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Overload and overvoltage in low-voltage and medium-voltage networks due to renewable energy – some illustrative case studies

Nicholas Etherden[a,b,*], Math H.J. Bollen[a,b]

[a] STRI AB, Gothenburg, Sweden
[b] Luleå University of Technology, Skellefteå, Sweden

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ABSTRACT

This paper presents the use of curtailment to allow more wind or solar power to be connected to a distribution network when overcurrent or overvoltage set a limit. Four case studies, all based on measurements, are presented. In all cases the hosting capacity method is used to quantify the gain in produced energy for increased levels of distributed renewable energy resources. A distinction is made between "hard curtailment" where all production is disconnected when overcurrent and overvoltage limits are exceeded and "soft curtailment" where the amount of production to be disconnected is minimized. It is shown that the type of curtailment method used has a large impact on the amount of delivered energy to the grid. The paper further discusses details of the curtailment algorithm, alternatives to curtailment, the communication needs and risks associated with the use of curtailment.

1. Introduction

The amount of renewable energy that can be connected to any distribution network without endangering the reliability or quality for other customers (the "hosting capacity") is limited by the overvoltage and overcurrent limits in the distribution network. As the proportion of renewable electricity production increases so does the risk that network components get overloaded and/or the network users will experience overvoltages [1–3].

The here applied "hosting-capacity approach" has been introduced to quantify the limits placed by the grid on renewable electricity production. The hosting capacity is in this context defined as the maximum amount of new production that can be connected without endangering the reliability or quality for other customers [1]. The traditional way of connecting a new production installation is based on a kind of "worst-case approach". The maximum installed capacity is such that the risk of, for example, overload or overvoltage is sufficiently small, and therewith the impact on other network users.

Curtailment of production is a method to connect more production without impacting other network users. Other methods are available to achieve this. The reader is referred to [1,3–6] and other publications for examples of such methods. This paper is an upgrade and extension of an earlier work by the same authors [7]. The examples discussed in this paper will be used to illustrate a general method to quantify the effectiveness of curtailment. This methodology offers the different stakeholders (network operators, owners of production units, regulators, equipment manufactures and others) a tool with which they can compare curtailment with network investments in primary infrastructure (lines, cables, transformers, etc.) or other methods such as energy storage and reactive-power compensation.

The general methodology used in this paper is introduced in Section 2, illustrated through four case studies in Sections 3–6, and followed by a general discussion and synthesis of the four cases in Section 7 and conclusions in Section 8.

2. Curtailment and hosting capacity

When curtailment is in place, there is no longer any technical limitation to the amount of production capacity that can be connected. Unacceptable impact on other network users is no longer prevented by limiting the installed capacity but by limiting the actual production whenever needed. In practice it will be economic considerations by the owner of the production units that limit the installed capacity. With increasing installed capacity the utilization of the installation (e.g. expressed as the ratio of annual

* Corresponding author at: STRI AB, Regnbågsgatan 8 B, 417 55 Gothenburg, Sweden. Tel.: +46 240 79 565.
E-mail addresses: nicholas.etherden@stri.se, nicholas.etherden@ltu.se (N. Etherden).

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production and installed capacity, MW h/MW) will decrease and thus the return on investment.

The proposed methodology, illustrated in this paper through four examples, calculates the curtailed and the produced amount of electricity as a function of the installed capacity. This relation can be used as input to investment decisions, for the choice of technology, and to develop appropriate investment models.

During the four case studies, a distinction is made between “hard curtailment” and “soft curtailment”. Both should be viewed as extreme cases: for the hard-curtailment case it is assumed that all production units downstream of a certain location in the grid are disconnected. This is very close to the traditional protection relaying approach but instead of tripping the overloaded components, the installations causing the overload are disconnected from the electrical grid. For the soft-curtailment case it is assumed that the production will be reduced just enough to remove the overload or overvoltage situation that would otherwise occur. The actual curtailment in reality will be somewhere in between these two extreme cases, where the actual amount of curtailment depends on the details of the curtailment scheme.

This paper illustrates that risks in four case studies and discusses different methods of keeping the risks under control. How a risk-based approach together with advanced communication and control equipment increases the amount of renewable energy that can be connected to the distribution network is investigated following the approach of [1,8].

3. Solar power at low voltage, limitation in subscribed power

3.1. Description of the case

The impact of solar power on the loading has been studied for a large hotel complex located at 38°N. Measurements of the consumption (1-min averages during 1-week) have been combined with a model of the production. The consumption is high from about 10 am through 10 pm with a maximum of about 590 kW; the minimum consumption is about 230 kW. More details of this example are shown in [1, Section 4.2.6].

In this example, the limitation is assumed to be set by the subscribed power. Exceeding this limit is assumed to result either in disconnection of the installation or in high fines to be paid on top of the network tariff. Increasing the subscribed power would result in a higher network tariff and/or the need for investments in the grid. Curtailment of production is studied here as an alternative.

3.2. Overloading

The production has been calculated for a horizontal panel as a function of the time of day for 21 June. The resulting maximum loading as a function of the installed power is shown in Fig. 1. The system loading (i.e. the maximum apparent power) slightly decreases up to about 300 kW solar power (region A in Fig. 1). For higher amounts of solar power than 300 kW, the maximum occurs when the sun is below the horizon and further production will no longer reduce the maximum (region B). When more than 1000 kW of solar power is installed, the maximum loading occurs at noon and will increase linearly with the installed capacity (region C). The value of 300 kVA per phase (slightly above the original maximum) is reached for 1140 kW installed capacity. For even more solar power, the owner of the hotel runs an increased risk that the apparent power exceeds the subscribed power. The consequence of this may be a tripping of the installation by the overcurrent protection or fines to be paid by the hotel owner to the network operator. When the hotel is supplied from a dedicated transformer of three times 300 kVA rating, adding more solar power will require a larger transformer. When the hotel is supplied from a shared transformer, a higher subscribed power is needed, the costs of which will have to be discussed with the network operator.

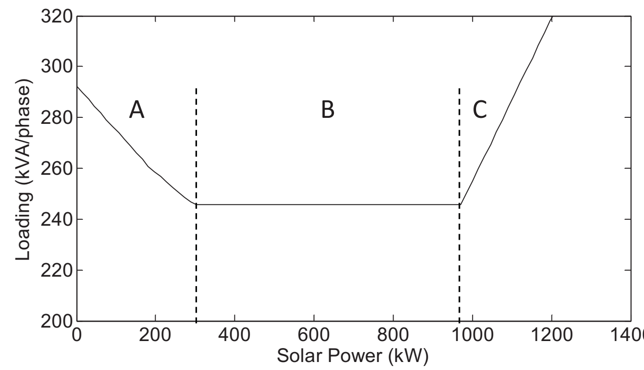

Fig. 1. Maximum apparent power per phase as a function of the installed solar capacity. (A = maximum from consumption at daytime; B = maximum from consumption in the evening; C = maximum from production at day time).

3.3. Curtailment

The impact on the amount of produced energy from solar power has been calculated for “hard curtailment” and for “soft curtailment”. For hard curtailment the whole solar-power installation is assumed to be disconnected once the supply current exceeds the subscribed power. For soft curtailment, the solar power production is reduced not to zero but just enough to keep the current below the threshold. Hard curtailment could in this case consist of an overcurrent relay at the point of connection that trips all production once the subscribed power is exceeded.

To estimate annual curtailment, solar production has been calculated for 12 weeks, spread equally through the year. Consumption has been assumed to be independent of the time of year and cloud cover assumed to reduce average solar energy production to 70% of its maximum value.

The results are shown in Figs. 2 and 3. For installed capacity below about 1150 kW no curtailment is needed, but for higher installed capacity the need for curtailment increases rapidly. For an installed capacity equal to 1500 kW, curtailment is needed for more than 600 h per year.

What matters is not the number of hours of curtailment, but total curtailed energy and total solar energy delivered to the grid. For hard curtailment (red solid curve) the curtailed energy increases as curtailed hours increases; with the annual production decreasing as installed capacity increases. So, hard curtailment is not a solution in this case.

With soft curtailment (green dashed curve) the amount of curtailed energy is reduced and the annual production continues to increase, but with a decreasing profitability. Up to about 1250 kW installed capacity the annual production corresponds to

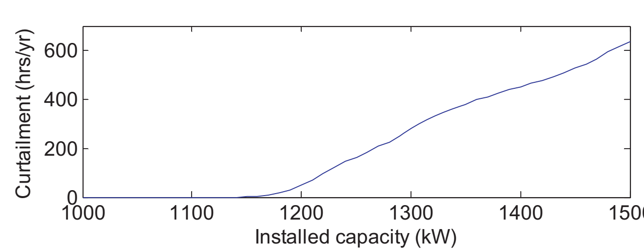

Fig. 2. Time during which curtailment is necessary to prevent the current from exceeding the supply rating.