Harmonic Propagation Analysis in Electric Energy Distribution Systems

L. C. O. Oliveira[1], G. A. e Melo[1], J. B. Souza[1], C. A. Canesin[1]
[1]São Paulo State University – UNESP
Ilha Solteira (SP), Brazil
canesin@dee.feis.unesp.br

B. D. Bonatto[2], F. N. Belchior[2], M. Oliveira[3], E. A. Mertens Jr[3]
[2]Federal University of Itajuba – UNIFEI
[3]Elektro Electricity and Services Co.
ernesto.mertens@elektro.com.br

Abstract— **An important alteration of the equivalent loads profile has been observed in the electrical energy distribution systems, for the last years. Such fact is due to the significant increment of the electronic processors of electric energy that, in general, behave as nonlinear loads, generating harmonic distortions in the currents and voltages along the electric network. The effects of these nonlinear loads, even if they are concentrated in specific sections of the network, are present along the branch circuits, affecting the behavior of the entire electric network. For the evaluation of this phenomenon it is necessary the analysis of the harmonic currents flow and the understanding of the causes and effects of the consequent voltage harmonic distortions. The usual tools for calculation the harmonic flow consider one-line equivalent networks, balanced and symmetrical systems. Therefore, they are not tools appropriate for analysis of the operation and the influence/interaction of mitigation elements. In this context, this work proposes the development of a computational tool for the analysis of the three-phase harmonic propagation using Norton modified models and considering the real nature of unbalanced electric systems operation.**

Keywords- Harmonic analysis; Nonlinear loads modeling; Harmonic propagation; Electric energy distribution systems.

I. INTRODUCTION

Looking for the modern human life facilities, several equipments and devices have been developed for use in different consumption sectors. These equipments usually incorporate, extensively, resources proportionate by the development of the power electronic and, therefore, they behave as nonlinear loads, generating distortions in the voltages and currents waveforms.

This scenario of increasing the harmonic distortions in currents and voltages, presents contributions of practically every consumption sector, that also share the undesirable consequences related to the loss of quality of the energy [1-8]. Furthermore, the main consequences are sensitive loads disconnection, electro-electronic equipments failure, and interruption of the supply, causing great damages, mainly in the industrial sector.

For the companies of the electric energy distribution sector, the loss of quality of the delivered electric power also presents important consequences. At first, the main consequences are the increase of the electric losses in the system and, consequently, the decrease of the profits. In the medium and long term, if measures are not taken aiming to keep under control the effects of such harmonic distortions, the major challenge will be to guarantee the increase of the consumption and the satisfaction of the customers in a competitive environment involving the companies of electric energy distribution sector.

Aiming to understand the ways of generation of harmonic distortion and the mechanisms of propagation of harmonic currents and voltages through electric systems, it is common the use of computational tools for the digital simulation of these phenomena. In this context, the main interested ones are the electric power utilities, which have been addressing efforts to incorporate procedures for evaluation of the electric power quality indexes in the planning, expansion and operation studies of the systems. The principal objectives aimed with this initiative involve the qualification and quantification of the effects of the harmonics in the connected equipment, in the operational cost of the system and in the continuity of the service. It is also an important tool for the technical analysis of new connections requisition, installation of equipment for mitigating the effects of these nonlinear loads in order to comply with the limits established by the legislation, and others [1-11].

In this context, this work has the objective of presenting a computational tool developed for harmonic propagation studies in distribution networks. This tool presents as main characteristics a three-phase representation of the electric network and the use of a mixed simulation technique that incorporates the positive aspects provided for the simultaneous use of models in the time and in the frequency domains. The computational implementation has been accomplished using a graphic and interactive platform, providing a friend interface and using a pre-existent data base.

II. METODOLOGY TO ANALYSE THE PROPAGATION OF HARMONICS DISTORTIONS

The connection of a nonlinear load affects the operation of the global electric system, once the non-sinusoidal currents generate harmonic distortions on the voltages ay the busbars or points of coupling of loads, as shown in Fig. 1.

Considering the adverse effects of the nonlinear loads on the equipment of adjacent consumers, the harmonic voltage and current magnitudes is of great concern for the utilities.

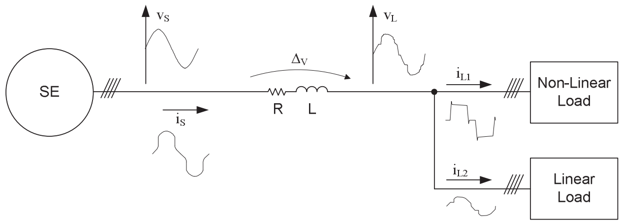

Figure 1. Harmonic distortion propagation.

Computational tools for the study of harmonic distortion propagation in the electric systems are indispensable. The better the system representation the bigger will be the quality of the obtained results, considering its accuracy. In this context, an important step in the elaboration of these tools is the characterization and modeling of the harmonic sources. On the other hand, the process of calculation to be used also constitutes a crucial factor for the fidelity of the results. Therefore, the analysis of distribution systems considering the presence of nonlinear loads, involves the necessity of modeling these loads and the main devices of the distribution system.

The modeling available in the literature for the harmonic penetration analysis can be divided into two groups: modeling in the time domain and in the frequency domain [1-8; 12-13].

The modeling in the frequency domain, normally, is more robust because the solution is found for each frequency, individually, and the errors are not cumulative. The method of currents sources are used to represent the nonlinear loads. It requires less time to reach the solution, but it presents difficulties with the dynamic, control, fast transients and representation of loads with characteristics of discontinuity.

The methodology of modeling in the time domain is based in integrations considering discrete times. The actual periods of operation within each cycle of the device operation, as well the power system, are described by differential equations. The solution is obtained considering a set of initial conditions for the state of the system and the stability, as well the accuracy depend on the time step adopted for the calculations. The harmonic components of the currents and voltages are obtained from the resultant waveforms, considering the discrete Fourier analysis.

III. LOADS MODELING

A relevant factor is the choice of a modeling technique that is adequate to represent the loads connected to the system, mainly those of nonlinear nature, in function of their operational characteristics, of the single-phase, bi-phase and/or three-phase groupings, as well their dependence with the supply voltage [3-4].

In the representation of this type of loads the reproduction of the current produced by the equipment, when they are under nominal condition of operation, is necessary. For this, one can think about the true reproduction of the electric, electronic and electromechanical original circuits. This strategy, while can provide very precise results, lead to a significant increase of the model complexity as well the resultant analysis, mainly when digital simulations are carried out. There is, yet, a great difficulty in obtaining the circuits that correspond to the equipment, once there is no commercial interest of the manufacturers in the divulgation of this kind of information. Additionally, this strategy cannot be directly applied to the representation of compound loads. Alternatively, the representation of nonlinear loads for equivalent harmonic currents or voltages sources can be adopted. This strategy can be applied when there is precise information about the harmonic content of the load complex current or the terminal voltage at a determined load. It is necessary to show up yet that, differently that occurs with nonlinear industrial loads, in general, that presents a behavior of “harmonic current sources”, the residential and commercial nonlinear loads behave as “harmonic voltage sources” [5].

For some specific applications, it is possible to carry out a harmonic analysis from the measurement of the waveforms presented by the nonlinear load currents. In preliminary studies it is common to use the harmonic content of this current to compose alternative models of the nonlinear loads, representing them as ideal sources of constant harmonic currents. The IEEE 519 standard (utility version) recommends the utilization of this methodology when the maximum voltage distortion at the busbar of interest is equal or inferior to 10% [4, 6-7].

To model a system as a constant current or as a voltage source cannot be precise enough in the case the operational conditions of the supply system vary a lot in relation to the conditions in which the harmonic spectrum of the voltage or current have been determined. Therefore, as the distribution systems consist, generally, of several impedances connected in parallel, when the operational condition of the supply systems is changed, the harmonic currents injected into the busbars, where the measurement has been carried out, can suffer changes in the presented values [8].

The representation of nonlinear loads as voltage dependent current sources becomes important as the currents generated by this loads suffer direct influence of the supply voltage. In this sense, the Norton model can be used when the characteristic of the equivalent load suggests its representation by current sources [6-8].

For estimating a Norton model, as shown in Fig. 2, measurements of harmonic current (I_h) and harmonic voltage (V_h) must be carried out in two distinct conditions of operation.

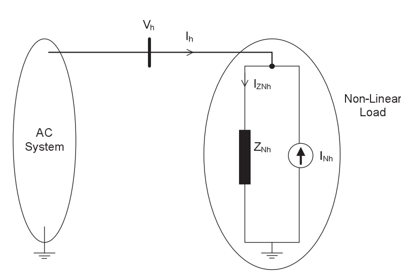

Figure 2. Norton Model.