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CURRENT HARMONICS GENERATED BY LAMPS: A COMPARISON IN DIFFERENT CONDITIONS OF SUPPLY VOLTAGE

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Abstract – In this paper an analysis of conducted harmonic emissions of different types of lamps is presented.

The growing use of non-linear loads (pc, printers, electronic devices, etc.) connected to power supply systems and their variability with time, are responsible of a continuously changing harmonic content in the distribution system. Therefore, to analyze their real behaviour, the lamps were tested using the general power supply of an office building as the source voltage, so that the harmonic distortion of the test voltage changed depending on the time of day and on different weekdays. Accordingly, the resulting current waveforms of the lamps significantly changed. The mean values of harmonic distortion of currents were analyzed and the differences between the lamps are shown.

Keywords: discharge lamps, LED, THD.

1. INTRODUCTION

The European Norms concerning Electromagnetic Compatibility (EMC) focus on the quality of power supply systems and equipment. In particular, the norms prescribe the limits for harmonic current emissions for equipment with an input current up to and including 16 A in specified test conditions [1] and define the measuring techniques [2].

The limits on harmonic distortion of the test voltage [2] are much more restrictive than the limits allowed in public distribution systems [3]. Therefore it is interesting to evaluate how the non-linear loads (in this paper the lamps) behave when the supply voltage has a harmonic content which is more consistent with the real voltage which can be found in a typical electrical power system.

Four different typologies of commercial lamps are taken under test: a fluorescent linear lamp with electromagnetic ballast, four compact fluorescent energy saving lamps (CFL), a LED lamp and a Hydrargyrum Quartz Iodide (HQI) discharge lamp. To understand the side effects that a massive use of these technologies might have on the electrical systems, it is important to study how they behave when used in a real environment.

The lamps were connected to a typical electrical power system and the measurements were done analyzing voltage and current harmonics in different days. The conclusions give the opportunity to have a qualitative idea of the real behaviour of lamps which are used or are going to be used more and more extensively. However, to evaluate the quality of a lamp, also other aspects must be considered, like efficiency, cost and life-time, as well as the way it will be used.

2. EXPERIMENTAL SETUP

The test bench configuration is shown in Fig. 1.

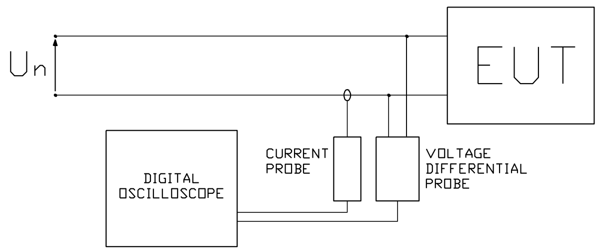

Fig. 1. Test bench configuration.

The equipment under test (EUT) is powered by a supply voltage U_n of 220V and with a frequency of 50Hz.

The EUT is made up by the lamp and the auxiliary components that may be needed (electromagnetic ballast, starter, etc.).

The instruments which were used are a Yokogawa DL1620 digital oscilloscope, a Chauvin Arnoux DP 25 voltage probe and a current probe by Tektronik with an AM502A amplifier. Even though better measurements might be achieved with more accurate instruments, for the goal of this research this configuration was sufficient.

The electrical load effect due to the voltage probe on the measured current is negligible, considering the high input impedance of the voltage probe (4 MΩ / 1,2 pF) and the entity of the measured currents.

During the tests the room temperature was between 19°C and 24°C with a relative humidity of 60÷65%. Therefore the instruments were used in the ambient conditions prescribed by the manufacturers.

Both the instruments and the lamps under test were given the time to warm-up before the measurements were done.

The oscilloscope was set to a sampling frequency of 50kS/s and to a record length of 10 000 samples. In this way the prescriptions of [2] were respected: the measurements were done applying a rectangular window to a set of data of

200 ms, corresponding to a time window of 10 periods of fundamental frequency (at 50 Hz).

With this set-up, the frequency resolution was 5 Hz and the Nyquist frequency was 25 kHz.

Since the oscilloscope calculates the power spectrum of the input signal applying a FFT algorithm on the given samples, it was necessary to calculate the amplitude of the single spectral line of voltage and current. The data measured by the oscilloscope were stored on file and elaborated using a work-sheet.

The grouping method proposed by [2] was used. The intermediate lines between two adjacent harmonics were summed to the harmonic of order *k* with the equation:

$$G_{g,n}^2 = \frac{C_{k-5}^2}{2} + \sum_{i=-4}^{4} C_{k+i}^2 + \frac{C_{k+5}^2}{2} \qquad (1)$$

In this equation, C_{k+i} is the r.m.s. of the spectral component corresponding to a spectral line of the FFT and $G_{g,n}$ is the resulting r.m.s. of the harmonic group of order *n*.

Among the distortion factors, the THD was considered [4], and it was calculated considering the first 40 harmonic groups, following the specifications of [1].

$$THD = \sqrt{\sum_{n=2}^{40} \left(\frac{G_{gn}}{G_{g1}} \right)^2} \qquad (2)$$

With regard to the evaluation of the uncertainty, the probes were considered to have an ideal behaviour, ignoring an uncertainty which is not significant in respect to the measured entities and the qualitative analysis proposed in this paper. Regarding the oscilloscope, it was possible to calculate the uncertainties of the input signals of voltage and current in the specific set-ups, but in order to estimate the uncertainty on the harmonic components, a study of the propagation of the uncertainty in the algorithm used to calculate the FFT would be necessary. This study is beyond the intent of this paper.

3. TEST VOLTAGE ANALYSIS

The systems under test were powered by a 220V - 50Hz, general power outlet of the laboratory.

Before, during and after every session of measurements the harmonic distortion of the voltage was measured, both with the load disconnected and with the load connected, and it was found to exceed the values recommended by [2]. This was due to the presence of harmonics of order 5, 7, 9, 11 and 13. The 5^{th} harmonic showed an amplitude which was between 2,3% and 3,5% of the fundamental. The maximum ratio allowed by [2] for the 5^{th} order is 0,4%.

An example of the voltage waveform and of its power spectrum is represented in Fig. 2 and in Fig. 3.

Although the THD and the harmonic components were above the limits of [2], they were still compatible with the maximum values admitted by [3] for the general power distribution system. So it is proper to suppose that this kind of voltage harmonic distortion might be present in many real environments.

The shifts in the voltage harmonic components strongly influenced the behaviour of the lamps and of their auxiliary components. In some case the shape of the current and the corresponding THD significantly changed.

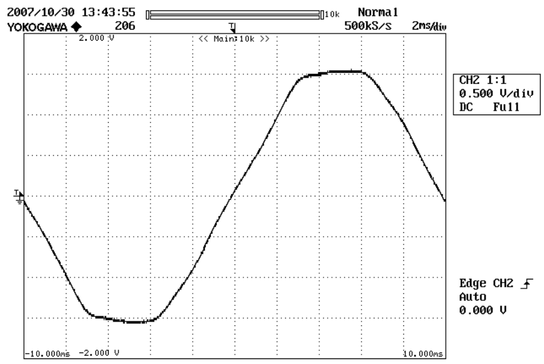

Fig. 2. Example of test voltage.

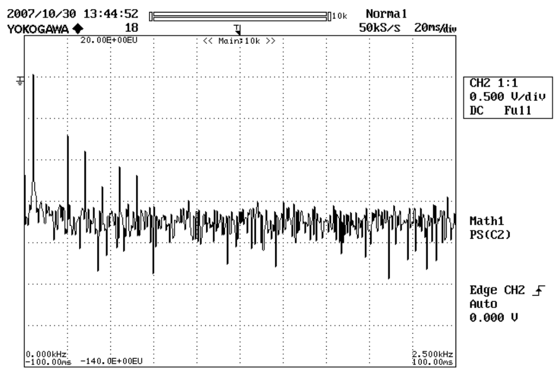

Fig. 3. Example of test voltage power spectrum. The scale is in dB, with reference 1 V_{rms}^2 at 0 dB.

4. MEASUREMENTS

The seven lamps taken under test are shown in Table 1.

Table 1. Type, model, consumption and luminous flux of examined lamps.

Integrated compact fluorescent lamp	Luxeco	50W	
	Osram Dulux EL LL 23W/827 E27	23W	1500lm
	Ikea GSU 420	20W	1000 lm
	REER – EUT-20W Starlite Compact	20W	
Linear fluorescent lamp with electro-magnetic ballast, starter and capacitor	Mazdafluor TF 36 W/BI	36W	2850lm
HQI discharge lamp with electro-magnetic ballast, starter and capacitor	Osram Powerstar HQI-TS 150/NDL UVS	150W	11250lm
LED lamp	Philips DecoLED 1W E27 WH 230-240V G50 1BL	1W	5lm

In the space of this paper, since it is not possible to show all the measurements, only the compact fluorescent lamps will be examined more in detail.

4.1. Compact fluorescent lamps

Four equivalent lamps by different manufacturers were examined (Table 1).

Let's consider the 23W lamp by Osram at first. A time window is shown in Fig. 4.

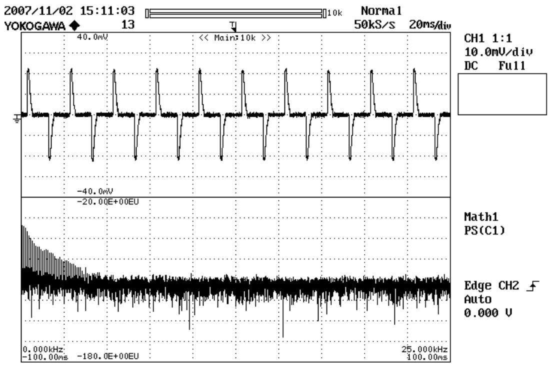

Fig. 4. Time window of 200ms (date: November 2, 2007).

By viewing a single period it is easy to see how the current waveform and its harmonic components changed with different supply voltage conditions.

Fig. 5. Voltage and current waveforms (date: November 2, 2007).

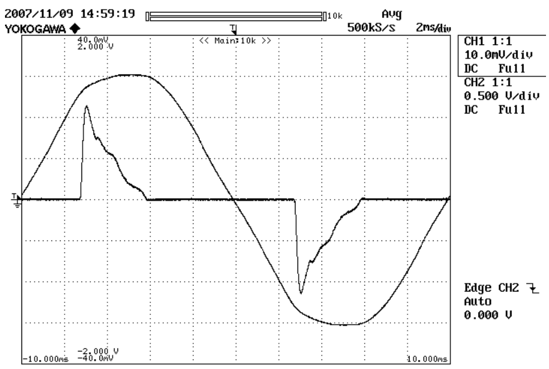

Fig. 6. Voltage and current waveforms (date: November 9,2007).

The calculated THD was between 121% (November 9, 2007) and 132% (November 2, 2007).

In Fig. 7 one of the measurements of the lamp sold by IKEA is shown. The current waveform is different than the Osram lamp measured on the same day (November 9, 2007), while the supply voltage had the same harmonic content. As a result, the THD was lower (113%).

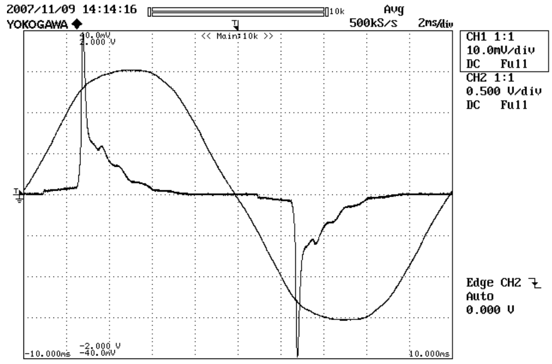

Fig. 7. Voltage and current waveforms (date: November 9. 2007).

The measurements were taken for all the four compact fluorescent lamps, in different days and with different harmonic content in the test voltage. The mean values of the harmonic currents expressed as a percentage of the input current at the fundamental frequency are shown in Table 2.

Table 2. Current harmonics as a percentage of the input current at the fundamental frequency for different bulbs of the same type.

Type of lamp	*Current harmonics* [%]									
	3	*5*	*7*	*9*	*11*	*13*	*15*	*17*	*19*	*21*
LUXECO 50W	85	67	54	48	43	34	25	20	21	20
OSRAM 23W	83	59	41	33	28	24	22	18	14	12
REER 20W	69	39	32	22	15	19	15	13	12	8
IKEA 20W	69	45	31	23	20	19	20	18	16	18

4.2. Comparison of the lamps

It is interesting to analyze the mean values of the assessed measures to compare the behaviour of all the different typologies of lamps (from Fig. 8 to Fig. 11).

4.3. Assessed measures and limits for harmonic currents

Since the specifications for the test voltage were not satisfied, it is not possible to say if the lamps under test complied or did not comply with [1]. Anyway a comparison between the limits given by the norm and the assessed results might be interesting for study reasons.

The compact fluorescent lamps up to 23W emitted current harmonics which could comply with the limits in most of the measurements, but in particular conditions of the supply voltage the harmonic currents were on the very edge of the allowed values. For example, the Osram 23W lamp, in the worst condition of supply voltage, produced currents of the 3rd and 5th order of 89% and 69% respectively, with a limit of 86% and 61%.

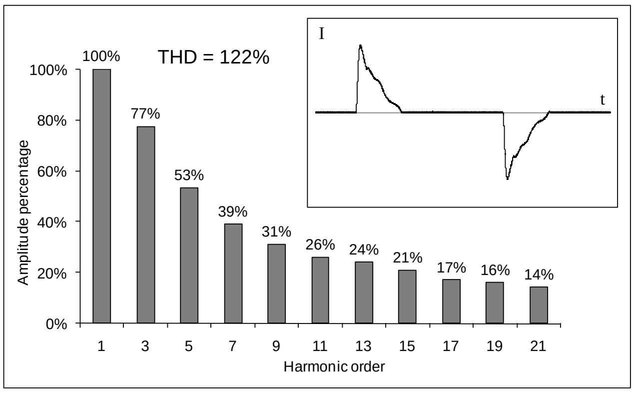

Fig. 8. Compact fluorescent lamp.
Current waveform and harmonic assessment.

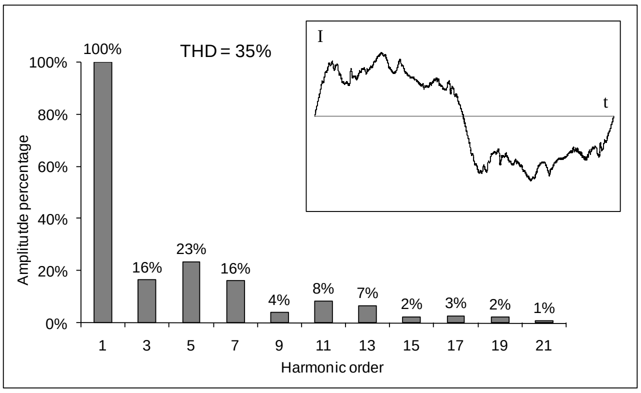

Fig. 10. HQI discharge lamp.
Current waveform and harmonic assessment.

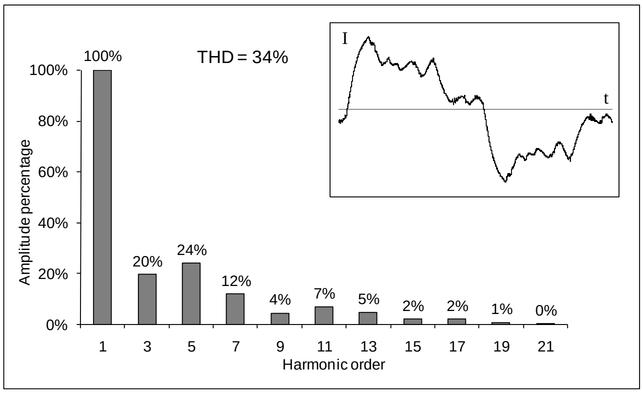

Fig. 9. Linear fluorescent lamp.
Current waveform and harmonic assessment.

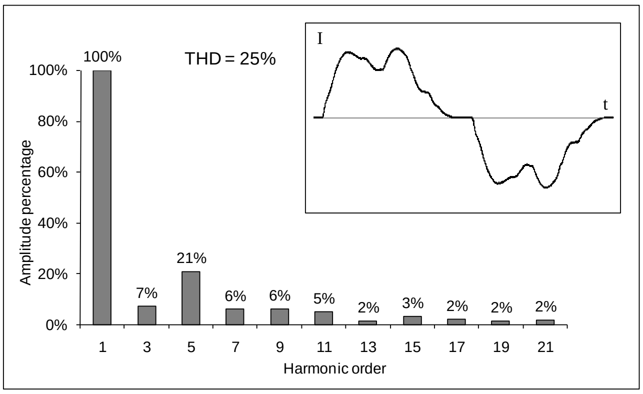

Fig. 11. LED lamp.
Current waveform and harmonic assessment.

A worse behaviour was shown by the lamps with an active input power over 25W. The linear fluorescent and HQI lamps had 5th and 7th current harmonics with a ratio up to 27% and 20%, while the 50W CFL lamp showed even higher values. Basically in the real environment these lamps never complied with the requirements of [1]. The reason may be due to both the high 5th and 7th harmonic content of the supply voltage and to the lower limits prescribed for equipment with a higher input current.

4. CONCLUSIONS

The measurements pointed out how conducted harmonic currents are strictly related to the auxiliary devices of the lamp and to the supply voltage. The discharge lamps (HQI and linear fluorescent), both connected to electromagnetic ballast and capacitor, have currents characterized by similar harmonic content. Their waveforms present the same number of peaks and a similar THD. The integrated lamps (CFL, LED) absorb currents with a very different THD and a harmonic content depending on their electronic circuits.

The THD parameter appeared not really significant to evaluate the quality of a lamp. The comparison between the compact fluorescent lamps pointed out how a lower THD can be achieved by a technology characterized by a fundamental component with a lower r.m.s. value and a different distribution of the harmonic components.

At the same time, it was very clear that the harmonic distortion of the supply voltage had a significant effect on the harmonic current emissions of the lamps, and that the two things were not linearly correlated. For this reason, it might be interesting to reconsider if the specifications for the test voltage in norms [1] and [2], should include wider limits to be closer to the supply voltage present in real distribution systems. This could be really useful to study and limit the harmonic current emissions produced by lamps.

REFERENCES

[1] CEI EN 61000-3-2 (2007) Fourth edition *Electromagnetic compatibility (EMC) Part 3-2: Limits – Limits for harmonic current emissions (equipment input current up to and including 16 A per phase).*

[2] CEI EN 61000-4-7 (2003) Second edition *Electromagnetic compatibility (EMC) Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.*

[3] CEI EN 50160 (2000-03) Second edition *Voltage characteristics of electricity supplied by public distribution systems.*

[4] D.A. Lampasi and L. Podestà "Comparison of different parameters for the analysis of electrical power systems under nonsinusoidal conditions", *10th IMEKO TC7 International Symposium*, Saint-Petersburg, Russia, June-July 2004.