Analysis of Harmonics in Low-Voltage Device Currents

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Abstract - **Current waveform measurement results of a number of low-voltage devices which are frequently used in residential and commercial load are presented in this paper. These devices are: indoor and outdoor lighting, computers, regulated electrical drives. As the measures of distortion in a waveform total harmonic distortion (THD), form factor (FF) and crest factor (CF) are used. The results direct attention to the sources of nonfundamental harmonics in distribution networks, and to necessity of these harmonics elimination.**

Keyword - **harmonics, distribution networks, distortion**

I. INTRODUCTION

Distribution systems are designed for linear voltage and current waveforms, i.e. nearly sinusoidal. However, non-linear loads can cause serious problems such as increase of power and energy losses in lines and transformers, capacitor failures, inadequate electronic equipment operation and inadvertent circuit breaker tripping [1,2]. Nonlinear currents can originate from any of three causes: 1. nonsinusoidal generation of voltage, 2. nonlinear devices in electrical networks, 3. nonlinear load devices. Generally, generated voltage which is then transformed into transmission level, is very close to sinusoidal and have little distortion. Transmission overhead lines and cables, as well as transformers are quite linear and cause little distortion to voltage or current waveforms. However, variable frequency drives, uninterruptible power supplies and some loads are nonlinear [3,4]. This means that a number of low-voltage devices can be the source of harmonics.

The authors have noticed that supply 0.38 kV voltage of residential, as well as commercial load have distortion. The waveform of the voltage measured at the Faculty of Electronic Engineering is presented in Fig. 1 a). The amount of third harmonic participation in its RMS value is 1.142%, and of fifth one 2.247%, etc., as seen from Fig. 1 b).

The fact that even supply 0.38 kV voltage is not purely sinusoidal, initiate the authors to measure current waveforms of different low-voltage devices which are commonly used in residential and commercial loads: lighting, regulated electrical drives and computers. In this sense, the aim of this paper is to determine harmonic sources in distribution networks.

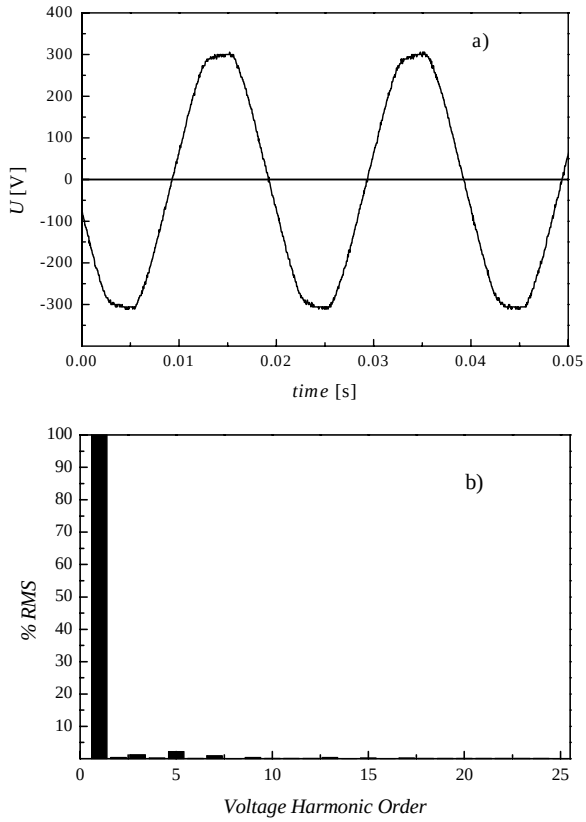

Fig. 1. Supply voltage: a) waveform, b) harmonic spectrum

II. MATHEMATICAL PROBLEM FORMULATION

Through Fourier analysis, any nonsinusoidal periodic waveform can be represented as the sum of a dc component and sine waves of various amplitudes and phase displacement from some relative angle. The sine waves all have frequencies which are an integer multiple of some fundamental frequency, which is 50 Hz in Europe, and 60 Hz in USA. So, any periodic voltage waveform *U(t)* can be expressed as the sum:

$$U(t) = U_0 + \sum_{h=1}^{N} U_h \sin(h\omega t + \theta_h) \qquad (1)$$

A similar equation could be written for a current waveform *I(t)*. Because these individual sine waves are all integer

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multiplies of a fundamental frequency, they are called harmonics. The harmonic order is defined as the integer multiple of the fundamental. For example, a 150 Hz harmonics frequency wave on a 50 Hz source would be called the 3rd harmonic. Eq. (2) shows how to find the root-mean-square (RMS) value of a current waveform where RMS value of each of the harmonics, I_h, is known:

$$I_{RMS} = \left[\sum_{h=1}^{N} \left(I_h \right)^2 \right]^{1/2} . \qquad (2)$$

One measure of the nonlinearity, or distortion, in a waveform is given by Eq. (3) and called total harmonic distortion (THD). THD is the ratio of the RMS value of the total harmonic currents (nonfundamental part of the waveform) and the RMS value of the fundamental portion, I_1, of the waveform. This value is usually expressed as a percentage of the fundamental current

$$THD = \frac{\left[\sum_{h=2}^{N} \left(I_h \right)^2 \right]^{1/2}}{I_1} 100\% . \qquad (3)$$

Two other measures of distortion are the crest factor and form factor. The crest factor is the ratio of the peak of a waveform to its RMS value. For a linear sinusoidal waveform, the crest factor would be the square root of 2, or 1.414.

$$Crest\_Factor = \frac{I_{peak}}{I_{RMS}} \qquad (4)$$

The form factor or distortion factor, is the ratio of the RMS value of a waveform to the RMS of the waveform's fundamental value, I_1. For a linear sinusoidal waveform, the form factor would be 1.0 [4].

$$Form\_Factor = \frac{I_{RMS}}{I_1} \qquad (5)$$

III. RESULTS

The measurements are performed for different low-voltage devices:

- fluorescent lighting,
- mercury lamps,
- variable frequency drive,
- computer.

Recorded current waveforms of signals, as well as measures of harmonics are given in next paragraphs.

Two kinds of lighting are considered: fluorescent lighting and mercury lamps. The first kind is for indoor and another for outdoor lighting. Fluorescent lighting which is frequently used and often dominant consumer of commercial load, has significant amount of nonfundamental harmonics [1]. In Fig. 2 a) and b) are presented waveform and current harmonic spectrum, respectively, for fluorescent lighting with magnetic ballast in steady state condition. The presence of 3rd harmonic in RMS value is significant - 18.52 %.

High pressure mercury lamps of 125, 250 and 340 W are considered, too and for every of them it can be noticed that during start-up waveform is significantly worse than in steady state. Therefore in Fig. 3, the waveforms for 250 W lamp at the beginning of its operation. Also, it is pointed out that although the capacitor which is commonly used for mercury lamps importantly improve power factor, it causes occurrence of nonfundamental harmonics. The power factor of the mentioned lamp changes from 0.565 for the case without capacitor to 0.846 with capacitor. In Figs. 4 and 5 the results for the first case and second case are presented, respectively.

Variable frequency drives are well know as a source of nonfundamental harmonics. Therefore, in Fig. 6 a) are shown waveforms when it operates with full load and 50 Hz frequency, and in Fig. 6 b) corresponding amounts of harmonics. It is pointed out that for other operation modes similar current waveforms and harmonic participation are obtained, so results of these measurements are not presented in figures. As seen from Fig. 6 a), variable frequency drive draws two current pulses for each half cycle of the voltage waveform. This is typical of most VFD's which employ six pulse conversion to commutate the three-phase line voltage to DC voltage [1].

The measurement result for computer Pentium II are presented in Fig. 7. Current waveform as well as harmonic spectrum show participation of great amount of harmonics. Comparison of current distortion measures for mentioned computer and PC 386 show that both are very bad considering the harmonic participation.

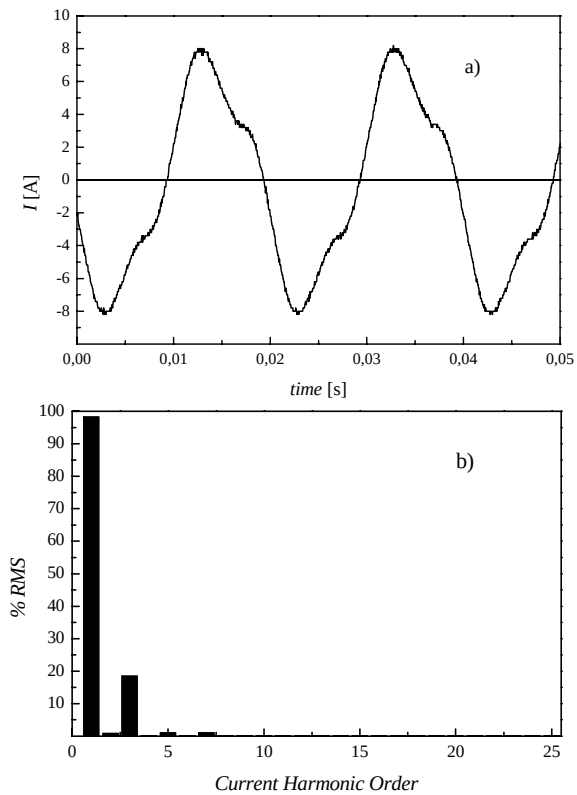

Fig. 2. Fluorescent lighting: a) current waveform, b) harmonic spectrum

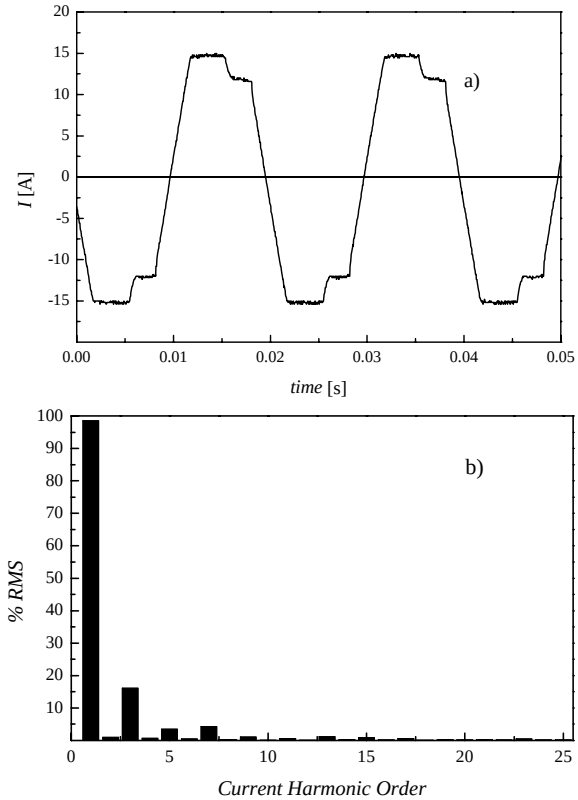

Fig. 3. Mercury lamp current at the beginning of operation: a) waveform, b) harmonic spectrum

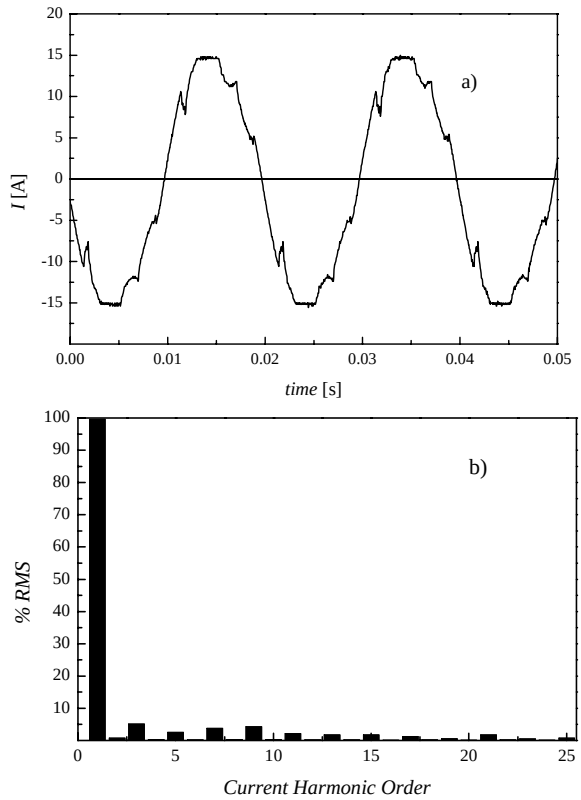

Fig. 4. Current of mercury lamp without capacitor in steady state: a) waveform, b) harmonic spectrum

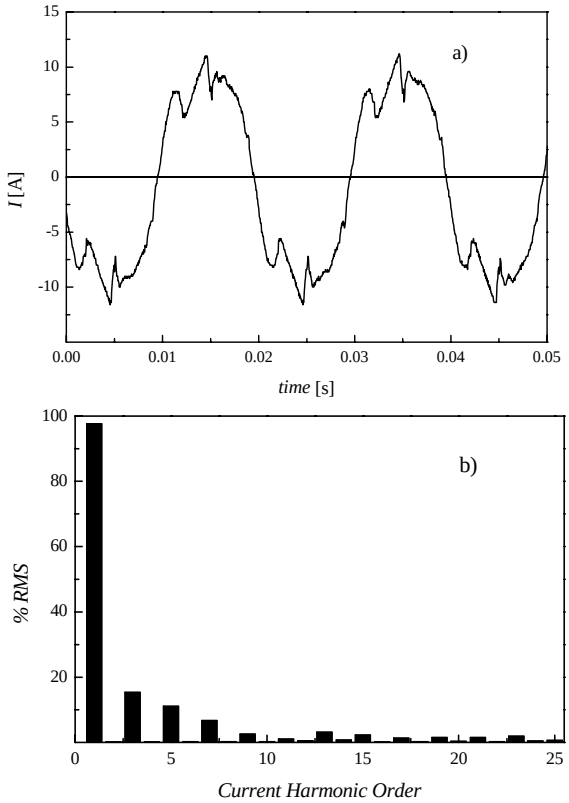

Fig. 5. Current of mercury lamp with capacitor in steady state: a) waveform, b) harmonic spectrum

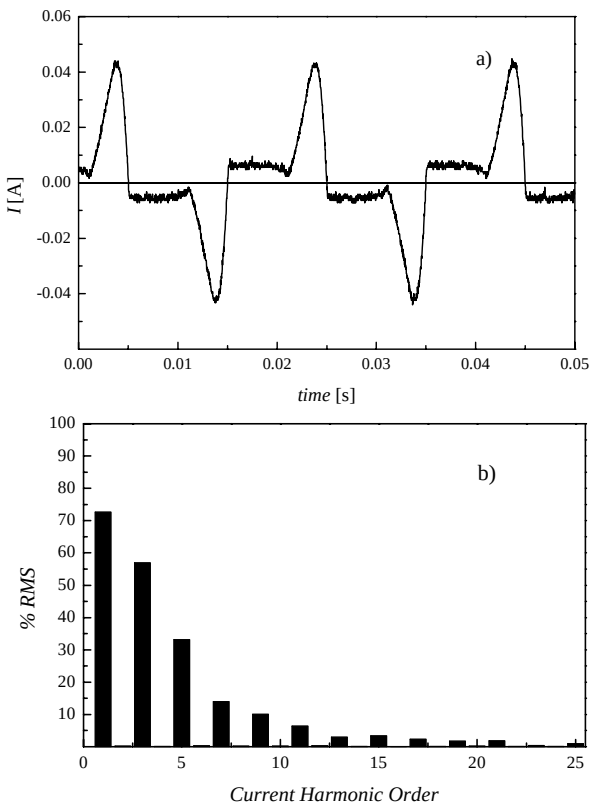

Fig. 6. Variable frequency drive: a) current waveform, b) harmonic spectrum

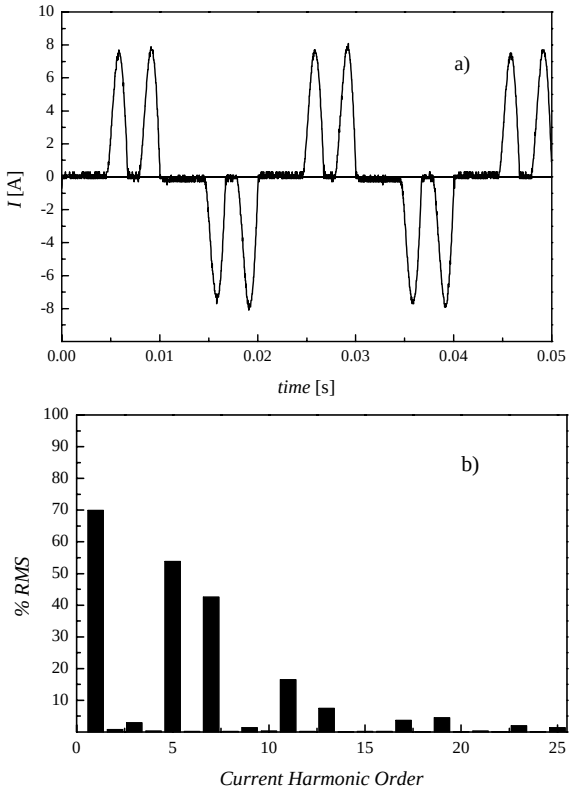

Fig. 7. Computer: a) current waveform, b) harmonic spectrum

In Table I, measures of distortion in the current waveforms of different devices, total harmonic distortion (THD), crest factor (CF) and form factor (FF), are given.

IV. Conclusion

The low-voltage device current waveforms, as well as harmonic analysis are presented in this paper. Values of THD, CF and FF are given for indoor and outdoor lighting, variable frequency drive and computers. Obtained results show that computers, variable frequency drives, as well as fluorescent lighting are the most important harmonic sources in distribution systems. Further investigations should be connected with determining the interaction between current harmonics of different devices and voltage harmonics in distribution networks.

Table I

THD, CF and FF of Current Waveforms for different devices

Device	Measures of distortion		
	THD	CF	FF
Fluorescent lighting	17.155	1.5487	1.0461
Steady state operation of mercury lamp (125 W) without capacitor	11.859	1.405	1.0021
Beginning of operation of mercury lamp (250 W)	17.835	1.2488	1.0157
Steady state operation of mercury lamp (250 W) without capacitor	20.808	1.4717	1.0235
Steady state operation of mercury lamp (250 W) with capacitor	22.566	1.5035	1.0251
Steady state operation of mercury lamp (340 W) with capacitor	12.709	1.4576	1.0080
Variable frequency drive at 50 Hz fully loaded	85.970	2.126	1.3187
Variable frequency drive at 30 Hz fully loaded	118.32	2.801	1.549
PC Pentium II	94.812	2.4628	1.378

References

[1] L. Tolbert, H. Hollis, P. Hale, "Survey of Harmonics Measurements in Electrical Distribution Systems", *IEEE IAS Annual Meeting*, pp. 2333-2339, San Diego, CA, 1996.

[2] IEEE Task Force, “Effects of Harmonics on Equipment”, *IEEE Trans. on Power Delivery*, vol. 8, pp. 672-680, 1993.

[3] A. Mansoor et. al, “Predicting the Net Harmonic Currents Produced by Large Numbers of Distributed Single-Phase Computer Loads”, *IEEE Trans. on Power Delivery*, vol. 10, pp. 2001-2006, 1995.

[4] R. Dwyer et. al, “Evaluation of Harmonic Impacts from Compact Fluorescent Lights on Distribution Systems”, *IEEE Trans. on Power Systems*, vol. 10, pp. 1772-1779, 1995.

[5] N. Mohan, T. M. Undeland, and W. P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, 1989.