TESTING ELECTRONIC EQUIPMENT USING WAVEFORMS GENERATED WITH PROGRAMMABLE SOURCES

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REZUMAT. Domeniul testarii echipamentelor electrice presupune utilizarea surselor programabile de putere. De obicei, aceste surse, prin bibliotecile software aferente, permit generarea de forme de unda specifice diferitelor aplicatii. Exista situatii in care aceste forme de unda, masurate cu analizoare spectrale la locul de amplasare al consumatorilor, trebuie reproduse in laborator in vederea incercarii performantelor echipamentelor proiectate, iar scopul lucrarii este calat pe aceasta problema.

Cuvinte cheie: forme de unda, surse programabile, software CIGUI.

ABSTRACT. **The field of electrical equipment testing requires the use of programmable power sources. Usually, these sources, through their respective software libraries, allow the generation of specific waveforms for various applications. Sometimes the situation requires that the waveforms, previously measured with harmonics analyzers on site, must be duplicated in the laboratory for the purpose of performance testing of the designed equipments. The purpose of the paper addresses this exact problem.**

Keywords: waveforms, programmable sources, CIGUI software

1. INTRODUCTION

Generating waveforms is useful in certain applications, such as:

- Procedures for compliance testing to effectual standards for electrical equipments
- Verifying distortion immunity characteristics for newly designed protection devices
- Generating in a controlled environment actual distortions, previously measured on site trough energy quality analyzers

In general, to perform tests with software-generated waveforms it is necessary to have in the laboratory a programmable power source.

2. GENERATING WAVEFORMS USING THE CIGUI SOFTWARE

The majority of AC power applications require the use of sinusoid waveforms. For immunity testing however, special waveforms may be necessary. This requirement is met by using an arbitrary waveform generator in the AC power source. This allows any waveform within the power amplifiers signal bandwidth to be generated in addition to the standard sinusoidal waveform.

The CIGUI [1] software may be used to synthesize the special waveforms needed for immunity testing. The following types of waveform generation are supported by the application:

1. Harmonic waveforms

These are waveforms defined by the amplitude and phase angle of the harmonic components with respect to the fundamental. Thus, the output waveforms are harmonically distorted waveforms.

2. Arbitrary waveforms

This type of waveforms is defined as individual time domain data points. This can be used to produce any type waveform. Arbitrary waveforms can be defined using the following mechanisms:

- Selecting from a library of built-in waveforms;
- Drawing the waveform by hand on screen;
- Loading the waveform data points from a disk file created with other programs;
- Downloading data from a digital scope.

Although arbitrary waveforms can be easily defined, the actual output of the AC source is always bandwidth limited and since the waveform shape is put out at a repetition rate equal to the programmed fundamental frequency, the output signal can only contain integer harmonic components of the fundamental frequency. This inherent bandwidth limitation and the finite number of data points available to define the waveform, this limits the nature of the output signal.

The most common used type of waveforms for immunity testing is the harmonic waveforms. In order to properly test the equipments, we need to simulate the harmonic distortion occurring on public utility networks by combining the right mix of harmonic components.

The definition of harmonic waveforms requires the amplitude and phase angle of the individual harmonic components that define the output waveforms and they can be inputted manually in the software for the first fifty harmonics. Nevertheless, they are limitations, such as a maximum 3,000 Hz value per component in the case of a 60 Hz fundamental. Because the bandwidth of the AC source output is usually less, at these frequencies only small signal amplitudes can be defined. By increasing the fundamental frequency, we also increase the effect of bandwidth limitations and the inclusion of the highest harmonic components may be less meaningful. For the purpose of most working applications, the most significant harmonics are the lower odd harmonics.

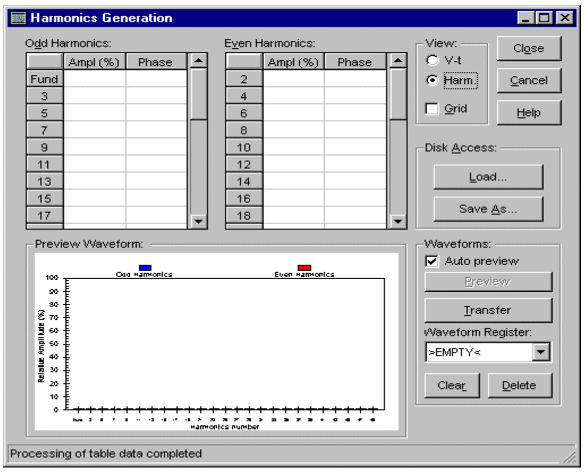

Fig. 1. Harmonics generation window

In the case of the regularly used waveforms, it is best to save them directly to disk, for easy access. Although it is possible to save the waveforms in the AC source memory, we need to take into account the fact that the source memory can be easily overwritten while running the application. Thus, saving the waveform on disk seems like the most sensible solution. On disk, the waveforms are stored in two formats: ASCII files which consist of the harmonic component amplitudes and phase angles, and files that contain the time domain data points and are compatible with the file format for arbitrary waveforms. The waveform file format is compatible with the AC source and the files can be transferred to the AC source memory through the next interfaces IEEE-488 and RS232C.

Arbitrary waveforms allow for a greater flexibility in defining the shape of the waveform. Even so, the output of the AC source depends on the bandwidth and slew rate limitations, which means it may not be possible to achieve the exact waveform specified in the software.

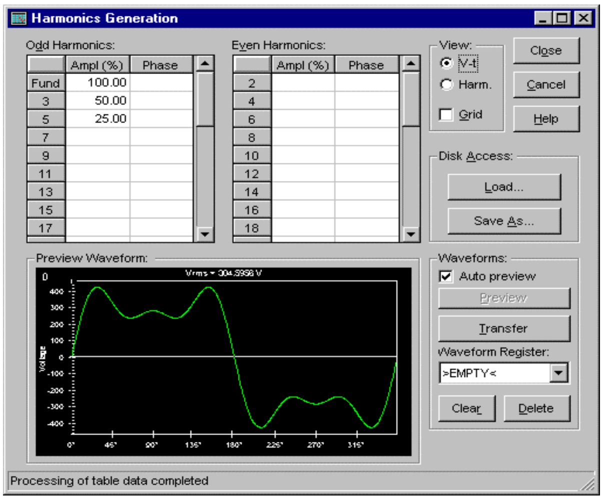

Fig. 2. Harmonic distorted waveform

Arbitrary waveforms can be generated by various approaches:

Selecting from the CIGUI library of waveforms;

Manually setting each data point amplitude in the waveform editor;

Drawing the waveform as a combination of line segments with the mouse;

Transferring an actual waveform captured with a digital storage oscilloscope.

It is possible to use the editor to access each actual voltage value of the arbitrary waveform data points. The method is laborious for inputting a complete waveform and is best suited for adjusting a previously created waveform.

A simple and easy way to input a waveform is drawing directly in the waveform window using the mouse. This method requires further tweaking, because it does not allow for an exact rendering of the desired waveform.

The CIGUI software enables you to transfer waveforms captured on a digital scope through the

IEEE-488 interface. For the time being, only the Hewlett Packard 54600 series of storage scopes is supported. The transfer is an easy process, allowing you to alter the data on a later time, with the only requirement of setting the scope to capture as close to one single period of the waveform as possible. In the event that this was not possible, there will be discontinuities in the output waveform.

3. APPLICATION 1: GENERATINFG WAVEFORMS FOR SIMPLE MODULATED VOLTAGE

Unfortunately, like in the case of other equipments, to supply electromagnetic equipment with variable frequency [2] means the use of a power converter system (rectifier and inverter). In the applications where the harmonic response quality is less important, the inverter is controlled in two distinct positions. In the other situations it is better to control it in three different positions (with modulated voltage), by a variable control angle, denoted α (figure 3).

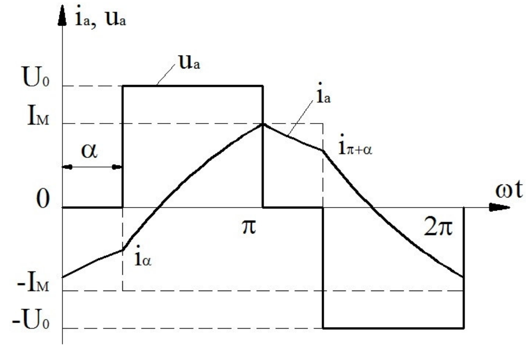

Fig. 3. Simple modulated voltage and load current

The load voltage u_a in this situation is:

$$u_a(\omega t) = 0\,;\; 0 \le \omega t \le \alpha \tag{6}$$

$$u_a(\omega t) = U_0\,,\; \alpha \le \omega t \le \pi \tag{7}$$

$$u_a(\omega t) = 0\,;\; \pi \le \omega t \le \pi + \alpha \tag{8}$$

$$u_a(\omega t) = -U_0\,;\; \pi + \alpha \le \omega t \le 2\pi \tag{9}$$

moreover, the expression of the load current, inferred by integrating the differential equations of the voltage balance is:

$$i(\omega t) = -I_M \cdot e^{-\frac{\omega t}{Q}},\; 0 \le \omega t \le \alpha \tag{10}$$

$$i(\omega t) = \frac{U_0}{R_a} + (i_a - \frac{U_0}{R_a}) \cdot e^{-\frac{\omega t - \alpha}{Q}}\;;\; \alpha \le \omega t \le \pi \tag{11}$$

$$i(\omega t) = -I_M \cdot e^{-\frac{\omega t - \pi}{Q}},\; \pi \le \omega t \le \pi + \alpha \tag{12}$$

$$i(\omega t) = -\frac{U_0}{R_a} + (i_{\pi+a} + \frac{U_0}{R_a}) \cdot e^{-\frac{\omega t + \pi - \alpha}{Q}}\;;\; \pi + \alpha \le \omega t \le 2\pi \tag{13}$$

In the above equations, R_a is the load resistance, L_a the load inductivity, $Q=(\omega \cdot L_a)/R_a$ and the currents I_M, I_α and $I_{\pi+\alpha}$ result from the limit conditions, as follows:

$$I_M = \frac{U_0}{R_a} \cdot \frac{1 - e^{-\frac{\pi - \alpha}{Q}}}{1 + e^{-\frac{\pi}{Q}}} \tag{14}$$

$$I_\alpha = -\frac{U_0}{R_a} \cdot \frac{e^{-\frac{\alpha}{Q}} - e^{-\frac{\pi}{Q}}}{1 + e^{-\frac{\pi}{Q}}} = \frac{U_0}{R_a} \cdot \frac{-e^{-\frac{\alpha}{Q}} + e^{-\frac{\pi}{Q}}}{1 + e^{-\frac{\pi}{Q}}} \tag{15}$$

$$I_{\pi+\alpha} = \frac{U_0}{R_a} \cdot \frac{e^{-\frac{\alpha}{Q}} - e^{-\frac{\pi}{Q}}}{1 + e^{-\frac{\pi}{Q}}} \tag{16}$$

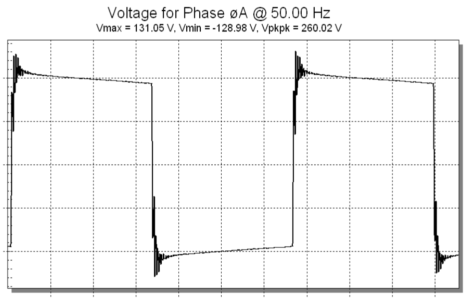

Fig. 4. Simple modulated voltage; $\alpha=180^0$.

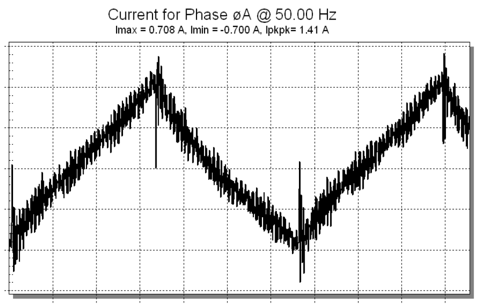

Fig. 5. Load current; $\alpha=180^0$.

The experimentations were achieved through tests with a programmable source [3, 4], which complies with the IEC 1000-3 standard. The source has the advantage that it completely isolates the electromagnetic equipment under testing from any other connected load from the same circuit, it allows precise voltage and frequency control and it can generate simple modulated voltage with a variable α switching angle.

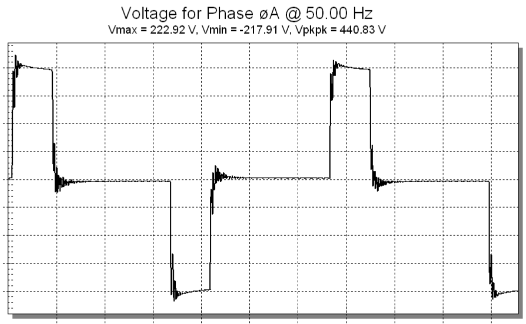

Fig. 6. Simple modulated voltage; α=45^0.

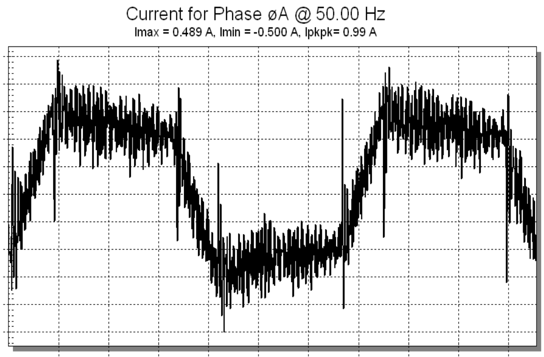

Fig. 7. Load current; α=45^0.

In choosing the source, we must take into account the fact the most important specified parameter and the most difficult to accomplish is the output voltage waveform distortion which appears when the source feeds a non-sinusoidal current. To fully appreciate the equipment's specifications, first we have to measure [5] the load current harmonics, if the supply voltage has voltage harmonic distortions.

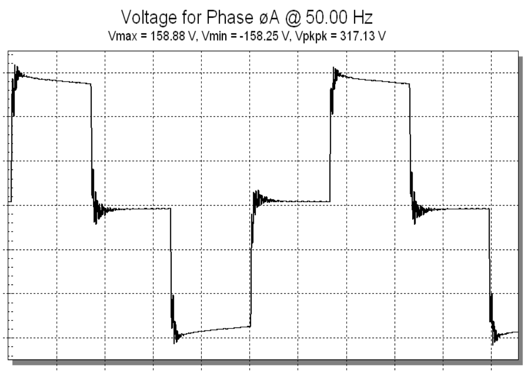

Fig. 8. Simple modulated voltage; α=90^0.

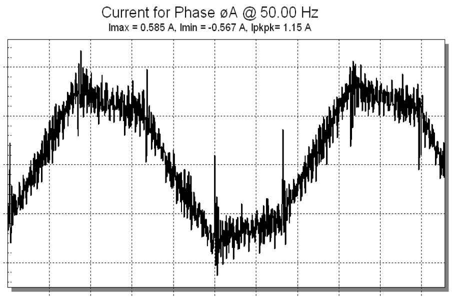

Fig. 9. Load current; α=90^0.

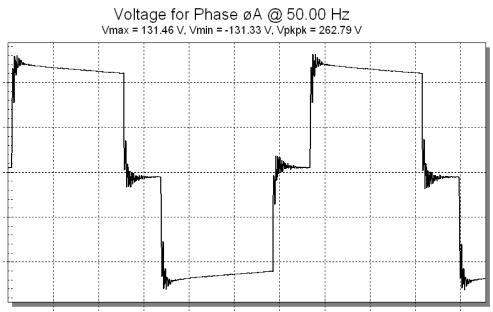

Fig. 10. Simple modulated voltage; α=135^0.

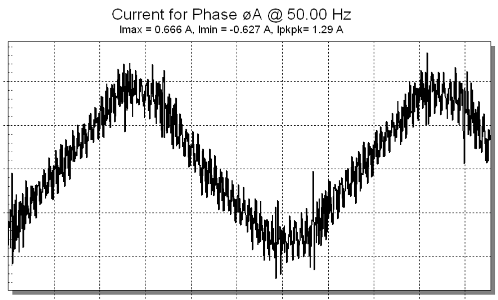

Fig. 11. Load current; α=135^0.

Ideally, as per IEC 1000-3-2 standard, the AC power source should have zero output impedance.

Nevertheless, this is difficult to achieve, especially in AC power sources where we obtain the necessary output voltage from multiple amplifiers in series. To comply with the conditions of the IEC 61000-2-2 standard [6], the AC power source must have a certain output impedance on the active conductor and null conductor respectively. This is easily achievable by using a programmable impedance.

The experimental tests performed for an electromagnetic device with a 14.4 Ω resistance and 1.12H inductance are detailed in figures 4 and 5 for simple modulated voltage. Figures 6 and 7 details the same for modulated voltage and an α=π/4 switching angle, figures 8 and 9 for α=π/2 switching angle and figures 10 and 11 for α=3π/4 switching angle,

4. APPLICATION 2: GENERATING WAVEFORMS FOR EMI FILTERS TESTING

The electromagnetic immunity compliance tests were achieved using BEST EMC device, produced by Schaffner Instruments. This equipment can be used for immunity tests in manually operation mode, or can be connected to a PC via serial interface RS-232, using the firmware WINBEST.

In other words, the main immunity tests [7, 8, 9] that must be performed are BURST, SURGE, electrostatic discharges (ESD), temporary voltage drops, short interruptions and voltage variations. The device is built to perform tests according to European Standards EN50082-1 and EN50082-2.

Compliance with conducted emission is usually performed with measurement devices, optimized to perform EMC measurements.

Spectral analyzers, much cheaper than EMC measuring devices are widely used for fast diagnosis, being adequate for viewing the frequency range and the nature of aggressive emissions.

In combination with a tracking generator, a spectral analyzer is useful to check the frequency response in high frequency circuits, like EMI filters.

Emissions generated by electrical equipment and leaded into the supplying lines, can be equally checked using a LISN and a Spectral Analyzer.

To put it in more simple words, a LISN is the equivalent of a filtering network [13], the EUT being connected to the supply lines through a low-pass filter (Fig. 12).

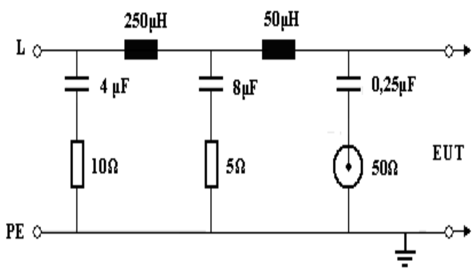

Fig. 12. LISN connected between Line and PE

The obtained spectrum has to be compared with the standardized limits of average and quasi-peak values.

Insertion loss can be measured both in common and differential mode, using a tracking generator having the output impedance of 50Ω and a spectral analyzer with input impedance of 50Ω.

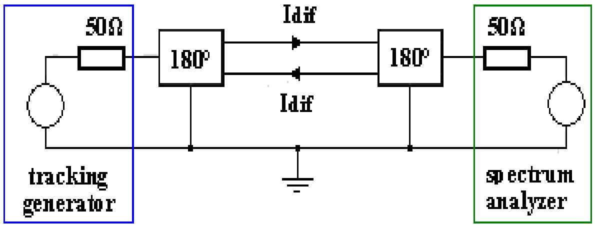

Fig.13. Wiring for measuring the EMI filters insertion loss in differential mode

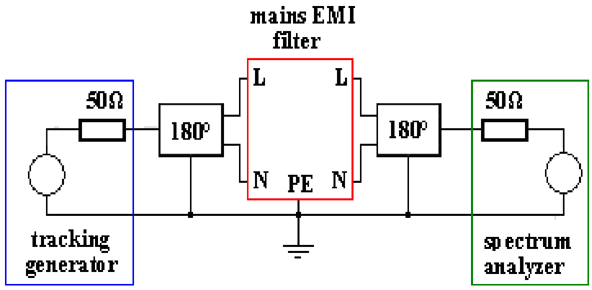

Fig.14. Wiring for measuring the EMI filters insertion loss in common mode

Table. 1 Measurements without power factor compensation

Time	THD (%)	V1 THD (%)	V2 THD (%)
10:26:35	3.8	3.7	3.7
10:26:40	3.8	3.9	3.6
10:26:45	3.8	3.3	3.3
10:26:50	6.3	6	6.3
10:26:55	6	6.7	7.4
10:27:00	6	6.9	7.4
10:27:05	5.7	6.5	7.2

Fig. 13 and Fig. 14 presents the setups for measuring the insertion loss of the low voltage EMI filter, in the differential and common mode respectively.

The authors have provided measurements of the harmonics level and THD, made at the location of a non-linear consumer, partially presented in Tab. 1.

The performance of the filter was tested in accordance to the existing conditions at the point where filter will be connected. In line with the existing harmonic disturbance spectrum (Fig. 15) it is possible to synthesize the form of the distorted wave (Fig. 16).

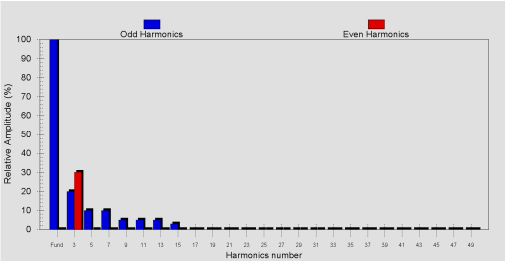

Fig.15. Voltage harmonic spectrum

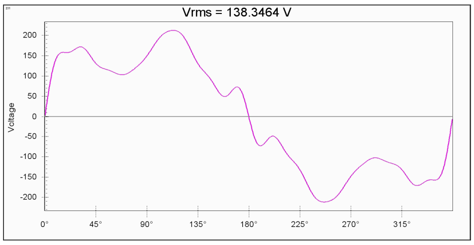

Fig.16. Synthesized waveform for testing EMI filter

Testing the EMI filter for immunity for harmonics and inter-harmonics, in accordance with IEC 61000-4-13 standard was achieved using the CTS-15003iX, California Instruments.

5. CONCLUSIONS

✓ Generating waveforms through programmable AC power sources is useful for accomplishing the testing procedures necessary for product certification.

✓ In addition, this procedure can be applied for verifying the characteristics of newly designed products, when the distortions caused by non-linear loads [10, 11, 12] at the desired site are known.

✓ In the future, the authors propose to work on a software solution to automatically write a desired waveform into the CIGUI software library.

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