-voltage feeders with 400-V nominal voltage. The specific conductivity of 1.68x10-8 Ωm for copper is used. The hosting capacity per phase is shown in Table I. Note that all values in Table I are per phase.

TABLE I
HOSTING CAPACITY AND LOADABILITY PER PHASE FOR 400V FEEDERS WITH 1% OVERVOLTAGE MARGIN

Cross section	Cable length				
	50 m	200 m	500 m	2 km	Load-ability
25 mm^2	16 kW	3.9 kW	1.6 kW	390 W	11 kW
50 mm^2	32 kW	7.9 kW	3.2 kW	790 W	18 kW
120 mm^2	76 kW	19 kW	7.6 kW	1.9 kW	27 kW
240 mm^2	150 kW	38 kW	15 kW	3.8 kW	40 kW

For short feeders (50 m) and for feeders with a large overvoltage margin the loadability will likely be exceeded before the overvoltage margin is exceeded. A lower limit of the hosting capacity with respect to overload is the sum of loadability and minimum consumption [8] and thus at least equal to the value in the most right-hand column. However for cable of 200 m or longer, the voltage rise is more likely to set the limit.

It should be noted here that the feeder resistance is the same for an overhead line as for an underground cable, for the same length and cross section. However, lines are typically used to connect more remote customers and the maximum length of a line is more typically determined by the maximum voltage drop, whereas cables are typically used to supply customers closer to a main substation and the length is mostly determined by the maximum loading. The result is that overvoltage problems appears more often with generation connected to overhead lines than with generation connected to underground cable feeders.

Uncertainty in production sources

The hosting capacity at a certain location depends on a lot of parameters, not all of which are known or can even be known when the calculations are performed. Consider for example the limits set by overvoltage, as discussed in the previous section. There it was assumed that the overvoltage margin was 1% of the nominal voltage. If however another production unit would connect to the same feeder, the remaining overvoltage margin will likely become smaller and thus also the hosting capacity.

For the connection of relatively large production units, where a request is sent to the network operator for each of them, it remains in theory possible to calculate the hosting capacity on a case by case basis. This could however result in the “threshold effect” where one unit is allowed to connect whereas the next unit is not allowed to connect (or requires a high connection fee) because its connection would exceed the hosting capacity.

For small production units, on the customer side of the meter, and for new types of consumption like electric heating or electric vehicles, it is very difficult for the network operator to know where new production will be connected. The hosting capacity approach has been extended in [9] to include this uncertainty. Instead of production units at one or more fixed locations, random locations are assumed for a given total amount of production connected to the feeder. A number of random scenarios were generated (using Monte-Carlo simulation techniques) with the same total amount of production but with different spread over the feeder. Different performance indices (like maximum voltage magnitude) were calculated. Instead of a single curve for performance versus installed capacity, as in Figure 2, a range of values for the performance index resulted, as in Figure 4. Instead of one value for the hosting capacity, this results in a range of values for the hosting capacity as well. In the figure, HC1 is the amount of generation above which the voltage may exceed its upper limit and HC2 the amount above which it will exceed this limit.

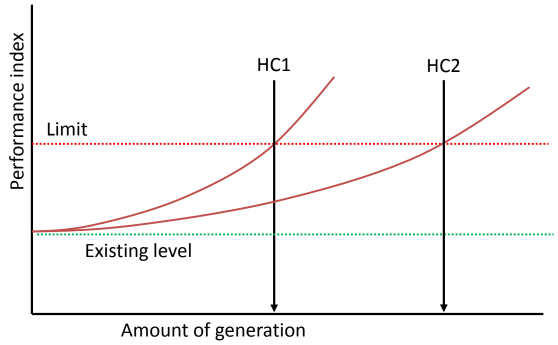

Figure 4. Range of hosting capacity values to accommodate for uncertainty in location and size of generation units

CURTAILMENT AND HOSTING CAPACITY

The hosting capacity as originally introduced was intended as a planning tool, either to decide about the need for investments to accommodate future growth or to decide about the connection for a specific new production unit. The amount of production is, under that paradigm, simply not allowed to exceed the hosting capacity. To connect more, mitigation measures are needed.

An alternative approach, akin to introducing operational methods to distribution, is to curtail production whenever the performance would otherwise be unacceptable. Instead of setting a limit to the amount of new production that can be installed, limits are set to the amount during the actual operation. Which method is more cost-effective depends on the investment costs for the installation, how often curtailment is needed, the costs of curtailment and the investment costs to enable curtailment.

Impact on produced energy

The impact of curtailment on the amount of produced energy per year is calculated for a number of cases in [10]. In that publication, a distinction is made between “hard curtailment” and “soft curtailment”. For hard curtailment, all production is disconnected when, for example, the loading of a distribution transformer exceeds a certain limit. For soft curtailment, the production is reduced so that the transformer loading becomes equal to its limit. In reality, the actual implementation will be somewhere in between these two extremes.

The impact of curtailment on the annual energy production is shown in Figure 4, for five different energy sources using the models and time series from [10] and [11]. The "DERmix" consists, in terms of energy, of 50% wind power, 25% solar power and 25% hydro run-off. In terms of installed capacity (at the hosting capacity, HC) this corresponds to 36 MW wind, 45 MW solar and 13 MW hydro. Biomass is assumed to be producing continuously, 100% capacity factor).

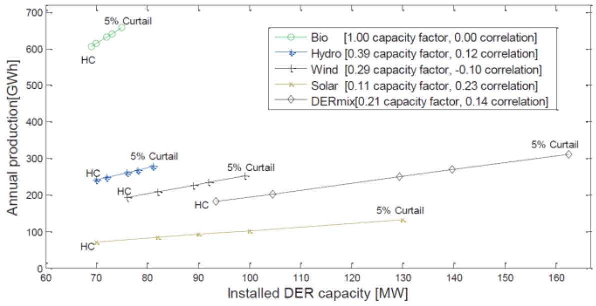

Figure 5. Installed production capacity leading to 0.1%, 1%, 2% and 5% probability of transformer overloading

The amount of additional installed capacity that requires, for example, 5% curtailment depends strongly on the energy source. It is biggest for solar power (having a small capacity factor) and smallest for biomass (having unity power factor). Different consumption profiles might however give different results, so the conclusions from this figure cannot be generalized.

Hosting Capacity Coefficient

A number of curtailment examples were presented in [10], some of the results of which are summarized in Figure 5. The horizontal axis is normalized to the "hosting capacity without curtailment", which in this case is the amount of installed capacity above which the voltage or power limits are exceeded for one time period.

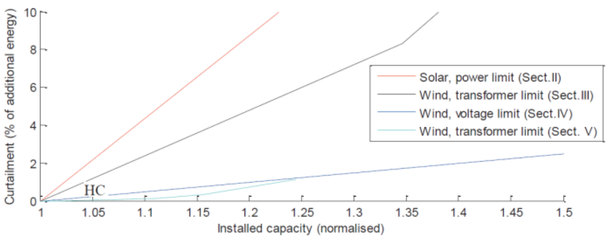

Figure 6. Need for curtailment as a fraction of installed capacity, for different cases. "Sect." in the caption refers to the cases in the different sections of [10].

The different cases give different slopes; i.e. more curtailment is needed to go above the initial hosting capacity. This slope can be used to compare the gain from curtailment for different locations, phenomena, types of production, types of curtailment algorithm, etc. The slope shows where it is most beneficial to install production above the initial hosting capacity. A high slope means that a lot of energy is curtailed which is not beneficial for the profitability of the investment.

For an objective comparison, the "Hosting Capacity Coefficient" is defined as the ratio of the curtailed energy and the installed capacity above the initial hosting capacity:

$$HCC = \frac{\text{curtailed energy}}{\text{capacity above HC}}$$

Note that the curves in Figure 5 are not linear, so that the HCC is a function of the installed capacity. This should be taken into consideration when making a comparison.

Hard versus soft curtailment

Another important conclusion from the work presented in [10] is that hard curtailment can result in a reduction of the amount of annually produced energy. This appears to be especially the case for solar power, where hard curtailment does not gain much energy compared to simply adhering to the hosting capacity as a planning tool. This is less the case for wind power. Further studies, using time series of production and consumption at different locations, are needed before this conclusion can be generalized.

The HCC can also be used to compare different algorithms for curtailment and as such is a recommended tool for research and development.

CONCLUSIONS

One of the biggest strengths of the hosting-capacity approach is that it allows an objective and comparable study of many different power system phenomena in very different grids with very different production and consumption. The hosting-capacity approach is therefore strongly recommended as a standard tool for distribution system planning as well as for development of curtailment, setting of regulation, and more.

It was shown in several studies that the hosting capacity strongly depends on the performance indices and limits and also on local properties like generation mix, the existing network and load profiles. Two important conclusions can be drawn from this:

- Hosting capacity studies can be used to get rules-of-thumb but those may not be generally valid and specific studies, including local properties of production, consumption and existing grid, are needed to obtain practically-useful values. Data collection of production and consumption profiles is essential here; the link with smart metering should be obvious.

- A concerted effort is needed towards finding a complete and appropriate set of performance indices and limits to be used in the hosting-capacity approach. This involves two types of indices: those directly related to the quality and reliability as experienced by the network user (like number of interruptions) and internal ones of direct relevance only for the network operator (like probability of unwanted protection tripping). Especially for the former ones the regulator will have to play an important role, but even here the network operators will have to be involved and might even take the lead in the initial development.

The hosting capacity approach has mainly been applied to new production but it can equally be applied to new consumption. The same set of performance indices and limits are valid for new consumption as for new production.

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