INTERCOMPARISON TO HIGH VOLTAGE IMPULSE AND AC HIGH VOLTAGE MEASUREMENT– Brazilian experience

Márcio Thelio Fernandes da Silva [1], *Ademir M. de Franca* [2], *Luiz Carlos de Azevedo* [3]

[1] Cepel, Rio de Janeiro, Brazil, thelio@cepel.br
[2] Inmetro, Rio de Janeiro, Brazil, amfranca@inmetro.gov.br
[3] Cepel, Rio de Janeiro, Brazil, luiz@cepel.br

Abstract: CEPEL and INMETRO, in order to strengthen high voltage metrology and to continue the "Implementation of the National System Calibration in High Voltage Measurements" project, promoted an intercomparison between standards for AC high voltage up to 200 kV and for full lightning and chopping impulse voltages (LI/LIC) up to 500 kV.

Key words: Comparison, Calibration, High voltage impulse, AC High Voltage, Accreditation laboratories.

1. INTRODUCTION

New investments in generation and transmission of large scale energy have mobilized industry and generate demand for testing new equipment. [1] To perform these tests, as well as to ensure reliability, accuracy and traceability, it is necessary to implement a high voltage metrology structure with calibrating standards and laboratories in sufficient numbers to meet the growing demand for accredited calibration services.

These standards are used for calibration of measurement systems mainly in high voltage industrial laboratories. Some of the standards for LI and LIC were calibrated more than five years ago. To perform calibrations at appropriate intervals has been a task of great difficulty for the institutions that have these standards, particularly those related to research labs and universities.

Currently there is a lack of laboratories with high voltage metrology infrastructure in Brazil. There are only five accredited laboratories for high voltage AC, including: CEPEL (CA2), IPT, IEE/USP, LABELO/PUCRS and SETTING. Brazil do not have accredited laboratories for HVDC, LI, LIC, switching impulse and current impulse, such laboratories would ensure traceability and reliability and support development of national industry electrical equipment.

Institutions with high voltage AC and impulses standards were invited to participate in this work, which will enable more reliable results, ensure traceability to internationally recognized standards and also allow each participant to evaluate the performance of their standards under different types of impulse and AC high voltage.

2. OBJECTIVE

The objective is to assure traceability and reliability for the measurements of high voltage AC, lightning, chopping impulse voltage, and also to support the deployment of the national high voltage metrology. Maintaining these standards calibrated and traceable is the main purpose of this work.

In 1995 a pilot project, called Program of Support for Scientific and Technological Development (PADCT) was funded by the MCT, aiming to provide the INMETRO`s LATRA, CEPEL`s CA2, LACTEC and IEE/USP laboratories with the necessary facilities, equipment and staff training to comply with IEC 60-2/94 - High Voltage Test Technique - Part 2: Measuring Systems. [2]

The participation in interlaboratory comparisons provides to demonstrate the quality, reliability and traceability of results that each laboratory is producing. The results produced by high voltage laboratories will contribute in the implementation of a national High Voltage Metrology system.

3. METHODOLOGY

In 2001 CEPEL participated in an international intercomparison work entitled "Traceability and Mutual recognizability of Impulse Voltage Measurements". This work was coordinated by the "Helsinki University of Technology" (HUT) with the participation of leading research institutions in the world, including: PTB, BNM-LNE, CESI, KEMA, NIST, IREQ, CSIRO, UNITUC, HIPOTRON, among other 26 institutions. [3]

For the intercomparison of the quantity high voltage AC, the INMETRO standard was calibrated and traceable by "Physikalisch Technische Bundesanstalt" (PTB) and INTI in the range of 1 kV to 200 kV. For the intercomparison of impulse voltage quantity, the CEPEL standard was calibrated by HUT in the range of 100 kV to 500 kV. The HUT acts as a National Institute of Metrology (NIM) in Finland via "Centre for Metrology and Accreditation" (MIKES), which has a mutual recognition agreement with INMETRO. This work was performed at CEPEL and

INMETRO facilities in Adrianopolis-RJ and Xerém-RJ, respectively, according to IEC 60060-1-2 [4, 5] standards. It began in the middle of 2009 and lasted 18 months.

Table 1 shows the operating range of the eleven (11) institutions that participated in this work, including: Utilities laboratories, the National Institute of Metrology (NIM), research labs, universities and calibration service labs. Also indicated below are the labs already accredited by INMETRO to provide calibration services for high voltages AC in the Brazilian Network of Calibration (RBC). Of the eleven institutions only two make tests with lightning impulse.

Table 1. Institutions, application and operation range. (A) Accredited.

Institutions / State	Application	Operation range
CEMIG - MG	AC	1,0 kV – 400 kV
CEPEL/CA2 (A) - RJ	AC	10 kV – 180 kV
CEPEL/CA2 - RJ	LI/LIC	100 kV – 500 kV
ELETRONORTE - PA	AC	10 kV – 70 kV
FURNAS/CTE.O - MG	AC	1,0 kV – 400 kV
IEE / USP - SP	LI/LIC	100 kV – 500 kV
IEE / USP (A) - SP	AC	1,0 kV – 35 kV
INMETRO - RJ	AC	1,0 kV – 200 kV
IPT (A) - SP	AC	1,0 kV – 100 kV
LABELO/PUCRS (A) - RS	AC	1,1 kV – 12 kV
LACTEC - PR	AC	10 kV – 200 kV
LACTEC - PR	LI/LIC	100 kV – 500 kV
SETTING (A) - SP	AC	1,0 kV – 40 kV

4. STANDARDS

CEPEL used a Standard Reference Measurement System (RMS) consisting of a resistive divider (R500REF) together with the channel 3 of HIAS REF 743, certificate TKKSJ487 calibrated in 2008 and valid until 2013. INMETRO used High Voltage AC Ratio Reference System's.

4.1. Standards uncertainty

Uncertainties for voltage and time parameters of the standards used in this work are reported bellow according to the requirements of IEC 60060-2.

- CEPEL standard
Quantity voltage:
LI : 0,5% to 0,7%;
LIC: 3,0%.

Time parameters:
T1 – Front time: 3,0%,
T2 – Time to half value: 1,5 %,
Tc – Time to chopping: 5,0 %.

- INMETRO standard
Quantity voltage:
AC High Voltage: 0,01%.

4.2. Calibration procedure

The RMS voltages of the participating institutions were compared, to determine the Scale Factor (SF) and check its performance characteristics. These checks were made by means of comparative measurements in HV and LV and also by the evaluation of the dynamic behavior according to IEC 60060-2.

To LI and LIC:

- Level: 100 kV, 200, 300, 400 e 500 kV;
- 10 impulses with each level;
- Two polarities;
- Waveforms: LI (0,84/50 µs and 1,5 µs/50 µs) and LIC (Tc = 0,5 µs);
- Step response (Square circuit).

To High Voltage AC:

- 1,0 kV to 200 kV.

In the second phase two RMS (for high voltage AC and LI/LIC) were circulated among all participants to evaluate reproducibility and to determine the SF and additional step response measurement.

The basic characteristics of each one are described below:

Impulses (LI) – Reference Measurement System (RMS5) composed of a 500 kV resistive divider, type RDV500-REF, coaxial cable 75 Ω/20 m, matching resistor 75 Ω and a peak volt DMI 551. Certificate CA2-INTER-001/2010 (SF = 256,0:1) see Figure 1.

High Voltage AC - Reference Measurement System (RMS7) composed of a 15 kV resistive divider, CEPEL manufacturing, coaxial cable 50 Ω/20 m and a Fluke 45 multimeter. Certificate Dimci 0596/2010 (SF = 2938,7:1) see Figure 2.

Figure 1. Photo of RMS5 to impulses LI/LIC.

Figure 2. Photo of RMS7 to AC High Voltage.

The SF, step response and uncertainty U, have been respectively determined, measured and calculated by all institutions to common levels, that is: 10 kV AC and ± 200 kV LI (with two waveforms: 0,84/50 µs and 1,5/50 µs).

The following environmental and thermal conditions have been met: temperature 22 °C ± 5 °C and relative humidity: 55% ± 20%. The instruments remained turned on for at least 30 minutes, before utilization, for thermal stabilization.

The names of the institutions were replaced by letters to preserve confidentiality.

4.2.1 AC High Voltage SF measurements

Each institution performed the calibration of the Scale Factor of RMS7 in their facilities to the AC level of 10 kV according to Table 2 and also the estimated uncertainty and coverage factor.

Table 2. Measurements SF, U and k.

Participants	SF	U	k
A	2943	16	2,37
B	2941,5	4,2	2,02
C	2947	11	2,00
D	2940	86	2,00
E	2939	12	2,00
F	2942	29	2,00
G	2953	38	2,00
H	2940	10	2,01
I	2942,6	5,7	2,07

4.2.2 Lightning impulse SF measurements

Each institution performed the calibration of the Scale Factor of RMS5 in their facilities for two lightning impulse waveforms for the 200 kV level, at both polarities according to Table 3 and also the estimated uncertainty and coverage factor.

Table 3. Measurements SF, U and k

Participant	Impulses	Voltage / polarity	SF	U	k
J	0,84 / 50 µs	+ 200 kV	254,4	3,0	2,00
		- 200 kV	253,9		
	1,50 / 50 µs	+200 kV	254,5		
		- 200 kV	254,0		
K	0,84 / 50 µs	+200 kV	256,0	5,6	
		- 200 kV	254,8	5,1	
	1,50 / 50 µs	+200 kV	253,6	3,0	
		- 200 kV	253,4	2,8	

4.2.2.1 Step response

The step response of RMS is shown in Figure 3. An evaluation of the step response was performed at RMS in each institution and the results are presented in Figures 4 and 5 and Table 4.

Each participant used their own software to calculate the parameters of the step response.

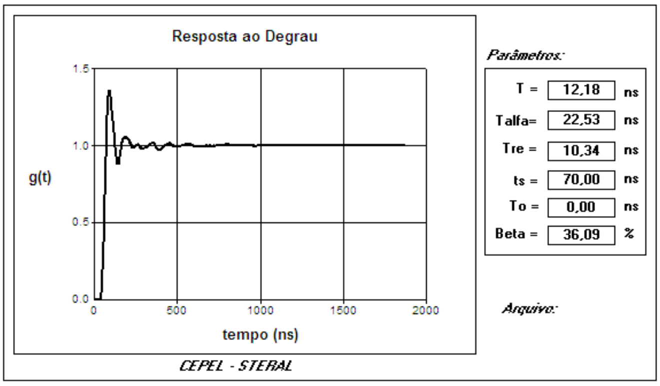

Figure 3. Step response of RMS5.

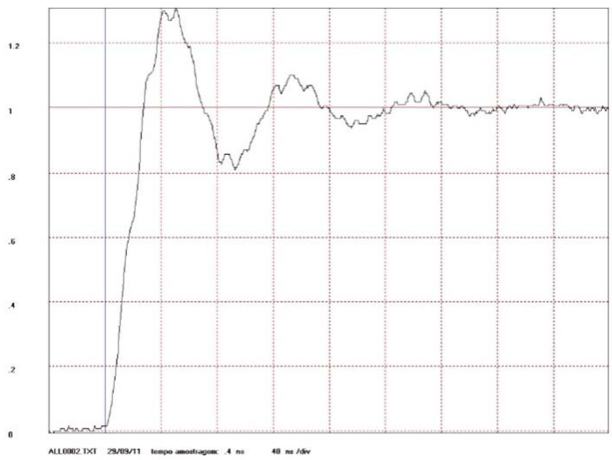

Figure 4. Step response measurement by participant J at 40 ns/div.

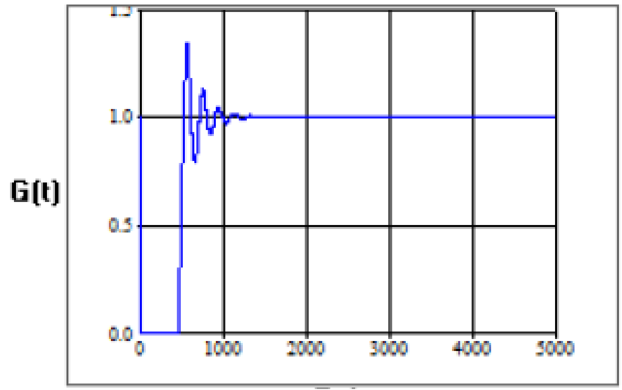

Figure 5. Step response measurement by participant K at 1000ns/div.

Table 4. Step response parameters.

Parameters	RMS5	Participant J	Participant K
T_N	12,18 ns	12,0 ns	10 ns
Tα	22,53 ns	16,4 ns	15,2 ns
ts	70 ns	87 ns	94,5 ns
To	0	0	0,7 ns
β	36,09 %	30,6 %	34,2 %

Where:
T_N – Experimental response time;
Tα – Partial response time;
ts – Settling time;
To – Initial distortion time;
β – Overshoot.

5. RESULTS

An evaluation of the results was performed using the method of normalized error, according to the standard ABNT-ISO/IEC GUIDE 43-1 [6], for each measure of SF and U performed by each participant of this work. The values measured by CEPEL and INMETRO were considered as reference (Val_{ref}).

The participants SF and results were compared with the reference values. The calculation of the normalized error is performed using the equation described below:

$$E_n = \left| \frac{Val_n - Val_{ref}}{\sqrt{U_n^2 + U_{ref}^2}} \right|$$

Where:

Val_n = SF value obtained by the participant "n";
Val_{ref} = SF reference value;
U_n = Uncertainty obtained by the participant "n";
U_{ref} = Uncertainty used as a reference.

The result of the comparison is considered technically satisfactory if the module of $E_n \leq 1$.

5.1 High Voltage AC measurement results

Table 5 present the results of each E_n calculated by participant for the SF measurement with High Voltage AC at 10 kV.

According to the IEC 60060-2 requirements of a Reference Measurement System there must be an uncertainty no great than 1% for measurement of High Voltage AC.

Table 5. Normalized error for High Voltage AC measurements.

Participant	SF	U	E_n
A	2943	16	0,3
B	2941,5	4,2	0,6
C	2947	11	0,7
D	2940	86	0
E	2939	12	0
F	2942	29	0,1
G	2953	38	0,4
H	2940	10	0,1
I	2942,6	5,7	0,7

5.2 Lightning impulse (LI) measurement results

Table 6 present the results of E_n for the measurement of SF of two laboratories with LI at 200 kV and also for two impulses waveforms of both polarities.

According to the IEC 60060-2 requirements of a Reference Measurement System there must be an uncertainty no great than 1% for measurement of LI.

Table 6. Normalized error for LI measurements.

Participant	Impulse (µs)	SF	U	E_n
J	+0,84/50	254,4	3,0	0,4
	-0,84/50	253,9		0,5
	+1,5/50	254,5		0,4
	-1,5/50	254,0		0,6
K	+0,84/50	256,0	5,6	0
	-0,84/50	254,8	5,1	0,2
	+1,5/50	253,6	3,0	0,7
	-1,5/50	253,4	2,8	0,8

6. COMMENTS AND CONCLUSIONS

All measurement systems of the institutions that participated in this work were calibrated and are traceable to national or international standards.

According to the results presented and considering the calculation of normalized errors, all results indicate reproducibility between different laboratories, and that the declared uncertainties are compatible with the measured ones, for accredited and not accredited laboratories, considering High Voltage AC and lightning impulses voltages.

The results of the evaluation of the parameters of the step response are satisfactory and compliant in spite of different types of generators, software and laboratory grounding arrangements. The response parameters measured are within the limits of IEC 60060-2/94, for use as a reference measurement system.

Given that one participant does not perform the Lightning Impulse front Chopped waveform tests (LIC), in this work the SF for the RMS has been determined only for full LI waveforms.

RMS5 and RMS7 standards were sent to the laboratories of origin to be recalibrated at the end of the work. There were no significant changes in the SF of the RMS used in this work.

As a contribution to national metrology, CEPEL is starting its laboratory accreditation process to full lightning impulse voltages (LI) and chopping in the front (LIC) up to 500 kV.

The results of this work assure traceability and reliability for the measurements of high voltage AC, lightning impulse voltage, and also support the deployment of the national metrology at high voltages. Maintaining these standards calibrated and traceable is the main purpose of this work.

The results produced in this work by high voltage laboratories will contribute to implement a national system of High Voltage Metrology in the country.

7. REFERENCES

[1] Ten Year Plan for expansion of energy MME – 2008 / 2017. www.mme.gov.br;

[2] Implementation of the National System Calibration in High Voltage Measurements, Project FINEP 0471/95;

[3] “Traceability and Mutual recognizability of Impulse Voltage Measurements” April 2002 report TKK-Sjt-54;

[4] IEC 60060 “High-voltage test techniques, Part 1: General definitions and test requirements” – 1989;

[5] IEC 60060 “High-voltage test techniques, Part 2: Measuring systems” - 1994;

[6] ABNT NBR ISO/IEC Guide 43-1: 1999, Proficiency testing by comparisons interlaboratories Part 1: Development and operation of proficiency testing programs.