

**REPORT OF THE RESEARCH AND DEVELOPMENT ACTIVITIES OF
INMETRO ELECTRICAL METROLOGY DIVISION
(2023-2025)**

Electrical Metrology Division
Instituto Nacional de Metrologia, Qualidade e Tecnologia
Av. Nossa Senhora das Graças, 50, Duque de Caxias, RJ, 25250-020, Brazil
Email: diele@inmetro.gov.br

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Scope

This report presents the recent research activities in electricity and magnetism performed at Inmetro to support the confidence-building mentioned in the CIPM Mutual Recognition Arrangement (CIPM MRA).

Research and Development

(a) Voltage

(b) Current

- A current primary standard based on Ohm's law in the range between nanoampere and milliamperes is under development. It is done by the integration of a standard resistor, directly calibrated using a Quantum Hall System, and a Josephson Voltage Standard. So far, a 5730A Fluke calibrator, working as a DC current source, was calibrated in the range of 50 μA to 10 mA, with uncertainties ranging between 0.5 $\mu\text{A/A}$ and 4.6 $\mu\text{A/A}$.

(c) Resistance

- The Inmetro achieved international recognition of its dc quantum Hall system (QHS) through the approval of the CMC for the 1 Ω and 10 k Ω ranges on 2023-12-21. The good results obtained in the BIPM.EM-K13.a&b key comparison supported such CMC (see below Inmetro participation in the comparisons performed by BIPM).
- The new services provided in the abovementioned ranges have improved the calibration uncertainty in terms of the Inmetro best capability from 0.25 $\mu\Omega/\Omega$ to 0.068 $\mu\Omega/\Omega$ in the 1 Ω range and from 0.15 $\mu\Omega/\Omega$ to 0.036 $\mu\Omega/\Omega$ in the 10 k Ω range. As a result of such improvement, Inmetro can now calibrate its standards on national territory, no longer needing to send them for calibration at the BIPM.
- Participation in the BIPM.EM-K12 comparison, which involves onsite measurements of 100 Ω standards against the Inmetro QHS and the BIPM transportable QHS and their scaling to the 10 k Ω /100 Ω and 100 Ω /1 Ω ratios, is planned for 2027 (see below Inmetro participation in the comparisons performed by BIPM).
- A measuring system based on the modified Wheatstone bridge is under development to measure dc resistance from 1 G Ω to 100 T Ω .

(d) Impedance

- Traceability chain to derive the capacitance unit from the dc quantum Hall effect. The calculable resistor, the quadrature bridge, and the inductive voltage divider calibration system based on the bootstrap method are under development.
- Inmetro uses an in-house built digital sampling bridge for accurate ac resistance (in-phase) and capacitance (quadrature) measurements since 2017. We are working on improvements to this system, including the development of a professionally built multilayer PCB for the analog circuit, which may lead to extension on the operating range and reduction of uncertainties.

(e) Power

- A PMU calibration system is under development to provide traceability to our Fluke 6135A PMU calibration system.
- Development of a measuring system for electrical disturbances related to power quality.
- Development and construction of an automated wideband voltage divider in cooperation with the Physikalisch-Technische Bundesanstalt (PTB) for use in electric power and harmonics measurements.

(f) High voltage

- Traceability of AC high voltage (HV) measurements from national low voltage (LV) standards. The methodology involves characterizing a reference HV potential transformer using an HV capacitance bridge and HV and LV standard capacitors.
- Implementation of a Hybrid Reference Measurement System to support the electrical sector infrastructure by calibrating conventional HV potential transformers (PTs) and Low-Power Instrument Transformers (LPITs), especially with IEC 61850 output. This includes ensuring traceability for measurement chain components such as Merging Units, Stand-Alone Merging Units, and Intelligent Electronic Devices (IEDs), which are key elements in high-voltage transduction for digital substations.
- Traceability of DC HV measurements to LV measurements based on the 'binary step-up' procedure, aiming at characterizing the HV DC resistive divider using national low-voltage standards.
- Traceability of HVAC measurements at harmonic frequencies for the power quality (PQ) operational range (initially from 50 Hz to 3 kHz), through the development of an expandable multi-harmonic reference measurement system from low voltage to high voltage.

(g) High current

- Implementation of a Hybrid Reference Measurement System to support the electrical sector infrastructure by calibrating conventional CTs and LPITs (especially with IEC 61850 output), ensuring traceability for measurement chain components such as Merging Units, Stand-Alone Merging Units, and IEDs, which are crucial in high-current transduction for digital substations.
- Traceability of High Current AC measurements at harmonic frequencies for the PQ operational range (initially from 50 Hz to 3 kHz), through the development of an expandable multi-harmonic reference measurement system from low to high current.

(h) Digitalization

- Development of an integrated web system for data processing related to calibration and lab management.

Regional Project

- (i) Regional project among Inmetro (Brazil), INTI (Argentina) and UTE (Uruguay), funded by the Brazilian government, to build a reference system for measuring electric power up to 100 kHz.

International Comparisons

- (a) Bilateral comparison of 1 Ω and 10 k Ω standards (ongoing BIPM key comparisons BIPM.EM-K13.a and 13.b) between the INMETRO (Brazil) and the BIPM - Inmetro e BIPM – from Nov-2020 to Sept-2021.
- (b) CCEM-K6a/K9 Key Comparison of AC-DC Voltage Transfer Standards (Ac-dc voltage transfer at 3 V, 500 V e 1000 V). Started in 2018. Inmetro's measurement report sent in February 2020.
- (c) CCEM-K12.2025. Key Comparison of AC-DC current transfer standards. Started in 2025. Inmetro's measurements are scheduled to June 2025.

- (d) SIM.EM-S13: Comparison of voltage, current and resistance – from 2017 to 2022.
- (e) CCEM-K5 Key comparison of electric power. Inmetro's measurement report sent in January 2021.
- (f) SIM.EM-S18 Comparison – from 2023 to 2025 – Comparison of voltage ratio standards – Voltage Transformer up to 40 kV.
- (g) BIPM.EM-K12: Quantum Hall resistance standards and their scaling to other resistance values – May/June-2027 (planned).

Publications

- Pinto, Marcus, Ventura, R, Landim, Regis and David, R. (2023). A reference system to calibrate low-current meters in the range of picoamperes to microamperes. *Journal of Physics: Conference Series*. 2606. 012027. 10.1088/1742-6596/2606/1/012027.
- Slomovitz, Daniel, Landim, R, de Souza, Heriguatí and Trigo, L. (2023). Bilateral comparison of dc voltage at 10 V between UTE and INMETRO. *Journal of Physics: Conference Series*. 2606. 012029. 10.1088/1742-6596/2606/1/012029.
- Geronymo, Gean. (2023). Digitalization of an Electrical Metrology Laboratory: Hybrid-remote calibrations. *Journal of Physics: Conference Series*. 2606. 012031. 10.1088/1742-6596/2606/1/012031.
- M. B. Martins, P. A. A. Esquef and R. T. de Barros e Vasconcellos, "Enhanced Step Location in the Magnitude and Phase of an AC Signal via Polynomial Approximation Total Variation (PATV) Filtering," *2023 IEEE 13th International Workshop on Applied Measurements for Power Systems (AMPS)*, Bern, Switzerland, 2023, pp. 01-06, doi: 10.1109/AMPS59207.2023.10297173.
- Silva, Márcio & Geronymo, Gean. (2023). Evaluation of the effects of leakage current in the calibration of standard resistors between two dc resistance bridges and a digital sampling impedance bridge. *Journal of Physics: Conference Series*. 2606. 012032. 10.1088/1742-6596/2606/1/012032.
- A. Goldstein and G. A. Kyriazis, "Parameter Estimation of wide-band FM signals from knowledge about their sinusoidal modulation," in *IEEE Transactions on Instrumentation and Measurement*, vol. 72, pp. 1-8, July 2023, Art no. 1502908, doi: [10.1109/TIM.2023.3292946](https://doi.org/10.1109/TIM.2023.3292946).
- G. A. Kyriazis and R. S. Ribeiro, "Modeling the Transimpedance Amplitude and Phase of Wideband Cage-Type Current Shunts," in *IEEE Transactions on Instrumentation and Measurement*, vol. 72, pp. 1-7, May 2023, Art no. 1502407, doi: [10.1109/TIM.2023.3279874](https://doi.org/10.1109/TIM.2023.3279874).
- Vitorio, Patricia, Souza, L., Landim, R. and Prado, Charles. (2023). Uncertainty assessment of a resistive voltage divider for binary step-up method implementation in HVDC applications. *Journal of Physics: Conference Series*. 2606. 012035. 10.1088/1742-6596/2606/1/012035.

Communications in Conferences and Symposiums

- G. Kyriazis and V. Teixeira, "Amplificadores de transcondutância de 12 A e 100 kHz." In: *Metrologia 2023 - XV International Congress on Electrical Metrology (XV SEMETRO)*, Nov. 2023.
- V. De Oliveira, "Attitude toward online privacy of Brazilian users with a focus on the Metrology community." In: *Metrologia 2023 - XV International Congress on Electrical Metrology (XV SEMETRO)*, Nov. 2023.
- G. Geronymo, "Enhancing Digital Calibration Certificate (DCC) Workflow: Python-based DCC Tools Development and Implementation." In: *Metrologia 2023 - XV International Congress on Electrical Metrology (XV SEMETRO)*, Nov. 2023.
- V. De Oliveira, R. Landim, and C. Prado, "A closer look at the mathematical model of a cryogenic current comparator." In: *Metrologia 2023 - XV International Congress on Electrical Metrology (XV SEMETRO)*, Nov. 2023.

- R. Ventura, L. Costa, M. Pinto, V. Teixeira, and L. Félix, In: Metrologia 2023 - XV International Congress on Electrical Metrology (XV SEMETRO), Nov. 2023.
- M. Martins, L. Souza, R. Zampilis, and M. Viegas, “Sistema de referência para medição sincrofasorial.” In: Metrologia 2023 - XV International Congress on Electrical Metrology (XV SEMETRO), Nov. 2023.
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- L. Costa, M. Pinto, and R. Ventura, “Ensaio de proficiência: estudo do comportamento temporal de um multímetro digital.” In: Metrologia 2023 - XV International Congress on Electrical Metrology (XV SEMETRO), Nov. 2023.