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Considerations on hosting capacity for harmonic distortions on transmission and distribution systems

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ABSTRACT

The increasing penetration of renewable/distributed sources with non-linear characteristics demands a clear methodology for determining the amount of generation which can be connected to the system without deteriorating the performance (the hosting capacity). This paper proposes a methodology for determining the hosting capacity regarding harmonic distortions. The method includes aggregation effects of harmonic currents, the influence of harmonic distortion limits and harmonic generation profile. To exemplify an application of the proposed procedure, a simple case study is performed and analyzed.

1. Introduction

The worldwide increase in electric power generation based on distributed renewable energy sources, such as wind and solar power, has concerned the grid operators regarding their impact on the electric power system. This integration is one of the most important challenges for the future power system.

The amount of new distributed energy sources that may be connected to a network depends on several factors. The characteristics of the generation units, electric parameters of the local network, regional normative requirements, load capacity, etc., should be taken into account [1]. The maximum amount of dispersed generation that can be supported by the network in a specific point of distributed system is called hosting capacity [2]. In other words, the hosting capacity is the greatest amount of distributed generation (DG) which can be connected to this singular point before a particular performance limit level is reached [3,4].

The term hosting capacity is mainly related to the DG integration issue. Nowadays it is an important matter for several areas in electric power system. Different indicators may restrict the maximum amount of DG which can be connected to the system, such as: over-voltages, under-voltages, harmonics, voltage unbalances, overloading, etc. The curve with the generic relation between the performance index and the amount of dispersed generation is shown in Fig. 1, where the concept of the hosting capacity is illustrated [5].

Distributed generation like wind-turbines and photovoltaic (PV) panels typically use power-electronic converters as an interface to the grid. Therefore, they are potential sources of harmonic currents [2]. The non-sinusoidal injected current may increase voltage distortion in the network to inappropriate values. In this context, the harmonic hosting capacity can be defined as the maximum amount of DG which can be connected to the network without exceeding the harmonic distortion limit for each harmonic component.

There are some studies aiming to determine the specific hosting capacity based on the under and over-voltage deviations [e.g., 1, 6] or on the overloading [7]. In this context, few of them address hosting capacity in terms of harmonic constraints [8–11]. In [8,9], a method for estimating the number of distributed energy resources with power-electronic interface that can be connected to a low-voltage network without exceeding acceptable distortion levels is presented. This approach can be applied specifically in the

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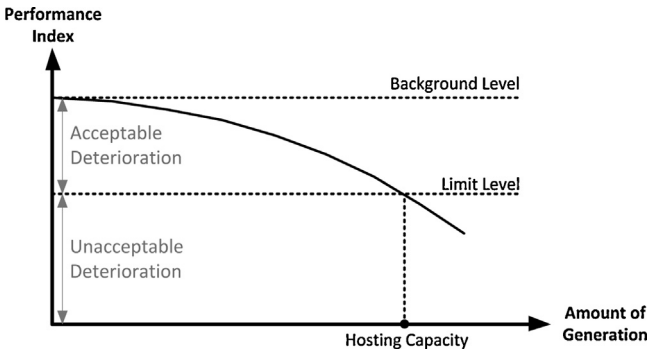

Fig. 1. Generic performance index versus the amount of dispersed generation.

frequency range from 2 kHz to 9 kHz. Additionally, in [10,11] a study that explores the impact of harmonic regulations on the capacity of distribution networks to host DG is performed. This effort incorporates harmonic voltage constraints into an established optimal power flow planning method. The optimal power flow has traditionally been used for economic dispatch [12,13]. These studies focus on how to maximize the hosting capacity avoiding costly network upgrades [11], but they are not able to calculate the hosting capacity. Therefore, despite the fact that hosting capacity for harmonics has been mentioned in the reported researches, a methodology to calculate the harmonic hosting capacity has not yet been defined.

Recently, a task force on DG, planning, and optimization, organized by some IEEE committees like PSPI (Power System Planning and Implementation), PSACE (Power System Analysis, Computing and Economics), and others, enumerates a large number of articles regarding the problematic of DG integration into transmission system [14]. Furthermore, the same reference has pointed out that the studies about net capacity and DG impact on transmission system still represent a challenge ahead. In this context and taking into account the aforementioned considerations, the current paper aims to propose a specific procedure for assessment of harmonic hosting capacity which can be applied to distribution or transmission networks.

In Fig. 2, the behavior of this specific indicator is depicted. In this graphic, the background distortion is the existing harmonic distortion at the evaluating point and the distortion limit is the maximum harmonic distortion allowed for this particular point of the system. This limit depends on the local grid requirements. Additionally, it is important to highlight that the shape of the curve of this graphic is generic, in practice it strongly depends on the DG harmonic phase angles (aggregation effects), and impedances in the network.

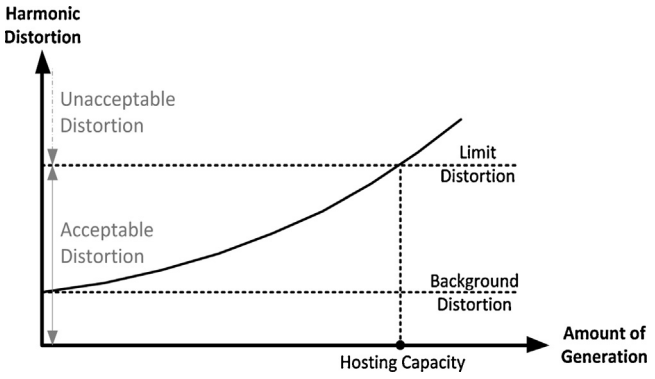

Fig. 2. Harmonic distortion versus the amount of dispersed generation – a generic dependency.

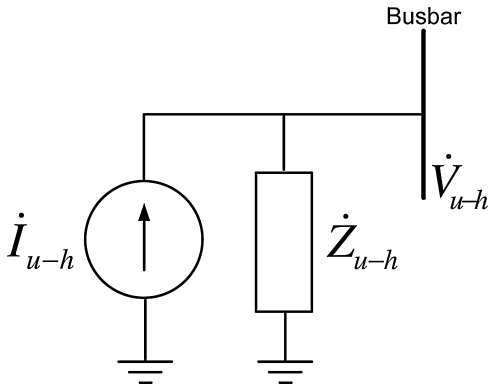

Fig. 3. Norton equivalent circuit for harmonic order *h*.

The paper is structured as follows: In Section 2, the harmonic hosting capacity methodology for assessment of the grid performance is shown. In Section 3, a case study aiming to exemplify the application of the proposed methodology is addressed. Section 4 discusses additional aspects related to aggregation effect, influence of harmonic source profiles, and impact of harmonic voltage limits. Finally, Section 5 draws some general conclusions.

2. Harmonic hosting capacity assessment

In order to estimate the harmonic hosting capacity, one or more quality indicators need to be calculated as a function of the installed capacity and compared with a predefined limit. In this context, to obtain a suitable indicator and threshold the following information is needed:

- requirements on voltage distortion set by the regulator or in other international documents/codes;
- the consequences of exceeding the threshold and the amount of risk the network operator is willing and/or allowed to take.

When this information is available, the calculation becomes a matter of applying circuit-theory.

In addition, it is worth mentioning that although the previously defined hosting capacity is expressed in terms of amount of (new) generation in Figs. 1 and 2, in this section the harmonic hosting capacity is presented in terms of (additional) harmonic current. The maximum number of units to be connected can be calculated taking into account the aggregation effects as discussed in the following sections.

2.1. The assessment procedure

Assuming a particular instant of electric system under analysis, a generic situation for harmonic distortion of order *h* can be considered using the Norton equivalent circuit exhibited in Fig. 3. In this figure, $\dot{Z}_{u\text{-}h}$ is the equivalent harmonic impedance of the utility system of order *h*, $\dot{I}_{u\text{-}h}$ is the equivalent harmonic current of order *h* produced by the utility system, and $\dot{V}_{u\text{-}h}$ is the harmonic voltage of order *h* at the utility busbar. The background distortion ($\dot{V}_{u\text{-}h}$) is due to the harmonic distortions from the same voltage level and also from upstream and downstream networks.

If the connection point has no previously existing harmonic content (busbar without background distortion), the values of $\dot{V}_{u\text{-}h}$ and $\dot{I}_{u\text{-}h}$ will be null. This is a particular case of this generic procedure.

The harmonic hosting capacity is defined as the maximum value of harmonic current of order *h* that will drive the harmonic voltage to a boundary of maximum acceptable distortion. Defining $V_{limit\text{-}h}$