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Unbalance and harmonic distortion assessment in an experimental distribution network

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ABSTRACT

The identification of voltage and current harmonic distortion and voltage unbalance sources is one of the main problems in electric distribution systems. In order to overcome it, in this paper the use of two novel indices is proposed. On the one hand, the Load Characterization Index (LCI) is suggested to calculate the harmonic distortion introduced by the load. This index identifies linear and non-linear loads in the power systems. On the other hand, the Unbalance Current Ratio (UCR) is suggested to assign the responsibility for system unbalance to load and source sides. Both indices can be calculated only from the measurement of the current at the input of the load and the voltage at the Point of Common Connection (PCC). The main objective of this paper is to test the performance of these two indices on an experimental three-phase electrical network. In order to do that, several experimental tests have been considered.

1. Introduction

Nowadays,the assessment of electric power quality is becoming increasingly important due to the widespread use of non-linear and time-varying loads. Otherwise, the uneven distribution of single-phase loads in the low voltage distribution system, among other causes, makes the voltage unbalance a problem in the power system. In this way, the IEEE Standard establishes the procedure to assess the voltage and current distortion and unbalance in the electric network PCC, [1,2]. Power monitoring equipment is frequently used to do that, [3–7]. However, the Standard does not regulate the procedure to assign the responsibility for the network harmonic distortion and/or unbalance to the different agents in the electric power system. This is a requirement to decrease these non-conformities, i.e., knowing the cause of the distortion and/or unbalance, the best location of the compensation systems is guaranteed and the most suitable procedure to mitigate them is established [8].

There are many proposals in technical papers to establish the responsibility of each agent for the harmonic distortion in power distribution networks [9–19]. One of the most significant methods is based on the sign of the harmonic active power. It can be used with measurements in a single-point, [10,11], or with distributed measurements systems, [12–15]. This method is based on the fact that the harmonic active power flows from source to load if the load is linear, whereas it flows in the opposite direction when it is a distorting load. One of the indices based on this concept is the Harmonic Global Index, HGI, which will be considered in the experimental results assessment.

Other methods are those based on the representation of load and source sides by means of their corresponding Norton circuits, [16]. There is a further technique called the critical impedance method, [17]. The drawback of these methods is the necessity of knowing the network and consumer harmonic impedances. Numeric techniques have also been used to establish each agent responsibility for the harmonic distortion in the electric network, for example, neural networks, [18].

Finally, there is another set of methods in the literature based on the current decomposition, [9,20,21,28]; among them, the Non-Colinear Index (NCI), [21], and the Non-Linear Index (NLI), [20], these will be used in the experimental results assessment in this paper. Another of those methods is the Load Characterization Index (LCI), [9], proposed by Herrera and Salmerón, which is based on the decomposition of current at the input of the load into two components: a current component which introduces harmonic distortion into the system and a second current component which does not introduce harmonic distortion, and whose harmonic distortion is the same as that of the voltage.

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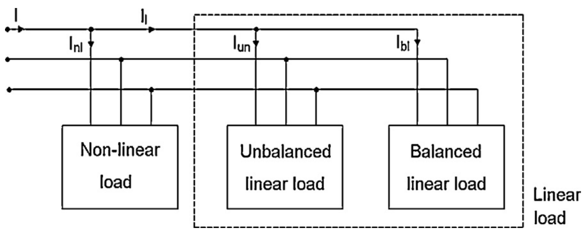

Fig. 1. Load current decomposition.

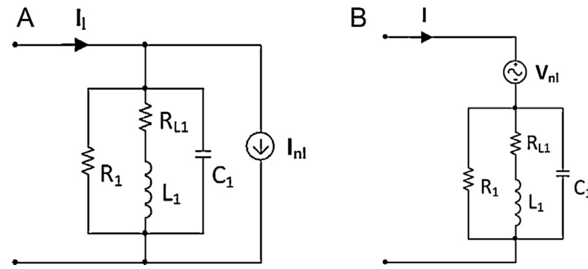

Fig. 2. Load equivalent circuit per phase: (a) equivalent circuit including current source and (b) equivalent circuit including voltage source.

On the other side, there are several publications which deal with unbalance problems, [22,23]. Some authors consider the harmonic distortion problem together with the unbalance one, [24–27], in order to characterize the unbalance without assigning responsibility to the load and source. One of the indices to identify the unbalance is the Unbalance Current Ratio (UCR), [25], proposed by Herrera and Vázquez [25], which is based on the decomposition of the current at the input of the load into three components: the non-linear, the unbalanced, and the linear balanced currents.

The main objective of this paper is to validate the LCI and UCR performance in an experimental power system. To do this, several experimental tests have been carried out in the Distribution Network and Protection Laboratory, D-NAP, at the University of Strathclyde. This laboratory is a three phase 400 V electrical network that can be split into a number of sub-networks or microgrids with controllable loads and generators.

The main advantage of the LCI is that it is able to identify the true sources of distortion even when there are capacitors in the system, [6], from only voltage and current measurements at the load input. For calculating the unbalance, the UCR is used. UCR and LCI are complementary, using the same procedures to be calculated, and the results presented by both are concordant with other indices published and improved in the case of the capacitors presence. Thus, the experimental values of the used indices will be compared with the HGI, [10], the SRI, [21], and the DAQ, [20], to verify their performance and to prove the better results in the presence of capacitors.

This paper is organized as follows. Section 2 presents the Load Characterization Index. In Section 3, the Unbalance Current Ratio is defined to assign each agent's responsibility for system unbalance. Section 4 describes the experimental platform used to test them. In Section 5, the results of different practical cases are shown and finally, in Section 6, the conclusions are presented.

2. The load characterization index

The Load Characterization Index (LCI), [9], is the chosen index to quantify the load responsibility for the system harmonic distortion in the microgrid. It is based on the decomposition of current at the input of the load into two components: a first current component which introduces harmonic distortion into the system, I_{nl} in Fig. 1, and a second current component which does not introduce harmonic distortion, and whose harmonic distortion is the same as that of the voltage, I_{l} in Fig. 1. This current component does not have to be sinusoidal (even without introducing harmonic distortion into the system) because it may be influenced by the system distortion.

The equivalent single-phase circuit that models the load according to the procedure to calculate the LCI is shown in Fig. 2, [9]. The first one, Fig. 2(a), consists of a linear load in parallel to a harmonic current source. The second one, Fig. 2(b), consists of the same linear load as Fig. 2(a) in series to a harmonic voltage source, [9]. The linear load is formed from three parallel branches: an inductive impedance (a resistor R_{L1} in series with an inductor L_1), a resistor R_1 and a capacitor C_1. There are two circuits because the non-linear loads can be of two different kinds: current distortion sources or voltage distortion sources.

To decompose the current at the input of the studied load, it must be assumed that the fundamental component of the current flows through the linear circuit of the model, Figs. 1 and 2(a). Although there are infinite possibilities of sharing fundamental current among the three parallel branches in the linear part, a set of the different values for each element must be tested and the index is calculated for a specific number of circuits. Then an array of index values is obtained, this is an index value for each set of values considered for the elements. Thus, the objective of the method is to find out the circuit that best represents the actual load, taking into account that the linear current component should flow through the linear part of the equivalent circuit. Furthermore, the best index value is the lowest one and the circuit that provides the smallest value for the index will be considered the equivalent to the analyzed load. The current flowing through the linear circuit is not linear, but presents the same distortion as the voltage. The difference between the total current and that flowing through the linear circuit is the non-linear current supplied by the distortion source, [9].

When studying a linear capacitive load the circuit presented in Fig. 2(a) is not useful. Thus, the circuit in Fig. 2(b) must be considered. The source voltage is divided into the drop in the linear load and the voltage at the source terminals. The fundamental component of voltage at point of common coupling must drop into the linear circuit. In the same way as the explained with the circuit in Fig. 2(a), an array of index values is obtained, considering the lowest index value and the circuit achieving the smallest index value, [9].

If one of the indices, correspond to the circuit in Fig. 2(a) or that in Fig. 2(b), has a null value, the studied load is linear and the LCI value is null. Otherwise, the LCI value is the corresponding to the circuit in Fig. 2(a). In this way, the current is decomposed and not the voltage. The index value is calculated as the percentage of the non-linear current on the total, i. e., the ratio of the norm of the non-linear current and the total, [9]. Norm is the square root of the sum of the square of each component and each phase of the electrical magnitude (non-linear current, total current, etc.). The row corresponding to the index value obtained allows the values of elements presented in circuits of Fig. 2 to be established and the current required by them to be calculated. This current will be used later to calculate the UCR, Fig. 3.

Finally, the capacitor behaviour and its effect in the network must be discussed. There are several ways of considering this element. Some consider that a component which amplifies the harmonics present in the network behaves as a non-linear load and so, the capacitor must be considered in this way. However, the technical standards promote the use of capacitance to compensate the power factor and so the users who must connect capacitors to improve their power factor should not be penalized by those same standards for the effect of that element in the network. It must be noted that the capacitor, which is a linear component,