USING MEASUREMENTS TO INCREASE THE ACCURACY OF HOSTING CAPACITY CALCULATIONS

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ABSTRACT

This paper has compared 5 different methods for calculating the hosting capacity in a distribution grid. The results show a large difference in the obtained hosting capacity depending on the method used. It was found that the use of measurements in the calculations greatly increases the hosting capacity, compared to when using assumptions based on a "worst case scenario", without increasing the risk for the network operator or other customers. It was also found that the statistical index used (i.e. 100, 99 or 95%) has a large impact on the calculated hosting capacity.

INTRODUCTION

The hosting capacity is a measure of the amount of new production that can be connected to a power system, either at a specific location or over a larger geographical or electric area. The term and the associated "hosting capacity approach" originated from the EU-DEEP project as a transparent method to communicate between different stakeholders concerning the connection of distributed generation to the power system [1, 2].

The calculation of the hosting capacity contains several uncertainties, which result in an uncertainty in the resulting value of the hosting capacity, which in turn may lead to an additional barrier to the integration of renewable electricity production. There are different ways of reducing this uncertainty, thereby increasing the amount of renewable electricity production that can be connected to the grid. One of those ways, and the one being the subject of this paper, is to obtain additional information from measurements in the grid.

HOSTING CAPACITY

The hosting capacity approach is in the literature typically presented as shown in Figure 1, where a performance index (vertical scale) and a performance limit (red dashed line) are defined first. The performance index is then calculated as a function of the amount of production (horizontal axis) resulting in the blue curve. The hosting capacity is where the performance index reaches the limit.

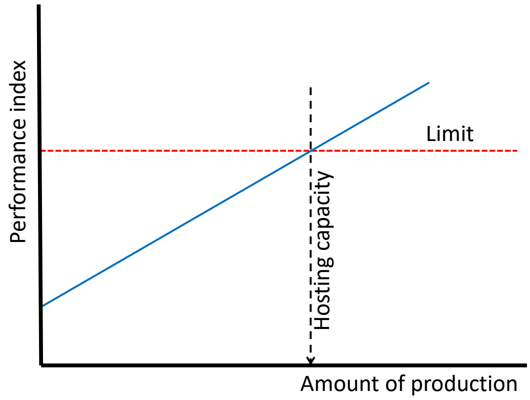

Figure 1. Basic description of the hosting capacity approach

In reality, more than one performance index should be complied with, and the resulting hosting capacity is the lowest of the values obtained for each of the indices.

UNCERTAINTY IN HOSTING CAPACITY

The hosting capacity is strongly impacted by the choice of performance index and limit. Especially a shift from a 100% value to a high-percentile for the performance index can result in a significant increase in the hosting capacity, without the need for any additional investments.

Another uncertainty first introduced in [3] and later for unbalance in [4], is the fact that the location of small production units is typically not known long in advance. Decisions made by individual customers determine where for example solar power installations will appear and, in the case of [4], to which phase a single-phase unit will be connected. Instead of one single value for the hosting capacity a range of values is obtained, as is shown in Figure 2. The consequences of this are discussed in [4] and [5].

The way in which the performance index is calculated introduces uncertainties as well, something that is not discussed that much in the literature. Not only is the future value of the performance index unknown, the existing value (for zero production) is also unknown. The range in hosting capacity increases even more and the lowest value of the hosting capacity range can become much lower than the "actual value".

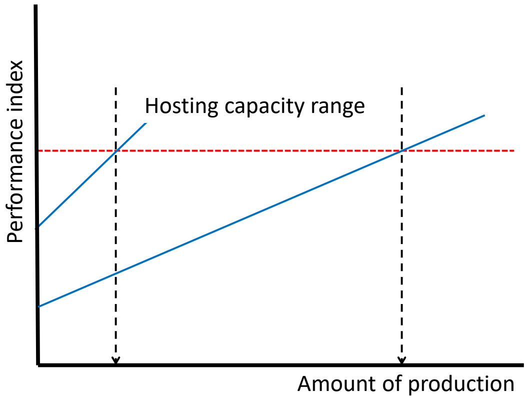

Figure 2. Uncertainty in e.g. the location of small distributed generation units and the chosen calculation method results in a hosting capacity range instead of a single value

It is the responsibility of the network operator to ensure appropriate quality and reliability for all customers, now and in the future. The consequence of this is typically that the lower limit of the hosting capacity range is used by the network operator. Connecting additional amounts of production will require investments in the grid which have to be carried either by the production units or which will be socialized over all customers. This will result in an additional barrier against renewable electricity production and in overinvestment in the grid.

As is shown in later sections of this paper, the calculations rarely result in the actual range, but instead typically just one value is obtained. This value will however be somewhere in the range shown in Figure 2. As we will see below, some calculations result in values towards the lower side of the range, thus giving an underestimation of the hosting capacity.

EXAMPLE – OVERVOLTAGES

Consider the connection of a solar-power installation to the low- or medium-voltage distribution grid, where overvoltages for customers close to the installation set the hosting capacity.

There are different approaches for calculating the hosting capacity, all resulting in different values of the hosting capacity, for example:

1) Assume zero voltage drops along the medium and low-voltage network during low load and up to 5% boost in voltage e.g. due to a distribution transformer with off-load tap-changers.
2) Assume an estimated minimum voltage drop, e.g. based on limited sets of measurements
    a) Using current measurements at the secondary side of the 130/10 kV transformer and an estimated resistance, *R*
    b) Using current measurements at the outgoing feeder and an estimated resistance, *R*
3) Consider the highest measured voltage on the LV side of a distribution transformer and assume zero voltage drop over the low-voltage network.
4) Consider time series of measured voltage and measured or estimated production for days with no cloud coverage to consider different time instants for maximum voltage, assuming maximum production from the solar panels.
5) Consider time series of measured voltage and measured or estimated production for corresponding dates to consider different time instants for maximum voltage and maximum production.

The resistance, *R*, refers to the resistance between the 10 kV bus in the main substation and the studied measurement location.

The fifth approach is considered the most accurate calculation method, but it still requires some safety margins to be considered. It is rarely possible to obtain data over a sufficiently long period (The so-called “30-year normal” is used in meteorology as a reference to remove year-by-year variations; hence a 30-year measurement period for weather data would seem appropriate with hosting capacity studies as well) and in those cases where multi-year measurement periods of the voltage are available, load patterns will likely have changed.

Future changes in load patterns will introduce further uncertainties.

In the case study below, we will however not consider these latter two uncertainties.

CASE STUDY

Measurements were performed at several locations in a medium-voltage network in the middle of Sweden. The network configuration is shown in Figure 3.

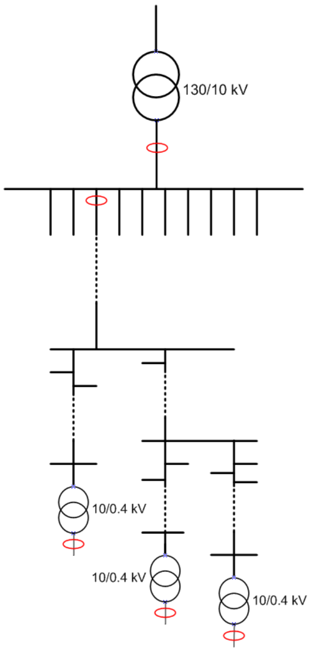

Figure 3. Medium-voltage network with measurement locations indicated

The hosting capacity according to method 1 in the previous section has been calculated for three measurement locations using the following expression [6, p.147]

$$P_{max} = \frac{U^2}{R} \cdot \delta_{max}$$

Where U is the nominal voltage at the measurement location, R is the resistance between the 10 kV bus in the main substation and the studied measurement location and δ_{max} is the relative overvoltage margin, using an overvoltage limit of 10%, calculated as

$$\delta_{max} = 1.1 * U - U_{est}$$

In method 1 U_{est} was calculated assuming a voltage at the upper side of the tap-changer deadband, zero voltage drops, and 5% boost due to a distribution transformer. The calculations resulted in an overvoltage margin of 1.7%, and a hosting capacity ranging between 13.6-18.6 kW for the studied locations.

Using method 2, the hosting capacity was calculated assuming an estimated minimum voltage drop, based on a limited set of measurements at the secondary side of the power transformer (it was assumed that the current was divided evenly over the connected feeders) or at the outgoing feeder under study. The overvoltage margin, δ_{max}, was recalculated taking this voltage drop into account. In this case, the overvoltage margin varied between 2.3 and 2.5%, and the hosting capacity between 20.5 and 25.6 kW, if only measurements on the secondary side of the transformer were used. If measurements on the outgoing feeder were used the corresponding numbers are 3.8-4.6% and 37.1-42.2 kW, respectively.

The hosting capacity was also calculated according to method 3, where the measured voltage at each location was used. The same equation as for method 1 has been used, but instead of an estimated overvoltage margin, the actual margin was calculated (i.e. replacing U_{est} with the maximum measured voltage). This resulted in an overvoltage margin ranging between 6.5 and 7.6%, with P_{max} ranging between 50.8 and 76.3 kW.

Method 3 only considers the highest measured voltage, but this value may occur during a time where there is limited production (e.g. at night in the case of solar power). In method 4 this is considered by comparing the actual voltage time series to a time series of production, assuming that there is limited or no cloud coverage (i.e. the "worst case" considering overvoltages).
Including the time series when calculating the hosting capacity leads to the following expression for the hosting capacity at time *t*:

$$P_{max}(t) = \frac{U^2}{R} \cdot \delta_{max}(t) \cdot \frac{P_{PVpeak}}{P_{PV}(t)}$$

where $P_{PV}(t)$ is the time series of production, P_{PVpeak} the installed peak power and $\delta_{max}(t)$ the overvoltage margin using the actual voltage time, calculated as

$$\delta_{max}(t) = 1.1 * U - U_{meas}(t)$$

The hosting capacity corresponds to the lowest value of $P_{max}(t)$, according to

$$P_{max} = \{P_{max}(t)\}_{min}$$

An example is shown in Figure 4, where the maximum possible production based on the relative overvoltage margin is shown for 24 hours together with the actual production of a solar plant during a day with limited cloud coverage. Instead of measured solar-power production, simulated solar-power production for cloudless days can be used. That limits the need for measurement data: only voltage variation data is needed in that case.

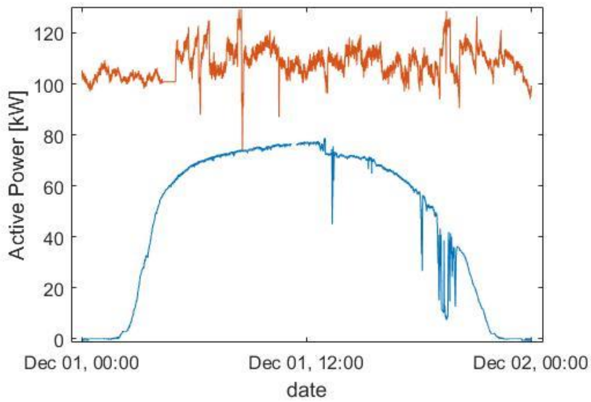

Figure 4. Hosting capacity calculated from time series of voltage (orange) at location 1 compared to production from a solar installation (blue) on a day with limited cloud coverage

For method 4, the calculations resulted in an overvoltage margin between 7.1 and 8.1%, and a hosting capacity between 72.7 and 86.2 kW.

Finally, the hosting capacity was calculated using method 5, where a time series of solar-power production was used for the same period of time as the voltage measurements. This resulted in an overvoltage margin between 7.6 and 9.0% and a hosting capacity between 75.9 and 90.8 kW. Figure 5 shows an example during one day with limited solar power production.

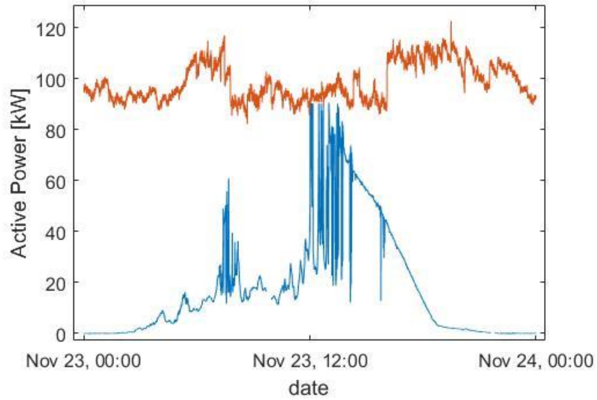

Figure 5. Hosting capacity calculated from time series of voltage (orange) at location 1 compared to production from a solar installation (blue) on the same day

Table 1 shows the overvoltage margin and resulting hosting capacity for the studied locations, using the methods described earlier.

Table 1 – calculated overvoltage margin and the resulting hosting capacity using the different methods, for three locations

Method	location 1		location 2		location 3	
	δ_{max} [%]	P_{max} [kW]	δ_{max} [%]	P_{max} [kW]	δ_{max} [%]	P_{max} [kW]
1	1.7	18.6	1.7	16.9	1.7	13.6
2a	2.3	25.6	2.4	23.8	2.5	20.5
2b	3.8	42.2	4.0	40.4	4.6	37.1
3	6.5	71.4	7.6	76.3	6.3	50.8
4	7.1	78.8	8.6	86.2	7.2	72.7
5	8.2	90.5	9.0	90.8	7.6	75.9

As can be seen from the results, there is a large difference in hosting capacity depending on the method used.

Simply by using measurements of current in the main substation together with some information about the underlying network (i.e. method 2a and 2b) a noticeable increase in hosting capacity can be seen, compared to the "worst case" assumed when using method 1. Especially for method 2b, when measuring at the outgoing feeder, an increase in hosting capacity of over 200% can be seen.

Method 3 considers the highest measured voltage at the studied location, and using this information over 350% more renewable production can be connected, compared to method 1.

If method 5 is used instead of method 1 over 450% more renewable production can be connected for the studied cases. It should be noted that method 4, which does not require any detailed data on solar production (i.e. actual time series) gives similar results as method 5. This conclusion holds when the worst-case (100% value) is considered, as the worst case for overvoltages is a cloudless day. However, when high percentiles (95% or 99%) are used, there is a higher difference in hosting capacity between these two methods (4 and 5) as presented in Table 2 and 3.

Table 2 – calculated overvoltage margin and the resulting hosting capacity using the different methods, for three locations, for the 95% performance index

Method	location 1		location 2		location 3	
	δ_{max} [%]	P_{max} [kW]	δ_{max} [%]	P_{max} [kW]	δ_{max} [%]	P_{max} [kW]
4	9.4	103.5	10.5	105.3	9.1	91.0
5	12.5	138.7	14.0	140.7	12.4	124.0

Table 3 – calculated overvoltage margin and the resulting hosting capacity using the different methods, for three locations, for the 99% performance index

Method	location 1		location 2		location 3	
	δ_{max} [%]	P_{max} [kW]	δ_{max} [%]	P_{max} [kW]	δ_{max} [%]	P_{max} [kW]
4	8.8	97.3	9.9	99.0	8.3	83.4
5	10.3	113.5	11.5	115.0	9.9	99.1

When using method 4, the hosting capacity would increase with over 15 and 25%, respectively, if the 99 and 95% values are used instead of the 100% value.
For method 5, an increase of over 50% for the hosting capacity can be seen when using the 95% value compared to when the 100% value was used. Using the 99% value would increase the hosting capacity with over 25%.

A limited amount of measurements (about one month) has been used for this study, but in reality long-term measurements (at least one year) are needed in order to capture e.g. seasonal variations.

DISCUSSION – FURTHER UNCERTAINTIES

Aside from the assumptions made in the case study, there are further uncertainties that should be addressed with regards to the calculation of the hosting capacity.

As mentioned previously, it is rarely possible to obtain data over a sufficiently long period, and future changes in load patterns will introduce further uncertainties.

The tilt of a panel and the direction of the tilt have a big impact on the variation of production with time. This in turn will impact the hosting capacity.

As is shown in the case study, the statistical index used (i.e. 100, 99 or 95%) has a large impact on the hosting capacity. Regulation in use today, e.g. EN 50160, use 95% values, but there is a push for the use 100% values. However, the use of 100% values may limit the amount of renewable energy sources that can be connected, or lead to unnecessary investments in the grid.

Another uncertainty is the impact of renewable production on nearby nodes. The calculations performed in this paper have looked at the amount of production that can be connected to a certain node, without considering the effect it will have on nearby nodes. In reality, the addition of production will impact nearby nodes as well, which may reduce the hosting capacity at those nodes. Looking at in another way: the hosting capacity of the distribution network as a whole is less (and possibly much less) than the sum of the hosting capacity values at the individual locations. Methods based on transfer impedance may be an approach to be used here, as was done in [5] but without the use of measurements. However, the main takeaway from the obtained results in this paper is valid also in such a case, i.e. the use of measurements will increase the hosting capacity, without increasing the risk.

The choice of method for estimating the hosting capacity is part of the risk management for the different stakeholders. Different calculation methods give different values for the hosting capacity, which are related to different levels of risks for different stakeholders. An overestimation of the hosting capacity increases the risk for among others the network operator (need for investment) and other customers (equipment damage due to overvoltages). This is the argument typically used (directly or indirectly) to justify the simple methods resulting in low values for the hosting capacity. The underestimation of the hosting capacity that is typically the result of this will however increase the risk for the owner of the production units (unnecessary costs for connection or unnecessary delay) and for society as a whole (less renewable electricity production).

Some of the methods presented here, based on measurements, allow for a higher hosting capacity without increasing the risk for the network operator or other customers.

CONCLUSIONS

This paper has compared 5 different methods for calculating the hosting capacity, at three different locations in a distribution grid.

It has been shown that the use of measurements in the calculations greatly increases the hosting capacity, compared to when using assumptions based on a "worst case", without increasing the risk for the network operator or other customers.

It has also been shown that the statistical index used has a large impact on the hosting capacity.

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