Distortion Sources Identification in Electric Power Systems

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1. Brief introduction

Distorted voltage and current waveforms is one of the problems associated to electric power quality. Thus, it is necessary to know the responsible of this problem by means of the commonly named distortion sources identification. Different indices have been introduced to evaluate a specific consumer distortion level. In this paper, a comparative analysis of these indices is carried out, having as reference a practical case. The results obtained show that, in fact, these indices can help to valuate the harmonic distortion, although none of them solve the question definitively.

Key words: Power quality, harmonics, distortion sources.

2. Introduction

A lot of works have been published up now about valuation and location of distortion sources in electrical systems, [1-3]. Two different approaches can be distinguished: a) those based on measurements taken on the point of common coupling PCC, b) those based on measurements taken on different points of the power system, [4]. This paper develops the first group. Different methods have been proposed, among others: 1) the method of harmonic power flux sense, [1-3,5], 2) the superposition and projection method, SPM, [6-7], 3) the connection and disconnection method to detect one load harmonic level, [8], 4) the critical impedance method, CIM, [9], and 5) hybrid methods that carry out an estimation of the parameters of an equivalent linear load through measurements on the PCC, [10-11].
Initially, this paper establishes the nature of the problem of harmonic sources detection to analyze the foundation of harmonic power flow sense method. After that, hybrid methods are presented introducing some indices that allow a comparative analysis of different propositions. Finally, a practical case is presented to illustrate the situation.

3. Harmonic power analysis

In a first approximation to the problem, balanced three-phase systems are considered with several loads connected to PCC. Figure 1 shows the equivalent single-phase circuit, which includes n+1 branches, n corresponding to the loads and 1 to the source. The net is represented by the Thevenin circuit constituted by a voltage source Vs in series to impedance Zs. Certainly, PCC in figure 1 represents an industrial distribution system.

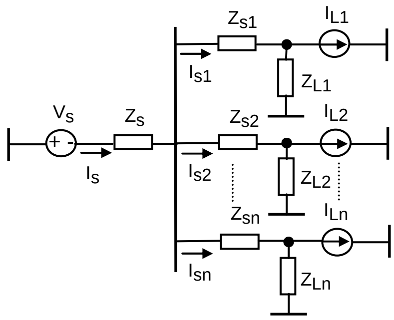

Figure 1. Balanced three-phase system equivalent circuit

Consumers are supplied by single impedances. Due to the system topology, it is necessary the measurement of voltage and current in each branch connected to the PCC. From these measurements, the consumers responsible of distortion are established. Besides, distortion generated by each one is quantified.
Harmonic active and reactive power measurements were the approach mainly adopted to identify the disturbances introduced by the consumer to the supply waveform quality, [1-3]. It suggests the necessity of finding an index which allows the evaluation of oscillations introduced by a specific load in the supply voltage system. The harmonic phase index, HPI, is defined as:

$$\xi_{HPI} = \frac{\|\mathbf{I}_L\|}{\|\mathbf{I}_S\|}100 \qquad (1)$$

where:

$$I_{Sk} = \begin{cases} 0 \; if \; P_k \leq 0 \\ I_k \; if \; P_k \succ 0 \end{cases} \qquad I_{Lk} = \begin{cases} 0 \; if \; P_k \geq 0 \\ I_k \; if \; P_k \prec 0 \end{cases} \qquad (2)$$

and P_k is the active power corresponding to the order-k harmonic.
This index has two advantages for the followed target. On the one hand, it is defined from the ratio of current rms values, that are the actual cause of perturbances

introduced by loads in the net. On the other hand, different harmonic values are not simply added, but in quadratic way. It avoids mutual elimination between different harmonics.

Another proposition, introduced by Srinivasan, defines the non-deforming current, *ind(t)*, as the component which does not distort the voltage waveform in the sense of Czarnecki, i.e., the part of the current collinear to the voltage. Thus, non-deforming current is the part of the current that presents the same distortion level as voltage. The deforming current is the difference between load current and non-deforming current, *id(t)*. It allows the definition of NC index as the ratio of deforming current rms value and load current rms value:

$$NC = \frac{I_d}{I}100 \qquad (3)$$

Dell'Aquila et al. in 2004 analyzed the problem, [12]. They defined the ideal load corresponding to a specific load like the linear load that requires a fundamental frequency active power equal to the fundamental frequency active power actually incoming to the load. The ideal load requires the linear current, $i_L(t)$. The non-linear load, $i_{nL}(t)$, is defined as the difference between load current and linear current. It allows the definition of NL index as the ratio of the non-linear load rms value and the load current rms value:

$$NL = \frac{I_{nLA}}{I_A}100 \qquad (4)$$

4. Analysis of a practical case

Harmonic distortion valuation introduced in previous section has been applied to a practical system constituted by three loads supplied by a sinusoidal voltage source. The first one is a resistive load (measuring point ML). The other two consist of three-phase rectifiers with an impedance in the continuous side: a capacitive impedance in one case (measuring point MNLC), and one inductive impedance in the other one (measuring point MNLI).

Table I includes the calculation of the distortion indices presented in previous section in the four measuring points. The indices calculated are voltage total harmonic distortion, VTHD, current total harmonic distortion, CTHD, harmonic phase index, HPI, non collinear index, NC, and non-linear current index, NL.

Table I

	VTHD	CTHD	HPI	NC	NL
PCC	7.9	21.8	22.1	27.6	25.8
ML	7.6	7.7	1.1	7.8	5.4
MNLC	8.2	37	39.7	42.6	41.1
MNLI	7.7	22	22.2	23.6	22.1

HPI index looks suitable to valuate the contribution of each load to the total distortion.

Tables II presents the results corresponding to the same system whose voltage THD before source impedance is now 14.8%. HPI presents values consequent with the corresponding to the before situation.

Table II

	VTHD	CTHD	HPI	NC	NL
PCC	18.1	17.3	16.9	29.8	26.6
ML	18.3	18.9	0.9	13.6	10.8
MNLC	18.3	30.7	31.6	43.9	40.7
MNLI	18.1	20.5	18.8	26.7	19.3

5. Conclusions

The indices HPI, NC and NL have been compared in this paper. Results establish the next conclusions: the active power flux direction method is mainly affected by phases of both harmonic sources; non collinear current to voltage index, NC, and non-linear current index, NL, are not useful from the practical point of view; harmonic phase index, HPI, solves the disadvantages underlined in the active power flux direction method, using in its definition current rms values in one or another direction in PCC.

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