Hosting Capacity in the Croatian Regulatory Environment

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Abstract

Installing distributed energy resources (DERs) in low voltage networks is limited by distribution grid codes, often defining a conservative connection power threshold, especially in the case of a single-phase connection or by the network's technical constraints. Calculating the maximum installed power in that way is called hosting capacity (HC). Traditional HC calculation presents an assessment of static connection limits, determined by the lowest or highest electricity demand, depending on whether export or import limits are calculated. In this paper, we calculate the available range of aggregated active power of DERs based on worst-case and base-case demand scenarios. The results suggest the potential grid code redefinition since the analysed network can accommodate additional DERs in the range of 300 and 500 kW, compared to the current grid code limits. When observing only the grid code limitations in the import limits analysis, the results show an unrealistically high integration of more than 750 kW DERs, which is even higher than the best-case scenario. In the worst-case scenario, no additional DERs can be installed due to the initial violation of the network's constraints. Dynamic export and import limits are in the theoretical range of values, showing the benefit of the concept.

1 Introduction

The share of distributed energy resources (DERs) in low voltage (LV) distribution networks is continuously increasing. In many cases, the integration is uncoordinated, without detailed technical analyses of DERs impact on LV networks operational aspects. To prevent the occurrence of violating technical constraints such as voltage magnitude, Distribution System Operators (DSOs) often decide on conservative planning approaches that define the connection of DERs with lower power that does not bring an LV network close to its technical limitations. In the Croatian case, threshold values for connection power of distributed generators (DGs) and additional consumption units are defined in the Croatian distribution system grid code [1]. Besides connection power, other values limiting the DERs integration are technical constraints such as voltage and current magnitude and other power quality indicators. Threshold values for these quantities are also defined in the national grid code, but also other relevant standards, including EN 50160 [2].

The mentioned limitations and threshold values are the basis for calculating DER hosting capacity (HC), i.e., the maximum allowable penetration of DERs without violating the defined network's constraints [3]. The HC assessment can be performed both in the case of distributed generators (DGs), such as PVs [4], and additional consumption units, such as electric vehicles [5]. HC can also be calculated when combining both consumers and generators [6]. The limitation of the HC calculation is the need to observe the worst-case base electricity demand, i.e., in the case of calculating export limits, minimum demand for all end-users is observed, while the calculation of import limits is performers for the case in which all end-users' demand is at the maximum. Such scenarios are unrealistic and unnecessarily limit DERs installed power.

To overcome the limitations, traditional HC calculations are becoming replaced by the concept of dynamic operating envelopes (DOEs) [7]. DOEs are calculated as dynamic HC, where import and/or export limits are calculated based on day-ahead [8] or near-real-time estimates of electricity demand [9]. The concept of DOEs enables the real-time management of DERs and move away from calculating static limits, allowing the increase in the share of DERs.

In this paper, we put the calculation of DER HC in the Croatian regulatory perspective, i.e., we analyse how the limitations and regulations defined in the Croatian distribution system grid code impact the values of HC, both in cases of observing DGs and additional consumption units. Additionally, we compare the calculated values to the theoretically maximum and minimal HC values. That way, we are able to assess if defined regulations are too conservative and if the methodology for calculating HC fits into the Croatian regulatory perspective. Finally, DOEs are calculated and compared to HC and grid code limitations to assess the benefits of the concept.

The rest of the paper is organised as follows: Section 2 describes the methodology and the mathematical model used in LV feeder simulations, and case studies and the justification for their selection is given in Section 3. The results of the simulations are presented in Section 4, with the conclusions given in Section 5.

2 Methodology

HC and DOEs are calculated using *pp OPF*, the Python-based tool based on the three-phase optimal power flow mathematical formulation [10]. Based on the relations between current, voltage and power values, on common expressions such as Kirchoff's current and voltage laws, and expressions constraining values of voltage and current magnitude, voltage unbalance, and maximum DERs power, the tool calculates an optimal solution defining the penetration of DERs.

The model is extended by an additional set of constraints. Both HC and DOEs are calculated using the measurements collected from the smart meters installed on a real LV feeder. In this study, the measurements represent the day-ahead electricity estimates, i.e., both HC and DOEs are assessed on an hourly basis for the next day.

End-users are three-phase connected to a network. In order to define the marginal cases, total demand of each node in each period needs to be defined, as shown in (1).

$$P_{n,t}^{total} = \sum_{p \in \{a,b,c\}} P_{n,p,t} \text{ }, \forall n \in N, \forall t \in T \tag{1}$$

For each node n the maximum and minimum total demand are calculated. That way, two marginal cases are defined, and two sets of electricity demand are used as input parameters in the optimization process. As a result, the maximum and minimum theoretical HC is calculated, both for import and export values. Such a definition of a problem allows the creation of an allowable range for export and import limits. As long as HC values are in the defined range, network constraints will not be violated. Furthermore, by defining this range, the assessment of DOEs in terms of the distance from technical constraints threshold values becomes easier and much more intuitive.

3 Case Studies

In this paper, a real-world LV feeder is modelled. The feeder consists of 63 three-phase nodes and 62 lines. End-users are located at 42 nodes. All end-users are three-phase connected to a network, with separately measured electricity demand for each phase. DERs are single-phase connected with the randomly selected connection phase. Also, the connection phase remains the same in all time periods. Such a model setup puts the results into a real-world perspective, making them relevant not only in research but also to DSOs in terms of potential changes in the relevant regulations and grid code limitations.

The main goal of the study is to assess the integration of DERs within the Croatian regulatory environment. As mentioned before, the Croatian distribution grid code defines the maximum connection power of an end-user, both in the cases of generators and consumption units. The maximum connection power of single-phase distributed generators (DGs) is 3.68 kW, while maximum electricity consumption power cannot exceed 20 kW. In the case of consumption units, existing end-users' power must be considered when calculating the maximum unit's additional connecting power.

As per definition, HC is often calculated as the worst-case scenario. The calculation happens for the case in which the electricity demand of end-users is the least favourable for the adoption of DERs. When assessing the maximum power of distributed generators (DGs), HC is calculated for the case of minimum demand for all end-users. Even though such a scenario is not realistic due to the simultaneity factor being different than 1, theoretically, it can happen and, therefore, is considered in many simulations. On the opposite, the maximum end-users' electricity demand is considered when assessing the HC of new consumption units.

We also analyse what happens in opposite cases, when maximum electricity demand for all end-users is observed in calculating generators' HC and minimum demand is considered when calculating consumption units' HC. By defining two marginal cases, we introduce the robustness in calculating DERs HC. Furthermore, such an approach gives the available range of export and import limits, which can be calculated based on real-time electricity consumption. Such an approach is known as calculating DOEs, which is also the final case study in the study.

To summarize, four defined case studies are:

- CS1: HC is constrained by Croatian distribution grid code,
- CS2 – End-users' electricity demand is at minimum,
- CS3 – End-users' electricity demand is at maximum,
- CS4 – End-users' electricity demand is measured at each time period, i.e., DOEs are calculated.

4 Results

DERs HC is assessed both for evaluating export and import limits. The results are obtained following the methodology and case studies defined in previous sections.

Figure 1 shows calculated export limits in all defined case studies. In the case of constraining export limits by the Croatian distribution grid code, the aggregated DERs active power is around 150 kW in all time periods. To put the results into perspective, they require comparison to the ones in other case studies.

In CS2, it is assumed that the electricity demand of all end-users is at the minimum, which is, in the case of calculating export limits, the worst-case scenario, i.e., the lowest export values are expected in CS2. However, even in this highly unlikely scenario, the export limits are almost three times higher than in CS1. This is the best indicator of the conservativeness of thresholds defined by the DSO.

In CS3, maximum export limits are expected due to the maximum electricity demand of all end-users. It is also an unlikely scenario, but it helps define the allowable range of export values. The export limit in CS3 is increased for an additional 200 kW compared to CS2. The results show that none of the considered network's constraints will be violated when aggregated export values are in the interval visible in Figure 1.

The concept of DOEs is explored in CS4. The calculation of export limits in this case is dynamic, i.e., the values are based on the electricity demand value in a specific period, and they are calculated for every hour during a day in this study. The results show the benefits of such an approach since export limits increase in comparison to CS2 and especially CS1. Also, the results are not close to the limit defined by CS3, meaning that voltage and current magnitude and voltage unbalance values are still far from defined thresholds.

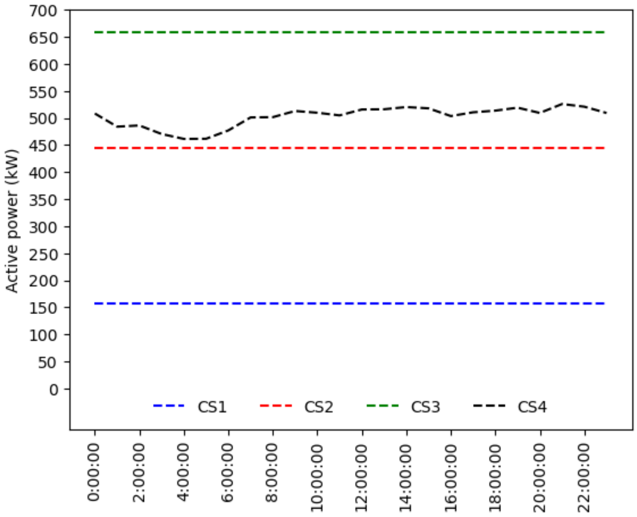

Figure 1 Hosting capacity – generators

Curves representing calculated export limits in CS1-CS4 are visualized in Figure 2. Unlike the conclusions drawn from CS1 analysis in the case of export limits, which show the conservativeness of the grid code definition, the results in CS1 in the case of calculating import limits show the opposite, i.e., the highest import limits occur in CS1. All end-users in the analysed LV feeder are three-phase connected to a network. The grid code defines that connection power for three-phase LV end-users may not exceed 20 kW. However, end-users need to pay the investment cost for each kW of connected power. Therefore, for most of them, connected power is limited at a much lower value than the grid code limitation. Since these power values are unknown, we focus only on the grid code limitation. For that reason, the export values in CS1 are higher than in other case studies.

CS2, in which electricity demand is minimal for all end-users, is not realistic due to the coincidence factor different than 1. Because of such an assumption, the import limits should be the highest. Consumption units HC in CS2 is higher in comparison to HC calculated in other case studies defined using electricity demand measurements. However, import limits in CS2 are still a few kW lower than in CS1, which shows that it is not enough only to rely on grid code definitions in analyses and simulations.

In general, maximum electricity demand in CS3 leads to the lowest HC when consumption units are observed. Also, this is the scenario usually considered when HC is calculated in the case of electricity import. A problem with this approach can be seen in Figure 2, in which export limits in CS3 are equal to zero. This means that no additional consumption units can be installed since the case in which all end-users have maximum demand leads to the violation of defined network constraints.

The results in CS4 show that real-time electricity demand enables dynamic import limits. The minimum values are greater than zero, making the concept beneficial for the DERs integration, while the maximum values are far from the upper limits calculated in CS1 and CS2, meaning that network constraints are not reached.

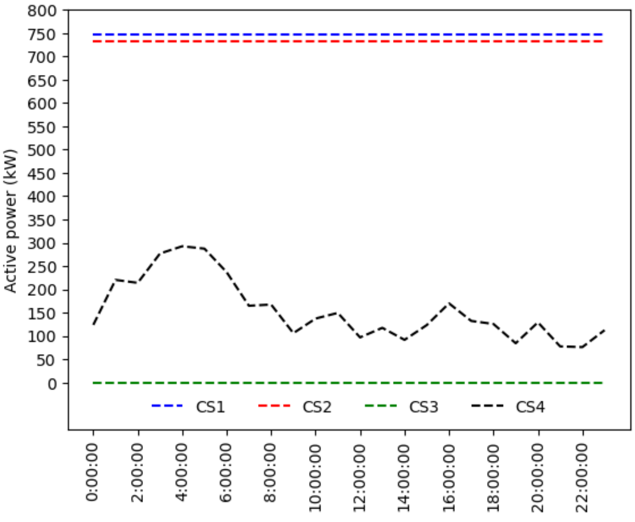

Figure 2 Hosting capacity - consumption units

4 Conclusion

In this study, we calculate the OPF-based static and dynamic export limits. The results showed that in the case of calculating export values, allowable connection power is the most limiting constraint since the threshold power defined by the grid code is around 300 kW times lower than the minimum DER power calculated based on the network conditions, even in the worst-case scenario, in which all end-users are assumed to have minimum electricity demand. In the opposite, also unrealistic scenario, the maximum electricity demand defines the upper export limits. The range between lower and upper export limits, i.e., between 150 kW and more than 650 kW, is a space in which dynamic export limits can be placed, which is shown with CS4. The results show the benefits of the DOE concept since it is not calculated based on worst-case scenarios. DOE values are higher than the theoretically minimal export, but the highest values are more than 100 kW lower than the theoretical maximum, meaning that the potential change in electricity demand can ensure further integration of DERs.

The results in CS1, when import limits are constrained by the Croatian distribution system grid code, are higher than in other case studies, i.e., they go above 750 kW. The reason is that the maximum import is defined based only on the grid code and not on the end-users' existing connection power. Minimum electricity demand slightly decreases static import limits to the value just below 750 kW in CS2, which are still high and enable the integration of a large share of additional consumption units. The problem with the definition of HC can best be seen from the results in CS3. In that case, in which all end-users have maximum electricity demand, some network constraints are already violated even without installing additional consumption units. Therefore, static import limits are equal to zero, i.e., no additional consumption units can be installed in a network. This conclusion, together with the results in CS4, in which import limits are in the range of 75-300 kW, shows the need to step away from the traditional understanding and definition of HC calculation since, in many cases, it is too conservative, limiting the share of DERs too much. The concept of DOEs, together with near real-time management allows the increase in the share of DERs and green energy transition without endangering the safe operation of distribution networks.

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