European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality (ICREPQ'10)
Granada (Spain), 23th to 25th March, 2010

Metrological Confirmation of Total Harmonic Distortion of Voltage Meters Used in Brazilian Electrical Power System

Marcelo Melo da Costa[1], Thiago Brito[2], Thiago Mota Soares[3]

[1]Centrais Elétricas do Norte do Brasil – Eletronorte
Belém - Brasil
marcelo.melo@eletronorte.gov.br

[2]Centrais Elétricas do Norte do Brasil – Eletronorte
Belém - Brasil
thiago.brito@eletronorte.gov.br

[3]Universidade Federal do Pará
Belém – Brasil
thiago_motasoares@yahoo.com.br

Key words

Power quality, total harmonic distortion, uncertainty, error, accuracy

1. Introduction

The widespread of power-electronic equipments in Brazilian electrical power system is provoking arise of a different type of disturbance that reduce the system's power quality called harmonic distortion.

The non-linear feature of these equipments is responsible for the injection of harmonic currents in the electric grid and thus causing the harmonic voltage distortion.

In Brazil, there are standards, as Network Procedure 2.8 published by Brazilian Electricity Regulatory Agency (ANEEL), which establishes the limits for some power-quality parameters. The table 1 shows the lower global limits related to the harmonic voltage indices.

Table 1. Voltage lower global Limits of harmonic voltages in percentage of fundamental voltage

V < 69 kV				V ≥ 69 kV			
ÍMPARES		PARES		ÍMPARES		PARES	
ORDEM	VALOR(%)	ORDEM	VALOR(%)	ORDEM	VALOR(%)	ORDEM	VALOR(%)
3, 5, 7	5%			3, 5, 7	2%		
		2, 4, 6	2%			2, 4, 6	1%
9, 11, 13	3%			9, 11, 13	1,5%		
		≥8	1%			≥8	0,5%
15 a 25	2%			15 a 25	1%		
≥27	1%			≥27	0,5%		
DTHTS95% = 6%				DTHTS95% = 3%			

The voltage upper global limits are defined as being 4/3 of the lower global limits. Furthermore, the ANEEL's Network Procedure 2.8 requires that the THDV (total harmonic distortion of voltage) meters must present its performances in accordance with the IEC 61000-4-7 [1].

The IEC 61000-4-7 standard establishes the guidelines for these meters' design as well as its maximum admissible errors. The table 2 shows the limits of maximum admissible errors THD meters.

Table 2. Accuracy Requirements for Current, Voltage and Power Measurement

Class	Measurement	Conditions	Maximum error
I	Voltage	$U_m \geq 1\%U_{nom}$ $U_m < 1\%U_{nom}$	$\pm5\%\ U_m$ $\pm0{,}05\%\ U_{nom}$
	Current	$I_m \geq 3\%I_{nom}$ $I_m < 3\%I_{nom}$	$\pm5\%\ I_m$ $\pm0{,}15\%\ I_{nom}$
	Power	$P_m \geq 150$ W $P_m < 150$ W	$\pm1\%\ P_{nom}$ $\pm1{,}5$ W
II	Voltage	$U_m \geq 3\%U_{nom}$ $U_m < 3\%U_{nom}$	$\pm5\%\ U_m$ $\pm0{,}15\%\ U_{nom}$
	Current	$I_m \geq 10\%I_{nom}$ $I_m < 10\%I_{nom}$	$\pm5\%\ I_m$ $\pm0{,}5\%\ I_{nom}$
I_{nom}: Nominal current range of the measurement instrument U_{nom}: Nominal voltage range of the measurement instrument U_m and I_m: Measurement values			

The metrological confirmation of this kind meters was performed through the application of a methodology developed by the Eletronorte Electrical Calibration Laboratory (CAEL), in the calibration of two power-quality analyzers from different manufacturers (A and B). The analyzer A fulfills the maximum error requirements of class 1 presented by standard IEC 61000-

4-7 until the 50th harmonic according to the manufacturer while the analyzer B just is in accordance with the maximum error requirements IEC 61000-4-7 until the 40th, in addition, the manufacturer doesn't inform which class the meter belongs.

2. Traceability

The Fluke 6100A, power quality calibrator is a programmable source of stable voltage and current signals, distorted by harmonics, flicker, interharmonics and other electrical power quality phenomena. This calibrator has enough metrological capability to calibrate power quality measurement instruments.

The Electrical Calibration Laboratory of Eletronorte performs calibration of harmonic distortion of voltage measuring instruments using a 6100A calibrator as standard. To achieve traceability to the metrological standards, the 6100A calibrator is calibrated every year in the Brazilian National Metrology Laboratory (NML) – INMETRO. INMETRO primary standard is based on the digital sampling method, established between the Brazilian NML and Physikalisch-Technische Bundesanstalt (PTB), the German NML, in 2004. The 6100A calibrator is calibrated using two voltage distorted signals (waveforms), which are defined according to ANEEL's Network Procedure 2.8. The signal 1 is used to evaluate electrical power systems with rated voltage lower than 69kV. The signal 2 is used when rated voltage is equal or greater the 69kV. In both signals the fundamental voltage is 115V.

The signal 1 was built using the lower global limits for systems with voltage levels lower than 69kV purposed by the ANEEL's Network procedure 2.8 until the 50th harmonic. The Fig 1 shows this waveform.

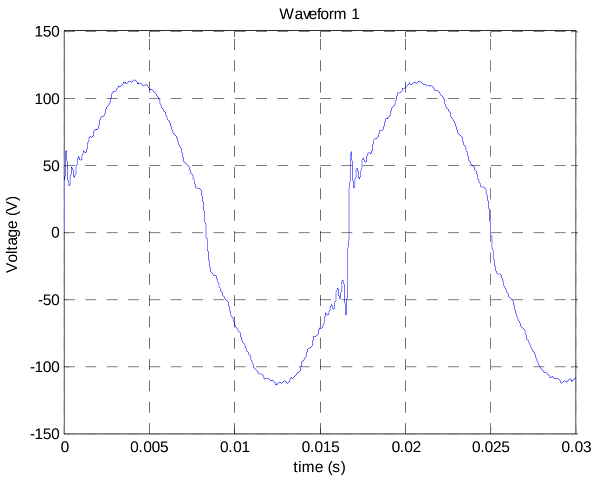

Fig 1. Waveform 1

Signal 2 was built using the lower global limits for systems with voltage levels equal or greater than 69kV as established by ANEEL's procedure 2.8. The Fig 2 shows the signal 2.

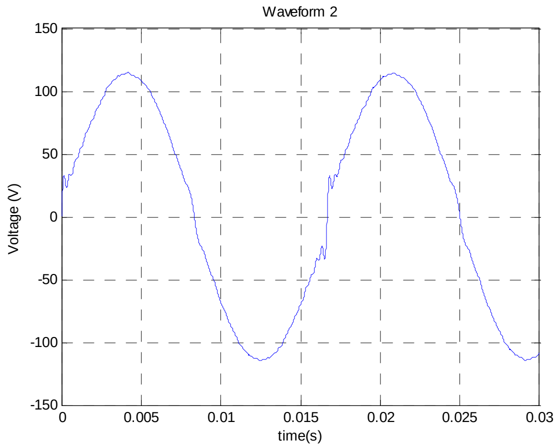

Fig 2. Waveform 2

The calibration certificate addressed by INMETRO shows the results for the fundamental and each harmonic voltage, and for the total harmonic distortion of voltage. The THDV uncertainties for first and second signals are 0.047 % and 0.092 %, respectively.

3. Methodologies and Uncertainties

To perform calibrations of harmonic distortion of voltage measuring instruments, a measuring procedure document was written by CAEL staff. This document describes the steps to perform calibrations, including measuring circuit set-up, the instruments configuration and how to evaluate measurement errors and uncertainties.

The calibrations were performed in CAEL. The temperature during the measurements was (23 ± 3) ºC, and the relative humidity of the air was (50 ± 20) %. The instruments' mains were supplied by stable voltage, which was guaranteed by a large voltage stabilizer.

In the calibrations, the 6100A standard was configured to source to the instrument being calibrated a harmonics distorted voltage signal, according to ANEEL Procedure 2.8, and consequently to its calibration certificate. After signal application, a routine inside the instrument is started. This routine is responsible for measuring the fundamental and the harmonic voltages, from 2nd to 50th orders, and the total harmonic distortion of voltage, in a measuring interval of 10 minutes. The measurements are then registered. Three measurements are performed for each harmonic voltage and for the THDv, in order to evaluate the repeatability of the instrument. Fig. 3 shows the measurement circuit.

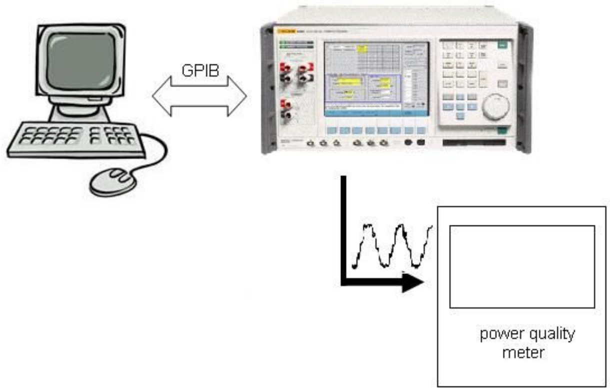

Fig 3. Measurement circuit used in calibrations

In the measurement uncertainty estimate, four independent input quantities are considered: repeatability of the instrument, finite resolution of the instrument readings, drift since last calibration and other errors of the standard (specified by its manufacturer) and uncertainty reported in the calibration certificate of the standard. Table 3 shows the characteristics of these uncertainty contributions. To estimate the uncertainty of measurement of harmonic voltage calibration Vh_x indicated by the instrument under calibration, all input quantities were assumed to be independent, so the method defined by the Guide to the Expression of Uncertainty in Measurement was used. The standard uncertainty is estimated using eq. 1, where x_i is each input quantity, and $u(x_i)$ is its standard uncertainty.

$$u(y)=\sqrt{\sum\left(\frac{\partial y}{\partial x_i}\right)^2 .u^2(x_i)} \qquad (1)$$

Table 3. Individual contributions to the measurement uncentainty

Input quantity	Probability distribution
Drift and other error of the standard	Uniform
Calibration of the standard	t-Student
Resolution of the instrument	Uniform
Repeatability of the instrument	Normal

The measurement model of the error of the instrument when measuring a harmonic voltage is defined in eq. 2, where Vh_X is the h*th* voltage indication of the instrument, Vh_S is h*th* voltage configured in the standard (corrected by its calibration certificate), δVh_S is the correction of the standard due to drift and other errors and δVh_{iX} is the correction of the instrument due to the finite resolution of its indication. Applying eq. 1 in eq. 2, the standard uncertainty of this error could be evaluated by eq. 3.

$$E_X = Vh_X - Vh_S - \delta Vh_S + \delta Vh_{iX} \qquad (2)$$

$$u(E_X)=\sqrt{u^2(Vh_X)+u^2(Vh_S)+u^2(\delta Vh_S)+u^2(\delta Vh_{iX})} \qquad (3)$$

Calibrated instruments only indicate $THDV_h$, not Vh_X, i.e., the ratio between a harmonic voltage and the fundamental voltage. So eq. 2 becomes eq. 6 and eq. 3 becomes 7, where $V1_X$ is the fundamental voltage measured but the instrument under calibration.

$$E_X = THDV_{hX}.V_{1X} - Vh_S - \delta Vh_S + \delta THDV_{hiX}.V_{1X} \qquad (4)$$

$$u(E_X)=\sqrt{V_{1X}^2.u^2(Vh_X)+u^2(Vh_S)+u^2(\delta Vh_S)+V_{1X}^2.u^2(\delta Vh_{iX})} \qquad (5)$$

The measurement model of the error of the instrument when measuring THDV is defined in eq. 4. Applying eq. 1 in eq. 4, the standard uncertainty of this error could be evaluated by eq. 5.

$$E_X = THDV_X - THDV_S - \delta THDV_S + \delta THDV_{iX} \qquad (6)$$

$$u(E_X)=\sqrt{u^2(THDV_X)+u^2(THDV_S)+u^2(\delta THDV_S)+u^2(\delta THDV_{iX})} \qquad (7)$$

The uncertainty due to the drift and other errors of the standard was calculated using eq. 6, which was proposed by [6]. The uncertainty of each harmonic voltage was calculated using manufacture's specifications.

$$u(\delta THDV_S)=\frac{1}{THDV_S^2}.\sum_{h=2}^{N}\left(\frac{Vh_S}{V1_S}.\frac{u(Vh_S)}{V1_S}\right)^2 + THDV_S^2.\frac{u^2(V1_S)}{V1_S^2} \qquad (8)$$

4. Results

The calibration of the two power-quality analyzers A and B, in the waveform 1 and 2, provided their errors and uncertainties in each harmonic component.

By the analysis of the graphic in Fig 4 and Fig 5, it was verified that the instrument A presented its metrological characteristics in accordance with the limits established in IEC 61000-4-7 standard as to the waveform 1 as to waveform 2, i.e., within ±5% of the voltage measured or ±0.05% of the nominal voltage range of the measurement instrument, as established in table 2.

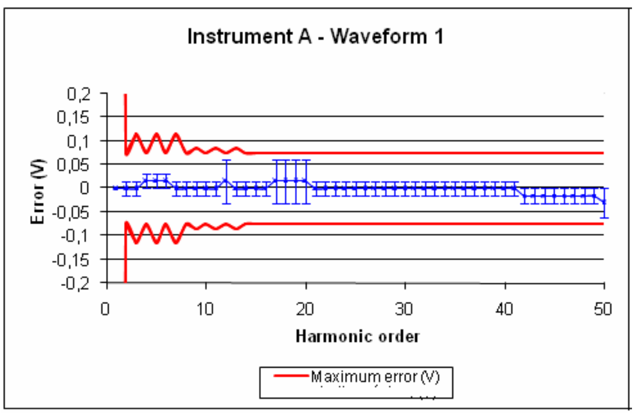

Fig 4. Results of the instrument A in waveform 1

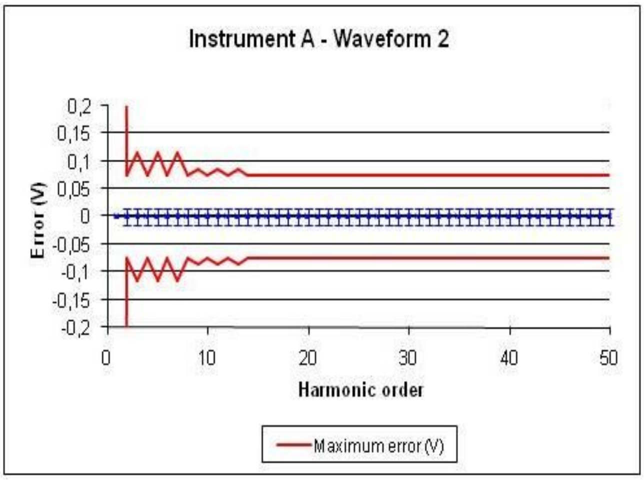

Fig 5. Results of the instrument A in waveform 2

The analyzer B also presented its metrological characteristic in accordance with the IEC 61000-4-7, as to waveform 1 as to waveform 2. This fact can be confirmed in the graphic of the fig 6 and Fig 7.

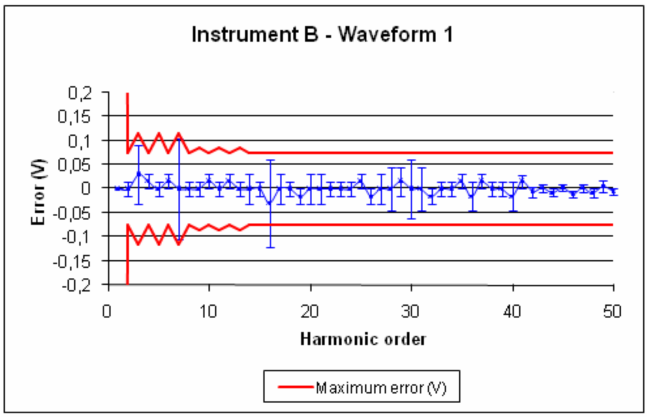

Fig 6. Results of the instrument B in waveform 1

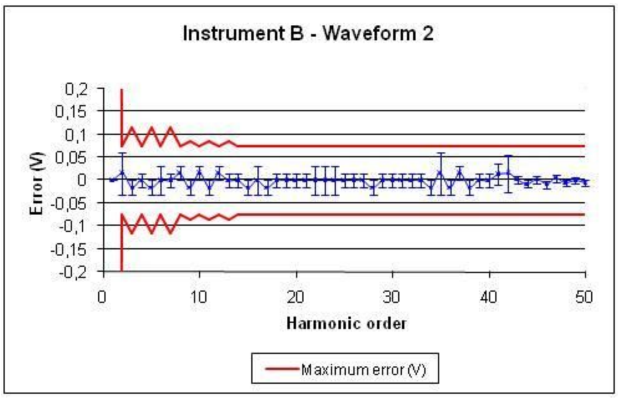

Fig 7. Results of the instrument B in waveform 2

Comparing the results obtained with the calibration of both power-quality analyzers, it was observed that the meter A presented uncertainty and error values smaller than the ones presented by the meter B. Although it must be emphasized that both meters exhibited excellent performances throughout the calibration procedure.

5. Conclusions

This article presented the results of metrological confirmation of two power quality measurement instruments commonly used in Brazilian electrical power system when measuring harmonic voltages. In resume, the instruments were much better than the IEC 61000-4-7 specifications as well as the manufacturer ones allow in its use for measurement campaign to ONS.

One obstacle to evaluate the metrological performance of power-quality meters was the difference between IEC 61000-4-7 specifications and the meters' readings. While IEC specifications are defined in terms of measurements of the voltage of the harmonic orders, the instruments indicate the THD_v, i. e., the ratio between the harmonic voltage and the fundamental voltage, in %. So it is necessary to do some mathematical conversations to perform the correct metrological confirmation.

As future works, it can be performed the metrological confirmation of a larger number of harmonic distortion in voltage meters, in order to define strict error limits for these instruments, thus improving metrological confidence measurements.

6. References

[1] ANEEL Procedimento de Rede 2.8, Gerenciamento dos indicadores de desempenho da rede básica e de seus componentes.

[2] IEC 61000-4-7, Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

[3] EA-4/02 Expression of the Uncertainty of Measurement in Calibration.

[4] ISO/IEC 98-1995 Guide to the expression of uncertainty in measurement(GUM).

[5] J. Arrillaga, N. Watson, Power System Harmonics, John Wiley & Sons,Inc., 2003.

[6] C. de Capua, C. Landi, G. C. Malafronte, "Measurement Uncertainty in Evaluating Total Harmonic Distortion Factor", IEEE Trans. On Instrumentation and Measurement, v. 1, 2001, pp. 675-679.