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A Case Study of Sharing the Harmonic Voltage Distortion Responsibility between the Utility and the Consumer

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Due to the harmful character of the harmonic distortions, standards and recommendations establish guidelines for the definition of limits for these distortions and other power quality indexes. The IEEE Standard 519, EN 50160 and IEC 61000-3-6 are examples of documents for this subject.

If the harmonic voltage distortion exceeds the allowed limits, mitigation procedures must be considered. The application of these procedures may cause great conflicts between supplier and the consumer due to the fact that high investments and costs are often involved. These difficulties are due, mainly, to the knowledge absence of the individual source and load contribution for the voltage distortions. In such a way, the search of technical and scientific methods to reach the trustworthy to quantify the parcels of responsibility between the parts involved would be most relevant. At the moment a few references may be found tackling this matter. Some of them are base on:

- Principles involving load modeling under distorted conditions;
- Harmonic active power flow;
- Conforming and non-conforming current components and;
- Superposition principles.

In general, such works attempt to find the main source of the distortions without worrying about the establishment of procedures toward the identification of the individual parcels of responsibility. Recognizing this limitation, this paper attempts an approach, based on site measurements and system information, that gives, at the end, the individual contribution of the supplier and the consumer responsibility upon a given harmonic voltage distortion.

The general idea is based on the classic concepts of electric circuits and superposition principles. In addition to the methodology itself, a case study, using a real electric system supplying industrial installation containing a large number of rectifier units is considered. The results are given to highlight the approach utilization and method physical consistence.

Using frequency domain techniques, it is possible to represent the utility and the consumer connected to the PCC by an equivalent Norton circuit, as given in (Fig. 1).

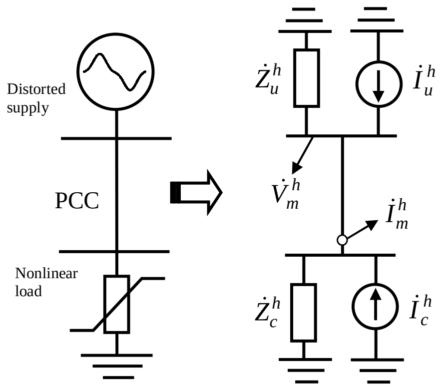

Fig. 1. Frequency domain Norton equivalent circuit for a generic harmonic order "h"

In the figure:

$\dot{Z}_c^h$ - Consumer equivalent impedance at order h;

$\dot{Z}_u^h$ - Utility equivalent impedance at order h;

$\dot{I}_c^h$ - Harmonic current produced by the consumer;

$\dot{I}_u^h$ - Harmonic current injected by the utility;

$\dot{V}_m^h$ - Harmonic voltage measured at the PCC;

$\dot{I}_m^h$ - Harmonic current measured at the PCC.

Throughout circuit basic equation it is possible to obtain the harmonic voltage contribution associated, exclusively, with the nonlinear effect of the consumer. The final result is:

$$\dot{V}^{h}_{pcc-c} = \dot{I}^{h}_{pcc-c} \cdot \dot{Z}^{h}_{u} \qquad (1)$$

In a similar way, the harmonic voltage parcel associated with the utility is given by:

$$\dot{V}^{h}_{pcc-u} = \dot{I}^{h}_{pcc-u} \cdot \dot{Z}^{h}_{c} = \dot{V}^{h}_{m} - \dot{V}^{h}_{pcc-c} \qquad (2)$$

Consequently, to determine the contribution of each part, is essential the knowledge of these harmonic impedances. Usually, the utility provides information related to its own harmonic impedances. On the other hand, it is important to observe that little or almost nothing is known about the load equivalent harmonic impedance. This guides for the necessity of the development of a strategy to the obtainment of such information.

The technique used in this paper considers a parallel association of the basic elements: resistance, capacitor and inductor (Fig. 2). These components are derived from site measurements and time domain computation techniques.

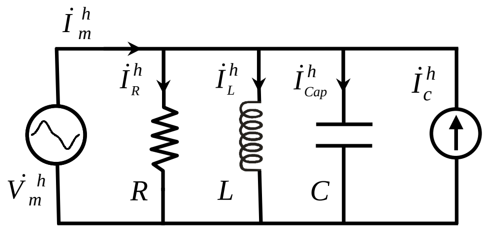

Fig. 2. Load equivalent circuit.

Where:

$$R = \frac{\sqrt{\sum_{h=1}^{H} \left(V^{h}_{m}\right)^{2}}}{\sum_{h=1}^{H} V^{h}_{m} \cdot I^{h}_{m} \cdot \cos\phi_{h}} \qquad \text{for all } V^{h}_{m} \cdot I^{h}_{m} \cdot \cos\phi_{h} > 0 \qquad (3)$$

$$C = \frac{\sum_{h=1}^{H} h \cdot V^{h}_{m} \cdot I^{h}_{LCK} \cdot sen(-\phi_{h})}{\omega \cdot \sum_{h=1}^{H} h^{2} \cdot \left(V^{h}_{m}\right)^{2}} \qquad \text{for all } V^{h}_{m} \cdot I^{h}_{LCK} \cdot sen(-\phi_{h}) > 0 \qquad (4)$$

$$L = \frac{\sum_{h=1}^{H} \frac{\left(V^{h}_{m}\right)^{2}}{h^{2}}}{\omega \cdot \sum_{h=1}^{H} \frac{V^{h}_{m} \cdot I^{h}_{LK} \cdot sen(\phi_{h})}{h}} \qquad \text{for all } V^{h}_{m} \cdot I^{h}_{LK} \cdot sen(\phi_{h}) > 0 \qquad (5)$$

With the intention of investigating the performance of the methodology the process was applied to a practical situation. The corresponding industrial installation used for this paper purpose is given in Fig.3.

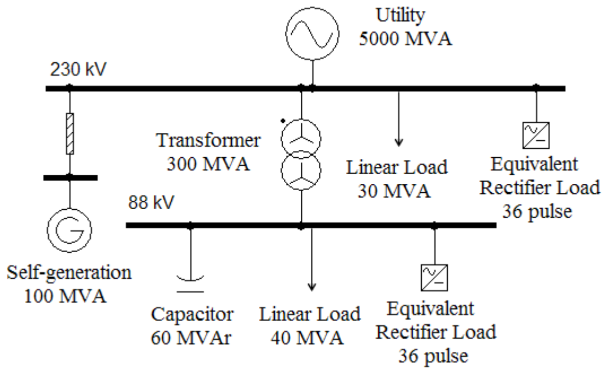

Fig. 3. Single line diagram of the industrial system

Once the necessary information is available to the use of the proposed methodology for sharing of responsibility upon the harmonic voltage distortion between the utility and the consumer, the method was applied and the final results are given in Table III and Fig 4. As shown, the values are related to the mentioned time interval of 5 minutes, due to this the minimum, maximum, average and P95 values are given.

TABLE III
Summary of the final sharing of responsibility at the PCC.

THD	Minimum	Maximum	Average	P95
Industry	0,88 %	1,19 %	1,04 %	1,16 %
Utility	0,98 %	1,28 %	1,12 %	1,28 %
Measured Value	1,44 %	1,97 %	1,67 %	1,94 %

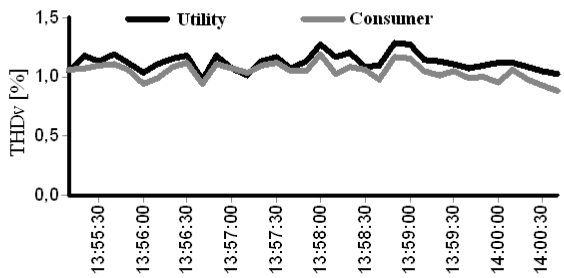

Fig. 4. Utility and consumer contributions to voltage THD at the PCC over the measured period.

The results indicate that there are no significant problems regarding harmonic distortions. Besides, the consumer and the utility contributions to total voltage distortion are almost the same.

Therefore, this article presented a proposal for sharing the harmonic responsibility between the supply and the load. By applying the methodology throughout a real case it was highlighted the steps and the final results about the distribution of harmonic distortion between the parts. The results have shown that, for the present situation, both the utility and the industrial consumer have equal responsibility upon the final THD.