VOLTAGE WAVE QUALITY IN LOW VOLTAGE POWER SYSTEMS

José M. R. Baptista [1], Manuel R. Cordeiro [1] and A. Machado e Moura [2]

[1] Department of Electrical Engineering
U.T.A.D., Vila Real University
Quinta de Prados, 5000 Vila Real (Portugal)
phone: +351 259350300, fax:+351 259350480,
e-mail: **baptista@utad.pt**, **cordeiro@utad.pt**

[2] Department of Electrical Engineering
F.E.U.P., Engineering Faculty of Oporto University
Rua Roberto Frias, 4200 Porto (Portugal)
phone: +351 225081440
e-mail: **mmoura@fe.up.pt**

Abstract. This paper deals with some disturbances that reach the electric power systems. These problems originated some interest due to the changes of the electric loads characteristics, which were predominantly electromechanical and today are predominantly non-linear. This is due to the electronic systems involved. Results of some measurements performed in electric grid of the Oporto Engineering Faculty Campus and in the University of Vila Real (UTAD) are presented and some solutions that had been implemented for the related problems minimization are also described.

Key words

Harmonic distortion, voltage sags, voltage fluctuations, flicker and active harmonic conditioner.

1. Introduction

The vertiginous evolution of the technological society showed through the irreversible automation of the industrial processes, justified for the increase of the productivity, flexibility and industrial product quality.

The electric power systems are subjected with increasing number of nonlinear loads. This evolution in the characteristic of loads allowed improvements in the quality of modern life and the production. These loads, at the same time that pollute the electric grid generating a series of impure signals and harmonics, are themselves more sensible to the effect created by these distortions.

2. Some problems that reaches the electric network

A. Overvoltages

An overvoltage is characterized by a drastic instantaneous increase of the voltage of the power system greater than 110 percent at the power frequency, with short duration. Of all the critical events, the voltage peaks are the potentially most dangerous ones and are at the origin of great damages. Overvoltages are usually the result of load switching (e.g., switching of a large load, or energizing a capacitor bank).

B. Voltage Sags

Voltage sag is a short-duration (typically 0,5 to 30 cycles) reduction in the rms voltage caused by faults on the power system (short circuits) and the starting of large loads, such as motors. Momentary interruptions (typically no more than 2 to 5s) cause a complete loss of voltage and are a common result of the actions taken by utilities to clear transient faults on their systems.

C. Frequency variations

Frequency variations are defined as the deviation of the power system fundamental frequency from its specified nominal value (50Hz in our case).

Frequency variations that go outside of accepted limits for normal steady-state operation of the power system can be caused by faults on the bulk power transmission system, a large block of load being disconnected, or a large source of generation going off-line.

D. Voltage fluctuations - Flicker

Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes. Loads, which exhibit continuous, rapid variations in the load current magnitude, can cause voltage variations that are often referred to as flicker. The term flicker is derived from the impact of voltage fluctuation on lamps such that they are perceived to flicker by the human eye. To be technically correct, voltage fluctuation is an electromagnetic phenomenon while flicker is an undesirable result in some loads.

E. Harmonic distortion

Harmonic distortion is a deformation of a voltage or current sinusoidal wave. A harmonic signal can be defined as a sinusoidal signal whose frequency is multiple of the fundamental frequency. Distorted waveforms can be decomposed into a sum of the fundamental frequency and the harmonics. Harmonic distortion originates in the non-linear characteristics of devices and loads on the power system.

F. Noise

Noise is defined as unwanted electrical signals with broadband spectral content lower than 200 kHz, superimposed upon the power system voltage or current in phase conductors, or found on neutral conductors or signal lines. Noise in power systems can be caused by power electronic devices, control circuits, arcing equipment, loads with solid-state rectifiers, and switching power supplies.

3. Harmonics – definitions and related parameters

It is, especially the sinusoidal voltage waveform that is necessary to keep since the production until the final receivers, passing thought the distribution, with the purpose to preserve its essential characteristics for the transmission of useful power to the terminal equipments.

The electric grid comes being target not linear load constant. This evolution in the characteristic of loads however allowed improvements in the quality of modern life, this type of loads, at the same time that they pollute the electric grid, generating a lot of impure signals and harmonics, they are well more sensible to the effect created by these distortions. When the voltage and current waveforms leaves of being sinusoidal, the disturbances appear, that affect numerous utility equipments, originating equipment failures.

The distorted loads, produces in the power system distorted currents. Distorted currents from harmonic-producing loads also distorted the voltage as they pass trough the system impedance. Thus a distorted voltage is present to other end users. Therefore, while it is the voltage with which we are ultimately concerned, we must address phenomena in the current to understand the basis of many power quality problems.

A. Harmonic definitions

According to EN 50160, a harmonic voltage is a sinusoidal signal whose frequency is multiple of the basic voltage frequency. The voltage or current waveforms in one point of the electric system can have the aspect of the figure 1 distorted signal. Analysing the signals in this figure we can say that the distorted signal is the result of the addition of the harmonic with the basic component. In this example the harmonic frequency is three times the basic frequency.

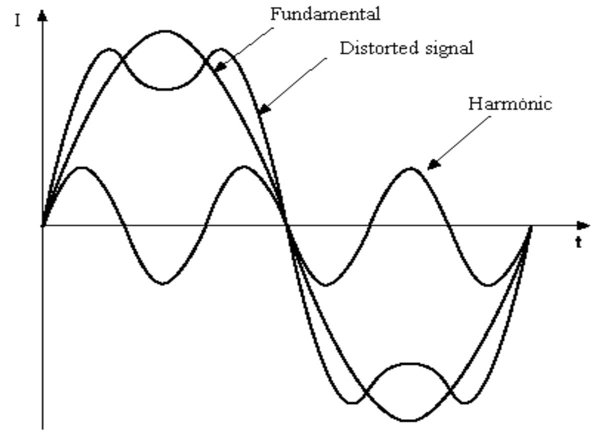


Fig. 1 – Example of a distorted signal

According to French mathematician Joseph Fourier, any periodic signal, can be decomposed in an sum of pure sine waves in which the frequency of each sinusoid is an integer multiple of the fundamental frequency of the distorted wave.

$$y(t) = Y_0 + \sum_{n=1}^{n=\infty} Y_n \sqrt{2} \sin(n\omega t - \varphi_n) \quad (1)$$

Where Y_0 represents the DC component amplitude that in steady state is normally null. The Y_n parameter represents the rms value of the order n harmonic, while φ_n represents the harmonic angle phase for t = 0. Therefore, we can define the harmonics as being sinusoidal oscillations whose frequency is multiple of the fundamental frequency.

B. Harmonic order

Harmonics are classified by three parameters: its order, the frequency and the sequence, in accordance with table1.

TABLE 1 – Harmonics classification

Order	1	2	3	4	...	n
Freq.(Hz)	50	100	150	200	...	n*50
Seq.	+	-	0	+	...	...

The harmonic number (order) represents the number of times that the frequency of this harmonic is bigger than the basic component (equation 2).

$$order = \frac{f_{harmonic}}{f_{fundamental}} \quad (2)$$

By table 1 it can be said that two harmonics types exist, odd and the pairs. The odd harmonics are the ones that are find in the electric installations, industrial and commercial buildings, while the harmonics of pair order only appear when asymmetry in the signal due to continuous component exists.

C. Total harmonic distortion (THD)

There are several measures commonly used for indicating the harmonic content of a waveform with a single number. One of the most common is total harmonic distortion (THD). Two equations exist to calculate the THD.

$$THD_f = \frac{\sqrt{(h_2)^2 + (h_3)^2 + ...(h_n)^2}}{h_1} \cdot 100\% \qquad (3)$$

$$THD_r = \frac{\sqrt{(h_2)^2 + (h_3)^2 + ...(h_n)^2}}{\sqrt{(h_1)^2 + (h_2)^2 + (h_3)^2 + ...(h_n)^2}} \cdot 100\% \qquad (4)$$

Where h_1, h_2, ..., h_n represents the harmonics rms value for order 1, 2, ..., n. THD_r represents the total harmonic distortion relatively to the total signal, in this case, $0<THD_r<1$, while THD_f represents the total harmonic distortion relatively to the fundamental component, this definition is used by IEC 61000-2-2, in this case values above 100% are possible to the THD_f.

4. Harmonic effects and consequences

The harmonic distortion is caused by nonlinear devices in the power system, like electronics systems, personals computers and fluorescent lamps, also helps in the increment of the amount of harmonics in an installation.

A. Harmonic effects

Heating of the conductors and other devices: The heating is one of the most important effect associated to the harmonics, being able to happen especially in the machines (motors, alternators, transformers) windings, and in the neutral conductor of an installation.

Protection devices switching: Signals with harmonics can have low current rms value and reach very high peak values. This fact takes protection devices to switchs off.

Resonance: Capacitors in parallel with an inductor form a resonant circuit, able to amplify some signals. When in a power system we place a capacitor bank that forms a resonant circuit, since the capacitor bank is placed in parallel with the electric grid that is predominantly inductive. This fact takes that some harmonics can be amplified, arriving in certain cases to destroy the capacitor bank.

Vibrations and couplings: The high frequencies contained in the harmonics, provoke electromagnetic interferences that can be radiated or conducted. The electromagnetic interferences can provoke vibrations in the electrical equipment and couplings in the communication networks. In the last case, this noise can provoke errors in the information transmitted.

Deterioration in the voltage waveform: When a power system has a great harmonic content, the current distortion provoked for non-linear loads leads to a deformation in the voltage waveform resulting in a flatness in the upper/lower part of this, as it can be seen in the figures presented in the following chapter.

B. Harmonic consequences

Conductors: The conductor's impedance depends on the frequency. The electrical grids are projected to work with one frequency (50 Hz in our case), when the frequency increases; the conductor's impedance also increases (skin effect). As consequence a superheating of the conductors is verified originating the insulation destruction and provoking short circuits and fires.

Computers and informatics loads: The computers are the elements that more harmonics produce and in simultaneous most sensible are to them. The harmonics components in an installation that feeds computers and informatics systems can be of such high form that they lead to the hard disks destruction, sporadically loss of data and resets.

Capacitors: The capacitors impedance fall with the frequency, therefore, how much bigger it is, the biggest will be the possibilities to appear parasitic currents. Overloads can exist whose consequence is the capacitors destruction.

Transformers: The effect in the transformers is diverse. On the other hand, as already it was said, it will have windings superheating, and at the same time, the impedance source increase due to the harmonics, provoking an increase in the transformer losses.

5. Active harmonic conditioners

Similar to solve of an efficient and definitive form the problems created by the harmonics, equipment called for active compensators of harmonics exists in the market. The concept of active harmonic conditioner, also calls active filters exists since some decades, however due to lack of adequate technology its development was limited. Figure 2 shows the basic principle of the "shunt-type" active harmonic conditioner.

Provided that the device is able to inject at any time a current where each harmonic current has the same amplitude as that of the current in the load and is in opposition of phases, then Kirchoff's law at point A guarantees that the current supplied by the source is purely sinusoidal. The combination of "non-linear loads + active harmonic conditioner" forms a linear load (in which current and voltage are linked by a factor k). This kind of device is particularly suited for harmonic compensation of LV networks irrespective of the chosen point of coupling and of the type of load (the device is self-adaptive).

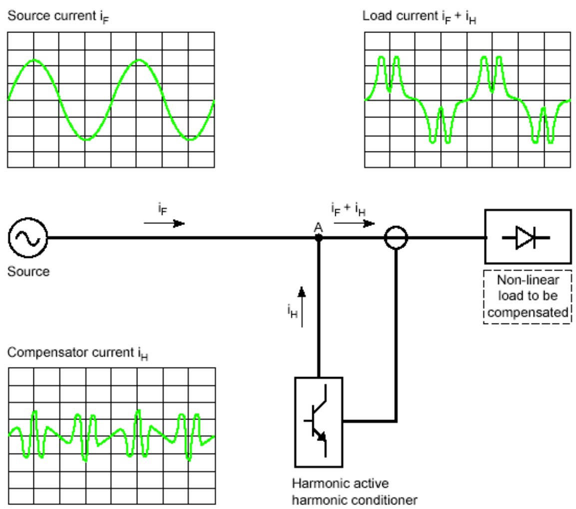


Fig.2 – Principle of compensation of harmonic components by “shunt type” active harmonic conditioner

The following functions are thus performed according to the level of insertion:
-Local harmonics compensation: if the active harmonic conditioner is associated with a single non-linear load,
-Global harmonics compensation: if the connection is made (for example) in the MLVS (Main Low Voltage Switchboard) of the installation.

The “shunt-type” active harmonic conditioner thus forms a current source independent of power network impedance, and with the following intrinsic characteristics:
-its band-width is sufficient to guarantee removal of most harmonic components (in statistical terms) from the load current. We normally consider the range H2 - H23 to be satisfactory, as the higher the order, the lower the harmonic level.
-its response time is such that harmonic compensation is effective not only in steady state but also in “slow” transient state (a few dozen ms),
-its power enables the set harmonic compensation objectives to be met. However this does not necessarily mean total, permanent compensation of the harmonics generated by the loads.

Provided that these three objectives are simultaneously achieved, the “shunt-type” active harmonic conditioner forms an excellent solution as it is self-adaptive and there is no risk of interaction with power network impedance. [5]

6. Experimental results

In this chapter some monitorizations results doing in different types of electrical installations are presented, some of which had been filtered, with active harmonic conditioners. It can verify the voltages and currents waveforms as well as the voltage harmonic spectrum in one of the phases and the total harmonic distortion in different situations.

In figure 3 the results gotten in a machinery laboratory without active harmonic conditioner are presented while in Figure 4 we can see the same signals with active harmonic conditioner.

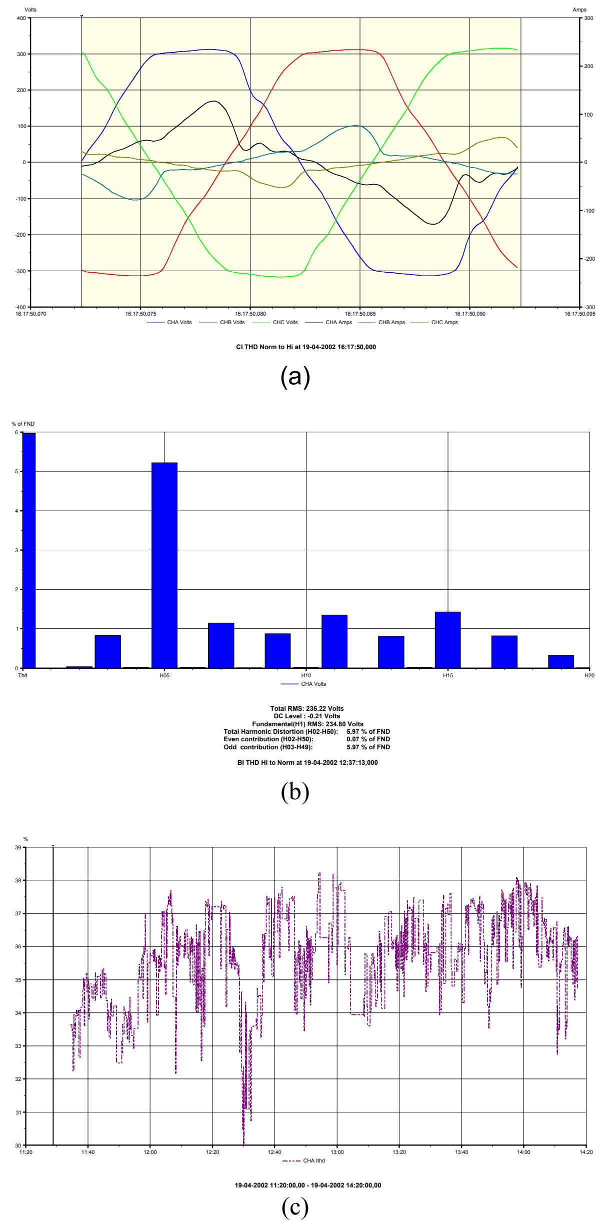
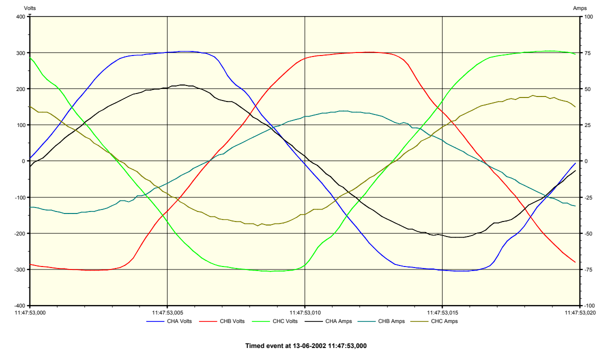
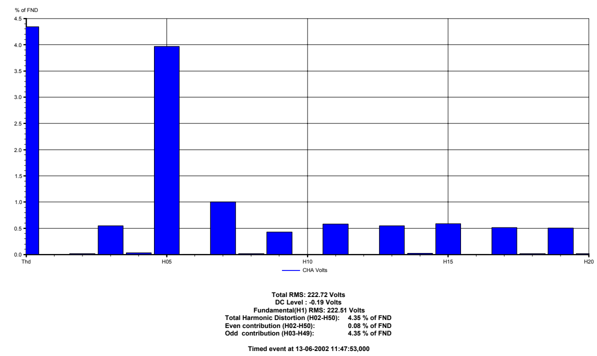


Fig.3 – Monitorizations doing at a Machinery Lab without active harmonic conditioner. (a) Currents and voltages waveforms. (b) Harmonic spectrum of voltage at phase A. (c) Total harmonic distortion variation (I_{THD}) – I_{THD} Average=35%.



(a)



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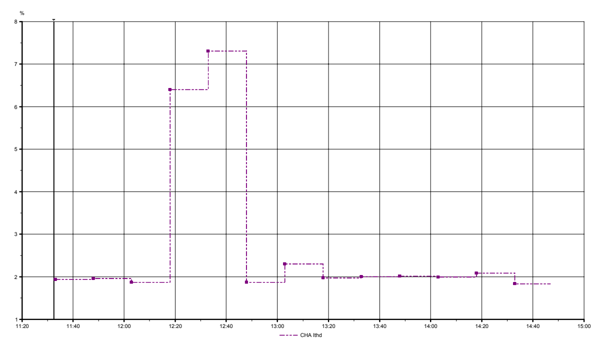
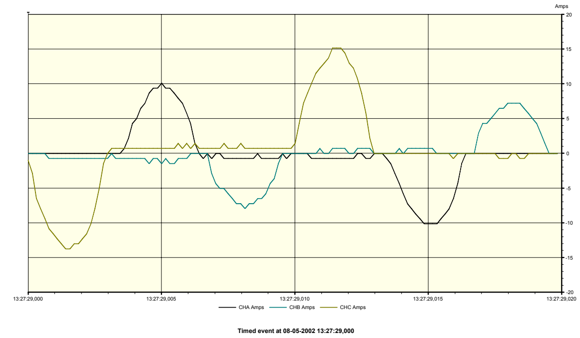


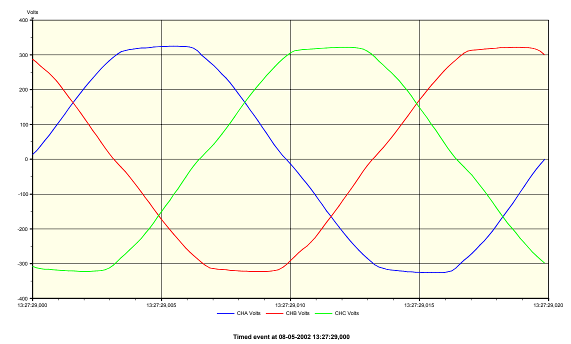
(c)

Fig.4 – Monitorizations doing at a Machinery Lab with active harmonic conditioner. (a) Currents and voltages waveforms. (b) Harmonic spectrum of voltage at phase A. (c) Total harmonic distortion variation (I_{THD}) – I_{THD} Average=2,5%.

Figure 5 shows the results gotten in a informatics laboratory with about 50 computers, without active harmonics conditioner. In that kind of installations the currents waveforms are pulsed due to the switching supply.



(a)



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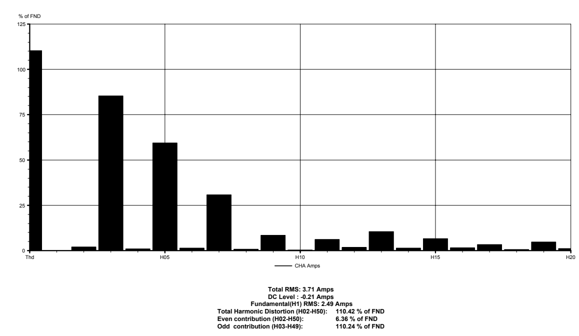
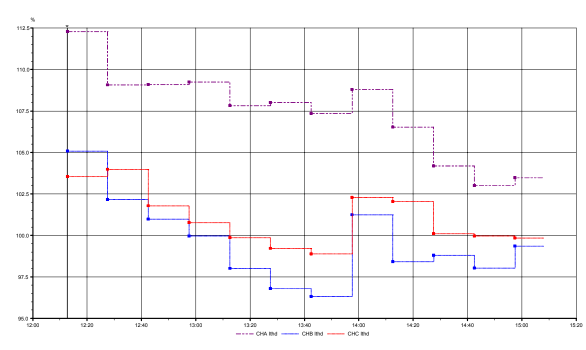


(c)



(d)

Fig.5 – Monitorizations doing at a Informatics Lab without active harmonic conditioner. (a) Currents and (b) voltages waveforms. (c) Harmonic spectrum of voltage at phase A. (d) Total harmonic distortion variation (I_{THD}) – I_{THD} Average=105%.

7. Conclusions

After detailed analysis and monitorization of electric installations supplying different types of loads we conclude that the waveform signals of voltage and current are very different. As consequence, the involved total harmonic distortion (THD) in the different installations types are also very different, being able to reach values above 100% for ITHD in the case of installations supplying informatics equipment.

As solution to minimize this kind of problems the active harmonics conditioner also called active harmonic filters are used. The performance of this equipment is sufficiently good, taking a remarkable decrease in the total harmonic distortion and a good improvement in the power system quality.

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