SIM.EM-S8
COMPARISON REPORT

Supplementary comparison of current ratio through instrument current transformers

March – 2020

Final Report

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1 Introduction

Under the auspices of the Committee Consultative of Electromagnetism, CCEM, the SIM Electromagnetic Working Group carried out a Supplementary comparison of current ratio using instrument current transformers. Usinas y Trasmisiones Eléctricas (UTE) was the pilot laboratory. The comparison measurements were conducted from 2013 to 2019.

The measurement parameters were ratio errors and phase displacements, at power frequencies and selected currents and ratios. The test points, current, burden and frequency, were chosen according to the measuring capabilities of the participants and the requirements of their services, taking into account their measurement standards and their measurement procedures.

1.1 Objective

The objective of this comparison was to compare the measurement capabilities of NMI´s in the Inter-American Metrology System (SIM), in the field of calibration of instrument current transformers. This is in accordance with the CIPM Mutual Recognition Agreement (MRA) objectives, that NMI´s must establish the degree of equivalence between their national measurement standards by performing regional comparisons.

As a future work, it is planned to link this round with the European round EUROMET.EM-S11, through the laboratory Physikalisch-Technische Bundesanstalt (PTB) which participated in both.

2 Organization

2.1 Coordinators and members of the review committee.

Alejandro Santos, UTE
Daniel Slomovitz, UTE
Jose Luis Casais, INTI

2.2 Participants

Participants are listed in Table 1. UTE acted as the pilot laboratory.

Table 1. Participant laboratories of the intercomparison

Organization	Country	Contact Person	E-mail	Address
UTE (PILOT)	Uruguay	Alejandro Santos	asantos@ute.com.uy	Usinas y Trasmisiones Eléctricas. Paraguay 2385, Montevideo 11800, Uruguay, tel. 598-29242042
INMETRO	Brazil	Patrícia Cals de Oliveira Vitorio	pcoliveira@inmetro.gov.br	Instituto Nacional de Metrologia, Qualidade e Tecnologia - (Inmetro) Diretoria de Metrologia Científica - (Dimci) Divisão de Metrologia Elétrica – (Diele) Tel. (021) 2679-9095/2679-3395
INM	Colombia	Alvaro Zipaquira Triana	azipaquira@inm.gov.co	Instituto Nacional De Metrología. Av, Cr 50 No. 26 – 55 Int. 2 CAN Bogotá - Colombia
CENAMEP	Panamá	Julio Gonzalez	jgonzalez@cenamep.org.pa	Centro Nacional de Metrología de Panamá (CENAMEP AIP). Panamá, Ciudad de Panamá, Clayton, Ciudad del Saber, Edificio 215. Apartado 0843-01353 República de Panamá.
CFE LAPEM	Mexico	Sergio Ochoa Márquez	sergio.ochoa@cfe.gob.mx	Laboratorio de Pruebas a Equipos y Materiales, LAPEM Edificio 5. Oficina de Metrología Av. Apaseo Ote. S/N Ciudad Industrial 36541 Irapuato,
INTI	Argentina	José Luis Casais	jcasais@inti.gob.ar	Instituto Nacional de Tecnología Industrial. Av. Gral. Paz 5445 B1650WAB San Martín Buenos Aires Argentina tel. 5411 4724 6200
PTB	Germany	Enrico Mohns	Enrico.Mohns@ptb.de	Physikalisch-Technische Bundesanstalt - PTB Bundesallee 100 D-38116 Braunschweig Germany

2.3 Comparison schedule

The comparison started in 06-2013 with measurements at the pilot laboratory. They were repeated at the middle and end of the period to assure the stability of the traveling standard. Large delays, compared to the initial schedule, occurred in almost all countries, mainly due to custom procedures. Table 2 shows the original schedule and Table 3, the real timing for each laboratory.

Table 2. Original schedule of the comparison.

Country	Receipt of Traveling Standard	Departure of Traveling Standard
Uruguay		June 1st, 2013
Brazil	November 11, 2013	December 20, 2013
Colombia	January 6, 2014	14 February 2014
Panama	March 3, 2014	April 11, 2014
Mexico	April 28, 2014	June 6, 2014
Argentina	June 20, 2014	August 1, 2014
Uruguay	August 15, 2014	September 26, 2014
Germany	October 20, 2014	November 28, 2014
Uruguay	December 22, 2014	

Table 3. Real timing of the comparison.

Country	Laboratory	Receipt of traveling standard	Sending of traveling standard
Uruguay	UTE		June 2013
Brazil	INMETRO	November 2013	December 2013
Colombia	INM	June 2014	June 2014
Panama	CENAMEP	July 2014	September 2014
Mexico	CFE-LAPEM	October 2014	July 2016
Uruguay	UTE	July 2016	September 2017
Argentina	INTI	September 2017	July 2018
Germany	PTB	August 2018	April 2019
Uruguay	UTE	May 2019	Round end

3 Traveling Standard

A two-stages current transformer: CONIMED type TI 1205, with the addition of an electronic compensator: LABUTE 201108, were used as traveling standard. Figure 1 shows the aspect of the CT and the compensator, and Table 4 the technical characteristics of the CT. The compensator allowed to connect the two secondary windings of the two-stage CT (A, S), to a single input that most comparing bridges have (see figure 2). Additionally, it reduces the CT error as well as the load influence (a variation of 1 VA affects the errors less than 0.1×10^{-6}).

Fig. 1. Traveling CT and electronic device.

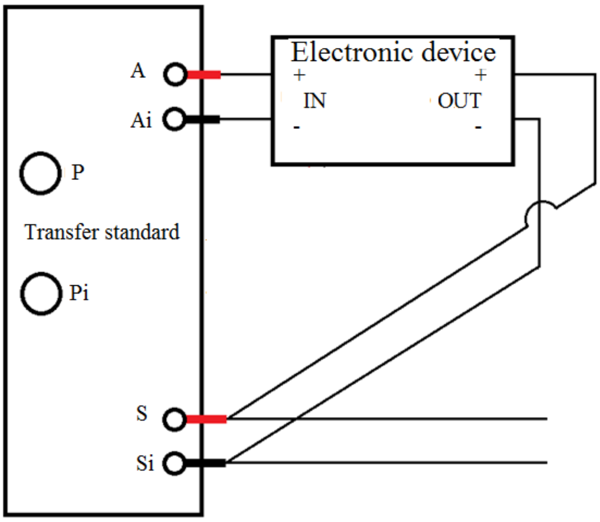

Fig. 2. Connection of CT to the electronic device.

Table 4. Rated characteristics of the traveling standard without the electronic device.

Trademark	CONIMED
Model	TI 1205
Serial Number	11023
Frequency	50 Hz, 60 Hz
Primary current	5 A to 1200 A
Secondary current	5 A
Burden	5 VA
Accuracy	± 0.005% ±0.5 min
Dimensions	0.22 X 0.44 X 0.55 m (Wide x long x height)
Weight	85 kg

For 500-A and 1000-A ranges, fixed copper bars were installed in the traveling standard. They were connected in series or parallel using auxiliary bars as figures 3 and 4 shows.

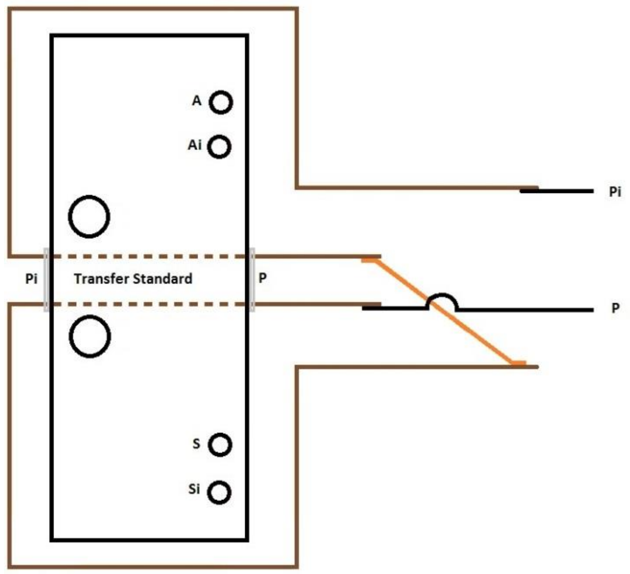

Fig. 3. Connection for 500-A to 5-A ratio.

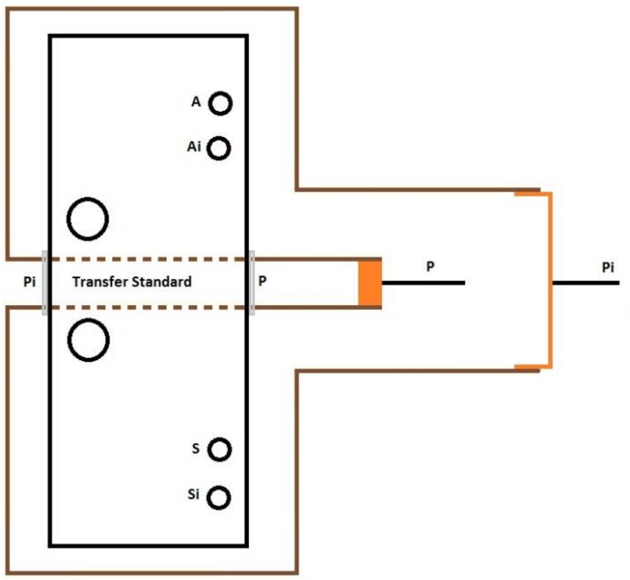

Fig. 4. Connection for 1000-A to 5-A ratio

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A heavy box was included to prevent damage during transportation (see figure 5). No significant accidents occurred.

Fig. 5. Transport box.

4. Measurement instructions

Laboratories were instructed on measurement procedure. The measurement methods are described in Annex C. The following additional details were taken into account.

4.1 Quantities to be measured

Current ratio and phase displacement were measured. The ranges of primary currents, I_n, were: 5 A, 10 A, 25 A, 50 A, 100 A, 250 A, 500 A and 1000 A. The rated output current was 5 A. For each range, the current testing points were: 5%, 20%, 100% and 120% of I_n.

4.2 Measurement conditions

The frequencies were 50 Hz, 60 Hz or both, according to the facilities of each laboratory. The burden was 6 VA with cos φ=1. The temperature should be in the range 20±5 °C.

4.3 Grounding

Primary terminal Pi of the traveling standard had to be close to ground potential, but not grounded. This was the terminal that was connected to the reference CT of the participating laboratories. Secondary terminal *s* was grounded. The electrostatic shield between primary and secondary windings was also grounded.

4.4 Measurement uncertainty

Error results and combined standard uncertainties, with a cover factor 95%, were provided to the pilot laboratory by each participant, according to the ISO Guide to the Expression of Uncertainty in Measurement.

4.5 Traceability

Table 5 shows, for each laboratory, its source of traceability, or if it is done to their own national standards.

Table 5. Source of traceability

Laboratory	Traceability to	Self traceability
UTE		X
INMETRO	METAS	
INM	PTB	
CENAMEP	INTI	
CFE	PTB	
INTI		X
PTB		X

5. Comparison reference value

The Comparison Reference Values (CRV) was determined as the weighted mean of each set of results. Only laboratories that have traceability not correlated to other NMIs were used for this calculation (UTE, INTI, PTB). In case of UTE, the results of 2019 were used. The CRV was determined according to the sum of weighted means as

$$CRV = \sum_{i=1}^{n} w_i \varepsilon_i$$

where ε_i was the reported ratio error or phase displacement value for lab $\boldsymbol{i}$, in µA/A and µrad, n was the number of laboratories with independently-derived measurement results, and the weight w_i was determined according to

$$w_i = \frac{\frac{1}{U_i^2}}{\sum_{i=1}^{n} \frac{1}{U_i^2}}$$

U_i was the combined standard uncertainty of measurement ε_i, in µA/A and µrad.

The uncertainty of the CRV was calculated according to the following equation

$$U_{CRV}^2 = \sum_{i=1}^{n} w_i^2 U_i^2$$

All calculations were done using expanded uncertainties. Tables 6 and 7 show the calculated CRV.

Table 6. Comparison reference values at 50 Hz.

Ratio	I/In %	ε_{ref} µA/A	$U\varepsilon_{ref}$ µA/A	δ_{ref} µrad	$U\delta_{ref}$ µrad	Ratio	I/In %	ε_{ref} µA/A	$U\varepsilon_{ref}$ µA/A	δ_{ref} µrad	$U\delta_{ref}$ µrad
5/5	120	0,6	2,2	0,1	2,2	100/5	120	1,3	2,2	2,0	2,2
	100	0,7	2,2	-0,1	2,2		100	1,4	2,2	2,0	2,2
	20	1,3	2,2	0,0	2,2		20	1,9	2,2	1,7	2,2
	5	2,7	2,2	0,5	2,2		5	3,7	2,2	2,3	2,2
10/5	120	0,7	2,2	-0,6	2,2	250/5	120	0,0	2,2	2,1	2,2
	100	0,8	2,2	-0,7	2,2		100	0,1	2,2	2,2	2,2
	20	1,9	2,2	-0,2	2,2		20	0,7	2,2	2,2	2,2
	5	2,9	2,2	0,1	2,2		5	2,9	2,2	3,2	2,2
25/5	120	1,9	2,2	0,8	2,2	500/5	120	2,7	2,2	-1,1	2,2
	100	1,9	2,2	0,7	2,2		100	2,7	2,2	-0,9	2,2
	20	2,6	2,2	1,0	2,2		20	2,4	2,2	0,4	2,2
	5	4,4	2,2	2,0	2,2		5	3,9	2,2	1,3	2,2
50/5	120	2,2	2,2	-1,4	2,2	1000/5	120	2,6	2,4	-1,0	2,4
	100	2,3	2,2	-1,4	2,2		100	2,4	2,4	-0,9	2,4
	20	2,8	2,2	-1,0	2,2		20	1,8	2,4	0,6	2,4
	5	4,7	2,2	0,0	2,2		5	3,3	2,4	1,8	2,4

Table 7. Comparison reference values at 60 Hz.

Ratio	I/In %	ε_{ref} µA/A	$U\varepsilon_{ref}$ µA/A	δ_{ref} µrad	$U\delta_{ref}$ µrad	Ratio	I/In %	ε_{ref} µA/A	$U\varepsilon_{ref}$ µA/A	δ_{ref} µrad	$U\delta_{ref}$ µrad
5/5	120	0,5	2,2	-0,1	2,2	100/5	120	1,3	2,2	1,9	2,2
	100	0,6	2,2	-0,1	2,2		100	1,5	2,2	1,9	2,2
	20	1,2	2,2	0,1	2,2		20	1,8	2,2	1,8	2,2
	5	2,6	2,2	1,0	2,2		5	3,2	2,2	2,3	2,2
10/5	120	0,7	2,2	-0,6	2,2	250/5	120	0,2	2,2	2,1	2,2
	100	0,8	2,2	-0,6	2,2		100	0,2	2,2	2,1	2,2
	20	1,4	2,2	-0,4	2,2		20	0,6	2,2	2,1	2,2
	5	2,5	2,2	0,6	2,2		5	2,1	2,2	2,9	2,2
25/5	120	1,8	2,2	1,1	2,2	500/5	120	2,5	2,2	-0,8	2,2
	100	1,9	2,2	1,2	2,2		100	2,6	2,2	-0,7	2,2
	20	2,0	2,2	1,4	2,2		20	2,1	2,2	0,5	2,2
	5	3,8	2,2	2,6	2,2		5	3,3	2,2	1,7	2,2
50/5	120	1,9	2,2	-1,0	2,2	1000/5	120	2,5	2,4	-0,9	2,4
	100	1,9	2,2	-1,0	2,2		100	2,1	2,4	-0,8	2,4
	20	2,3	2,2	-0,6	2,2		20	1,1	2,4	0,5	2,4
	5	3,8	2,2	0,6	2,2		5	2,7	2,4	1,7	2,4

6. Measurement reports.

Measurement values and uncertainty budgets, as reported by each laboratory, are presented in Annexes A and B respectively.

7. Report of the comparison.

7.1 Drift. No significant variation was observed in the traveling CT during all the comparison period (six years). So, no correction was made due to this factor. Selected curves are shown below.

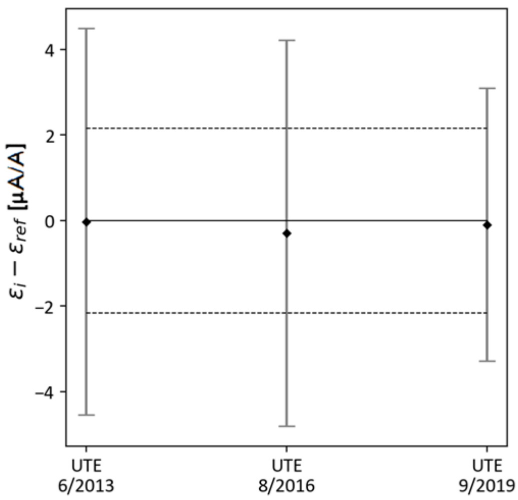

Fig. 6. Ratio 5/5, I/In = 5%, Frequency 50 Hz, Current error drift

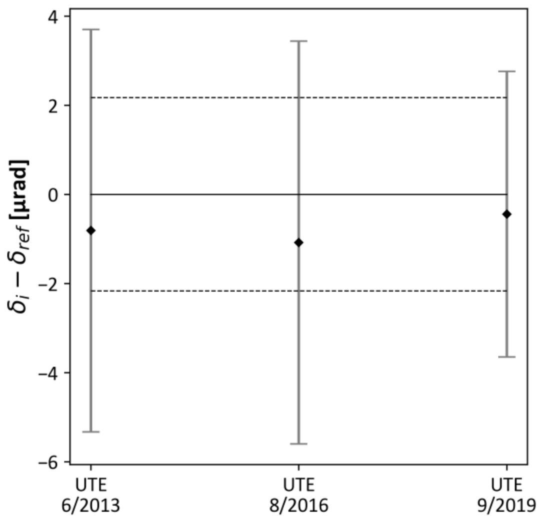

Fig. 7. Ratio 5/5, I/In = 5%, Frequency 50 Hz, Phase displacement drift

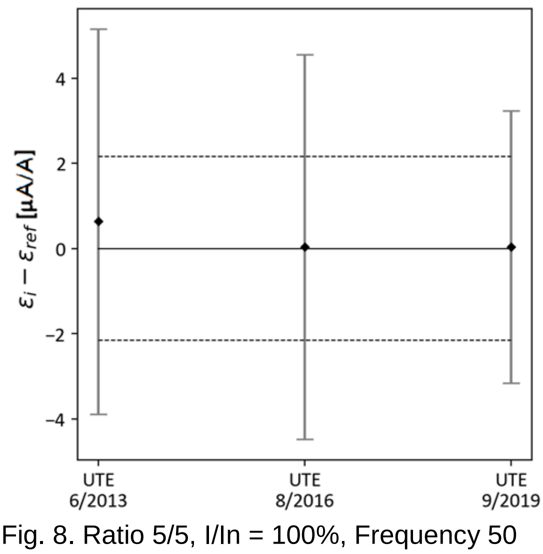

Fig. 8. Ratio 5/5, I/In = 100%, Frequency 50 Hz, Current error drift

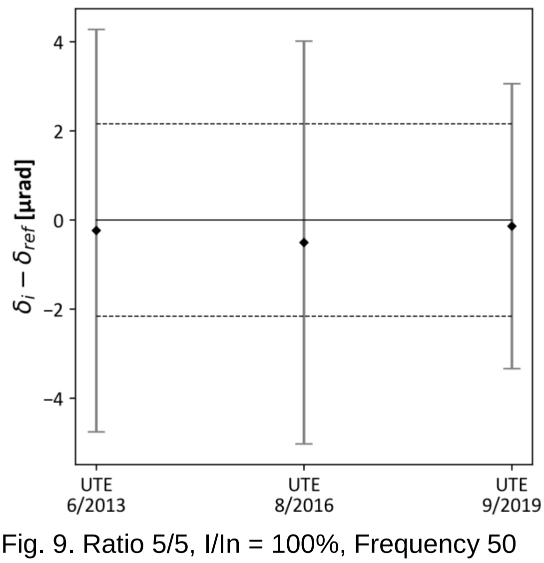

Fig. 9. Ratio 5/5, I/In = 100%, Frequency 50 Hz, Phase displacement drift

7.2 All results of the participant laboratories are shown in Tables 8 to 16. These show the differences between the informed values and the CRV. All data are expressed in μA/A and μrad, although some of them were informed in other units.

Table 8. Current error and phase displacement deviations from reference values at 50 Hz.

		UTE (2013)				UTE (2016)				INTI				PTB				UTE (2019)			
Ratio	I/In	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	μA/A	μA/A	μrad	μrad	μA/A	μA/A	μrad	μrad	μA/A	μA/A	μrad	μrad	μA/A	μA/A	μrad	μrad	μA/A	μA/A	μrad	μrad
5/5	120	0,6	4,5	-0,4	4,5	-0,1	4,5	-0,6	4,5	-1,6	15,0	2,9	15,0	0,0	3,0	0,0	3,0	0,1	3,2	-0,2	3,2
	100	0,6	4,5	-0,2	4,5	0,0	4,5	-0,5	4,5	-1,7	15,0	3,1	15,0	0,0	3,0	0,0	3,0	0,0	3,2	-0,1	3,2
	20	0,5	4,5	-0,5	4,5	-0,1	4,5	-0,8	4,5	-0,3	15,0	3,0	15,0	0,0	3,0	0,1	3,0	0,0	3,2	-0,2	3,2
	5	0,0	4,5	-0,8	4,5	-0,3	4,5	-1,1	4,5	-0,7	15,0	3,5	15,0	0,1	3,0	0,3	3,0	-0,1	3,2	-0,4	3,2
10/5	120	0,9	4,5	-0,3	4,5	-0,1	4,5	-1,0	4,5	-1,7	15,0	-2,4	15,0	0,1	3,0	0,2	3,0	0,0	3,2	-0,1	3,2
	100	0,9	4,5	-0,2	4,5	-0,1	4,5	-0,8	4,5	-1,8	15,0	-2,3	15,0	0,3	3,0	0,1	3,0	-0,2	3,2	0,0	3,2
	20	0,2	4,5	-0,7	4,5	-0,6	4,5	-2,0	4,5	-0,9	15,0	-1,8	15,0	-0,4	3,0	0,3	3,0	0,6	3,4	-0,3	3,2
	5	0,3	4,5	-0,8	4,5	-0,6	4,5	-4,5	4,5	-0,9	15,0	-0,1	15,0	0,0	3,0	0,4	3,0	0,0	3,2	-0,4	3,2
25/5	120	-0,1	4,5	0,4	4,5	0,5	4,5	-0,5	4,5	-2,9	15,0	-3,8	15,0	-0,2	3,0	0,0	3,0	0,3	3,2	0,2	3,2
	100	0,0	4,5	0,4	4,5	0,5	4,5	-0,4	4,5	-2,9	15,0	-3,7	15,0	-0,1	3,0	-0,1	3,0	0,3	3,2	0,3	3,2
	20	-0,2	4,5	0,2	4,5	0,2	4,5	-0,2	4,5	-2,6	15,0	-3,0	15,0	-0,2	3,0	-0,1	3,0	0,4	3,2	0,2	3,2
	5	-0,4	4,5	-0,3	4,5	0,7	4,5	-0,8	4,5	-2,4	15,0	-2,0	15,0	-0,4	3,0	0,1	3,0	0,6	3,2	0,0	3,2
50/5	120	0,6	6,4	0,4	6,4	0,8	6,4	-0,7	6,4	-4,2	15,0	-0,6	15,0	-0,1	3,0	-0,1	3,0	0,3	3,2	0,1	3,2
	100	0,5	6,4	0,4	6,4	0,7	6,4	-0,7	6,4	-5,3	15,0	-0,6	15,0	-0,2	3,0	-0,1	3,0	0,4	3,2	0,1	3,2
	20	0,5	6,4	0,2	6,4	0,5	6,4	-0,5	6,4	-3,8	15,0	-1,0	15,0	-0,2	3,0	0,0	3,0	0,4	3,2	0,1	3,2
	5	0,6	6,4	0,1	6,4	0,5	6,4	0,2	6,4	-4,7	15,0	0,0	15,0	-0,1	3,0	0,0	3,0	0,4	3,2	0,0	3,2

Ratio	I/In	UTE (2013)				UTE (2016)				INTI				PTB				UTE (2019)			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
100/5	120	1,1	7,8	1,5	7,8	0,4	7,8	-1,1	7,8	-4,3	15,0	4,0	15,0	0,3	3,0	-0,2	3,0	-0,2	3,2	0,1	3,2
	100	1,0	7,8	1,5	7,8	0,3	7,8	-1,1	7,8	-4,4	15,0	6,0	15,0	0,3	3,0	-0,2	3,0	-0,2	3,2	0,0	3,2
	20	0,9	7,8	0,6	7,8	0,5	7,8	-1,0	7,8	-2,9	15,0	11,3	15,0	0,2	3,0	-0,3	3,0	-0,1	3,2	-0,1	3,2
	5	0,5	7,8	0,2	7,8	0,7	7,8	-1,1	7,8	-1,7	15,0	10,7	15,0	-0,1	3,0	-0,2	3,0	0,2	3,2	-0,3	3,2
250/5	120	2,1	9,0	2,3	9,0	3,2	9,0	0,5	9,0	-6,0	15,0	8,9	20,0	0,4	3,0	0,0	3,0	-0,2	3,2	-0,2	3,2
	100	2,0	9,0	2,3	9,0	3,1	9,0	0,5	9,0	-6,1	15,0	7,8	20,0	0,3	3,0	0,0	3,0	-0,1	3,2	-0,2	3,2
	20	1,2	9,0	1,5	9,0	2,6	9,0	-0,2	9,0	-5,7	15,0	6,8	20,0	0,3	3,0	0,0	3,0	-0,1	3,2	-0,2	3,2
	5	1,0	9,1	0,9	9,0	2,8	9,1	0,7	9,0	-5,9	15,0	6,8	20,0	0,0	3,0	0,1	3,0	0,2	3,2	-0,3	3,2
500/5	120	0,5	10,1	4,7	10,1	0,2	10,1	1,2	10,1	-1,7	15,0	0,1	20,0	0,1	3,0	0,0	3,0	-0,1	3,2	0,0	3,2
	100	0,5	10,1	4,6	10,1	0,2	10,1	1,0	10,1	-1,7	15,0	-0,1	20,0	0,1	3,0	0,1	3,0	0,0	3,2	-0,2	3,2
	20	1,3	10,1	3,3	10,1	0,7	10,1	-0,3	10,1	-1,4	15,0	-0,4	20,0	-0,2	3,0	0,1	3,0	0,3	3,2	-0,1	3,2
	5	1,1	10,1	3,0	10,1	1,3	10,1	-0,6	10,1	-1,9	15,0	0,7	20,0	-0,2	3,0	0,0	3,0	0,3	3,2	-0,1	3,2
1000/5	120	2,4	11,1	3,8	11,1	2,8	11,1	0,9	11,1	-5,6	15,0	6,0	20,0	0,4	3,0	-0,3	3,0	-0,3	3,9	0,3	3,9
	100	2,6	11,1	3,7	11,1	3,1	11,1	0,9	11,1	-6,4	15,0	5,9	20,0	0,2	3,0	-0,3	3,0	0,0	3,9	0,3	3,9
	20	2,7	11,1	2,7	11,1	2,4	11,1	0,5	11,1	-5,8	15,0	6,4	20,0	-0,5	3,0	-0,5	3,0	1,2	3,9	0,6	3,9
	5	1,8	11,1	2,0	11,1	1,5	11,1	-0,2	11,1	-6,3	15,0	5,2	20,0	-0,3	3,0	-0,6	3,0	1,0	4,0	0,8	3,9

Table 9. Current error and phase displacement deviations from reference values at 60 Hz for ratio 5/5.

Ratio	I/In	UTE (2013)				INMETRO				INM				CENAMEP				CFE LAPEM			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
5/5	120	0,5	4,5	-0,4	4,5	-4,5	45,0	-7,9	47,0	6,5	96,0	-24,9	163,2	19,2	74,5	14,3	112,9	-180,5	230,0	407,3	349,1
	100	0,5	4,5	-0,4	4,5	-3,6	45,0	-10,9	47,0	5,4	96,0	-34,9	163,2	19,3	74,5	14,3	112,9	-180,6	230,0	407,3	349,1
	20	0,3	4,5	-0,7	4,5	-8,2	45,0	-7,1	47,0	-41,2	96,0	-176,1	165,9	19,9	74,5	10,8	112,9	-181,2	230,0	378,0	349,1
	5	-0,3	4,5	-1,4	4,5	-16,6	64,0	-7,0	70,0	-128,6	107,8	-296,0	175,7	21,6	74,5	0,9	112,9	-172,6	230,0	377,2	349,1

Ratio	I/In	UTE (2016)				INTI				PTB				UTE (2019)			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
5/5	120	-0,2	4,5	-0,6	4,5	-2,5	15,0	3,1	15,0	0,0	3,0	0,0	3,0	0,1	3,2	-0,1	3,2
	100	-0,1	4,5	-0,7	4,5	-2,6	15,0	3,1	15,0	0,1	3,0	0,0	3,0	0,0	3,2	-0,1	3,2
	20	-0,3	4,5	-1,0	4,5	-2,2	15,0	3,9	15,0	0,0	3,0	-0,1	3,0	0,1	3,2	0,0	3,2
	5	-0,7	4,5	-1,8	4,5	-2,6	15,0	3,0	15,0	0,0	3,0	-0,5	3,0	0,1	3,2	0,4	3,2

Table 10. Current error and phase displacement deviations from reference values at 60 Hz for ratio 10/5.

Ratio	I/In	UTE (2013)				INMETRO				INM				CENAMEP				CFE LAPEM			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
10/5	120	0,8	4,5	-0,4	4,5	-4,7	45,0	-9,4	47,0	9,3	96,0	-65,4	163,1	18,6	74,5	14,1	112,9	-210,7	230,0	466,0	349,1
	100	0,8	4,5	-0,4	4,5	-3,8	45,0	-12,4	47,0	8,2	96,0	-84,4	163,2	18,7	74,5	14,2	112,9	-200,8	230,0	466,1	349,1
	20	0,5	4,5	-0,6	4,5	-8,4	45,0	-7,6	47,0	-24,4	96,0	-184,6	163,2	18,9	74,5	12,0	112,9	-201,4	230,0	465,8	349,1
	5	0,2	4,5	-1,3	4,5	-16,5	64,0	-8,6	70,0	-49,5	107,7	-255,6	175,7	19,6	74,5	7,6	112,9	-182,5	230,0	406,7	349,1

Ratio	I/In	UTE (2016)				INTI				PTB				UTE (2019)			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
10/5	120	-0,5	4,5	-0,7	4,5	-2,7	15,0	-1,4	15,0	0,0	3,0	0,1	3,0	0,1	3,2	0,0	3,2
	100	-0,4	4,5	-0,6	4,5	-2,8	15,0	-1,4	15,0	0,0	3,0	0,0	3,0	0,2	3,2	0,0	3,2
	20	-0,5	4,5	-1,6	4,5	-2,4	15,0	-0,6	15,0	-0,1	3,0	0,1	3,0	0,2	3,2	0,0	3,2
	5	-0,4	4,5	-4,3	4,5	-2,5	15,0	-0,6	15,0	0,0	3,0	-0,2	3,0	0,2	3,2	0,2	3,2

Table 11. Current error and phase displacement deviations from reference values at 60 Hz for ratio 25/5.

Ratio	I/In	UTE (2013)				INMETRO				INM				CENAMEP				CFE LAPEM			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
25/5	120	-0,3	4,5	0,0	4,5	-6,8	45,0	-7,1	47,0	-19,8	96,0	-17,1	163,1	19,3	74,5	13,4	112,9	-191,8	230,0	435,3	349,1
	100	-0,3	4,5	-0,1	4,5	-5,9	45,0	-9,2	47,0	-20,9	96,0	-8,2	162,7	19,4	74,5	13,4	112,9	-191,9	230,0	435,2	349,1
	20	0,0	4,5	-0,2	4,5	-4,0	45,0	-1,4	47,0	-56,0	96,0	-127,4	163,1	19,1	74,5	12,0	112,9	-202,0	230,0	464,0	349,1
	5	-0,4	4,5	-0,8	4,5	-6,8	64,0	0,4	70,0	-100,8	107,8	-223,6	173,7	17,2	74,5	10,1	112,9	-213,8	230,0	491,9	349,1

Ratio	I/In	UTE (2016)				INTI				PTB				UTE (2019)			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
25/5	120	0,3	4,5	-0,8	4,5	-3,8	15,0	-2,1	15,0	-0,1	3,0	-0,4	3,0	0,2	3,2	0,5	3,2
	100	0,2	4,5	-0,7	4,5	-3,9	15,0	-2,2	15,0	-0,1	3,0	-0,5	3,0	0,2	3,2	0,6	3,2
	20	0,4	4,5	-0,6	4,5	-4,0	15,0	-1,4	15,0	0,1	3,0	-0,5	3,0	0,0	3,2	0,6	3,2
	5	0,5	4,5	-1,0	4,5	-3,8	15,0	-1,6	15,0	-0,3	3,0	-0,8	3,0	0,6	3,2	0,9	3,2

Table 12. Current error and phase displacement deviations from reference values at 60 Hz for ratio 50/5.

Ratio	I/In	UTE (2013)				INMETRO				INM				CENAMEP				CFE LAPEM			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
50/5	120	0,3	6,4	0,6	6,4	-0,9	45,0	-12,0	47,0	0,1	96,0	-46,0	162,6	24,1	74,5	12,6	112,9	-201,9	230,0	466,4	349,1
	100	0,3	6,4	0,5	6,4	1,1	45,0	-14,0	47,0	-1,9	96,0	-63,0	163,1	24,2	74,5	12,7	112,9	-201,9	230,0	437,3	349,1
	20	0,4	6,4	0,4	6,4	-0,3	45,0	-7,4	47,0	-33,3	96,0	-188,4	161,0	23,7	74,5	11,1	112,9	-202,3	230,0	436,9	349,1
	5	0,5	6,4	-0,1	6,4	-1,8	64,0	-11,6	70,0	-100,8	107,7	-323,6	175,2	22,0	74,5	10,0	112,9	-193,8	230,0	435,7	349,1

Ratio	I/In	UTE (2016)				INTI				PTB				UTE (2019)			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
50/5	120	0,6	6,4	-0,9	6,4	-4,9	15,0	-1,0	15,0	0,1	3,0	-0,3	3,0	0,1	3,2	0,4	3,2
	100	0,5	6,4	-0,9	6,4	-4,9	15,0	-1,0	15,0	0,1	3,0	-0,2	3,0	0,1	3,2	0,3	3,2
	20	0,3	6,4	-0,5	6,4	-5,3	15,0	-0,4	15,0	0,1	3,0	-0,3	3,0	0,1	3,2	0,4	3,2
	5	0,2	6,4	-0,6	6,4	-4,8	15,0	-0,6	15,0	0,0	3,0	-0,5	3,0	0,2	3,2	0,6	3,2

Table 13. Current error and phase displacement deviations from reference values at 60 Hz for ratio 100/5.

Ratio	I/In	UTE (2013)				INMETRO				INM				CENAMEP				CFE LAPEM			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
100/5	120	0,7	7,8	1,1	7,8	-0,3	45,0	-6,9	47,0	-42,3	96,0	-8,9	162,7	26,4	74,5	13,5	112,9	-181,3	230,0	347,1	349,1
	100	0,5	7,8	1,1	7,8	0,5	45,0	-8,9	47,0	-40,5	96,0	-26,9	163,2	26,6	74,5	13,5	112,9	-181,5	230,0	318,1	349,1
	20	0,6	7,8	0,4	7,8	1,2	45,0	-3,8	47,0	-66,8	96,0	-98,8	162,7	26,6	74,5	11,4	112,9	-171,8	230,0	318,2	349,1
	5	0,1	7,8	0,2	7,8	0,8	64,0	-5,3	70,0	-103,2	107,8	-186,3	175,6	24,5	74,5	10,8	112,9	-173,2	230,0	463,1	349,1

Ratio	I/In	UTE (2016)				INTI				PTB				UTE (2019)			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
100/5	120	0,0	7,8	-1,0	7,8	-5,3	15,0	7,1	15,0	0,2	3,0	-0,3	3,0	0,0	3,2	0,1	3,2
	100	-0,1	7,8	-1,0	7,8	-5,5	15,0	10,1	15,0	0,2	3,0	-0,4	3,0	0,0	3,2	0,0	3,2
	20	0,3	7,8	-1,1	7,8	-4,8	15,0	12,2	15,0	0,2	3,0	-0,5	3,0	0,0	3,2	0,0	3,2
	5	0,2	7,8	-2,0	7,8	-4,2	15,0	10,7	15,0	0,0	3,0	-0,5	3,0	0,2	3,2	0,1	3,2

Table 14. Current error and phase displacement deviations from reference values at 60 Hz for ratio 250/5.

Ratio	I/In	UTE (2013)				INMETRO				INM				CENAMEP				CFE LAPEM			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
250/5	120	1,3	9,0	2,4	9,0	-5,2	45,0	-10,1	47,0	-40,2	96,0	-14,1	162,0	24,0	74,5	9,8	112,9	-20,2	230,0	-2,1	349,1
	100	1,3	9,0	2,4	9,0	-4,2	45,0	-11,1	47,0	-41,2	96,0	-28,1	163,1	24,2	74,5	9,9	112,9	-70,2	230,0	114,3	349,1
	20	0,7	9,0	1,8	9,0	-2,6	45,0	-7,1	47,0	-63,6	96,0	-74,1	162,0	23,9	74,5	8,7	112,9	-140,6	230,0	259,7	349,1
	5	0,8	9,0	1,4	9,0	-2,1	64,0	-11,9	70,0	-91,1	107,8	-98,9	175,6	21,2	74,5	9,1	112,9	-222,1	230,0	346,2	349,1

Ratio	I/In	UTE (2016)				INTI				PTB				UTE (2019)			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
250/5	120	2,5	9,0	0,3	9,0	-6,2	15,0	10,9	20,0	0,3	3,0	0,0	3,0	-0,1	3,2	-0,3	3,2
	100	2,4	9,0	0,3	9,0	-5,2	15,0	11,9	20,0	0,2	3,0	-0,1	3,0	0,0	3,2	-0,2	3,2
	20	2,2	9,0	-0,2	9,0	-5,6	15,0	10,9	20,0	0,3	3,0	0,0	3,0	-0,1	3,2	-0,2	3,2
	5	2,7	9,0	1,0	9,0	-5,1	15,0	10,1	20,0	0,4	3,0	0,0	3,0	-0,2	3,2	-0,3	3,2

Table 15. Current error and phase displacement deviations from reference values at 60 Hz for ratio 500/5.

Ratio	I/In	UTE (2013)				INMETRO				INM				CENAMEP				CFE LAPEM			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
500/5	120	-0,2	10,1	4,5	10,1	0,5	45,0	-0,2	47,0	-35,5	96,0	-1,2	162,0	21,1	80,1	15,9	116,7	-12,5	230,0	-57,4	349,1
	100	-0,3	10,1	4,4	10,1	1,4	45,0	-4,3	47,0	-44,6	96,0	-8,3	161,0	21,3	80,1	15,6	116,7	-2,6	230,0	-57,5	349,1
	20	0,8	10,1	3,2	10,1	1,9	45,0	-1,5	47,0	-66,1	96,0	-38,5	162,0	21,0	80,1	12,1	116,7	7,9	230,0	-87,7	349,1
	5	1,1	10,1	2,5	10,1	0,7	64,0	-2,7	70,0	-92,3	107,8	75,3	175,2	16,4	80,1	11,3	116,7	26,7	230,0	-118,0	349,1

Ratio	I/In	UTE (2016)				INTI				PTB				UTE (2019)			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
500/5	120	-0,4	10,1	1,4	10,1	-1,5	15,0	-2,2	20,0	0,0	3,0	0,0	3,0	0,1	3,2	0,0	3,2
	100	-0,5	10,1	1,3	10,1	-1,6	15,0	-2,3	20,0	-0,1	3,0	0,1	3,0	0,2	3,2	0,0	3,2
	20	0,2	10,1	0,1	10,1	-2,1	15,0	-3,5	20,0	-0,1	3,0	-0,1	3,0	0,2	3,2	0,1	3,2
	5	1,0	10,1	-0,8	10,1	-1,3	15,0	-2,7	20,0	-0,2	3,0	-0,2	3,0	0,3	3,2	0,3	3,2

Table 16. Current error and phase displacement deviations from reference values at 60 Hz for ratio 1000/5.

Ratio	I/In	UTE (2013)				INMETRO				INM				CENAMEP				CFE LAPEM			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
1000/5	120	2,2	11,1	3,9	11,1	-3,5	45,0	-6,1	47,0	-36,5	96,0	-3,1	163,1	20,5	80,1	14,8	116,7	-12,5	230,0	-28,2	349,1
	100	2,5	11,1	3,8	11,1	-1,1	45,0	-8,2	47,0	-43,1	96,0	-6,2	162,7	21,1	80,1	14,7	116,7	-12,1	230,0	-28,2	349,1
	20	3,3	11,1	3,6	11,1	-0,1	45,0	-1,5	47,0	-69,1	96,0	-36,5	163,1	21,8	80,1	11,9	116,7	-11,1	230,0	-58,7	349,1
	5	3,5	11,1	4,0	11,1	-1,7	64,0	-4,7	70,0	-100,7	107,7	80,3	174,6	16,9	80,1	11,4	116,7	-22,7	230,0	-59,8	349,1

Ratio	I/In	UTE (2016)				INTI				PTB				UTE (2019)			
		$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$	$\varepsilon_i - \varepsilon_{ref}$	$U\varepsilon_i$	$\delta_i - \delta_{ref}$	$U\delta_i$
	%	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad	µA/A	µA/A	µrad	µrad
1000/5	120	2,1	11,1	1,4	11,1	-6,5	15,0	3,9	20,0	0,4	3,0	-0,2	3,0	-0,3	3,9	0,1	3,9
	100	2,4	11,1	1,3	11,1	-6,1	15,0	3,8	20,0	0,2	3,0	-0,3	3,0	0,1	3,9	0,3	3,9
	20	2,5	11,1	0,9	11,1	-5,1	15,0	4,5	20,0	-0,1	3,0	-0,4	3,0	0,6	3,9	0,5	3,9
	5	1,9	11,1	0,3	11,1	-5,7	15,0	2,3	20,0	-0,1	3,0	-0,6	3,0	0,5	3,9	0,9	3,9

7.3 The following figures show selected results. The dotted line indicates the uncertainty of the CRV.

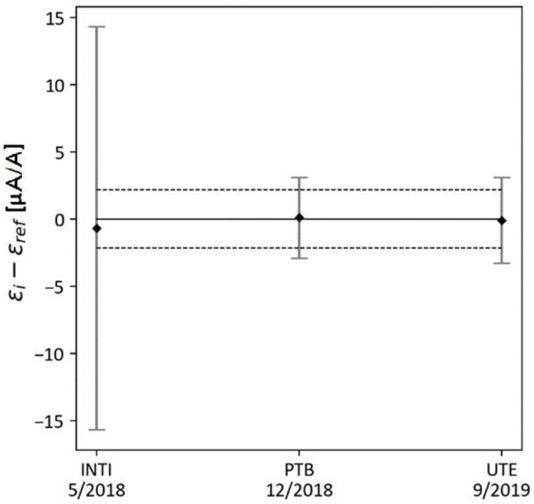

Fig. 10. Ratio 5/5, I/In = 5%, Frequency 50 Hz, Current error comparison results

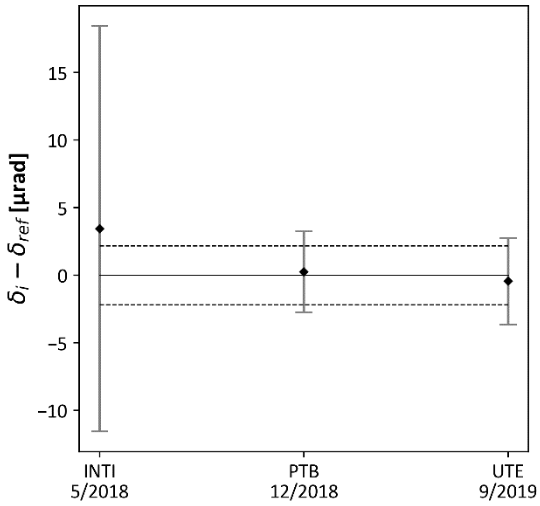

Fig. 11. Ratio 5/5, I/In = 5%, Frequency 50 Hz, Phase displacement comparison results

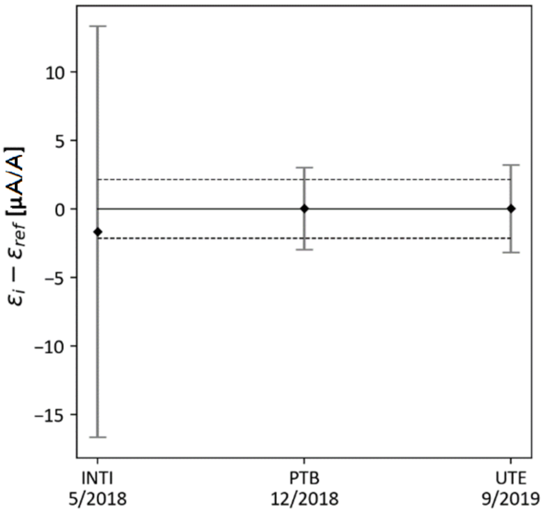

Fig. 12. Ratio 5/5, I/In = 100%, Frequency 50 Hz, Current error comparison results

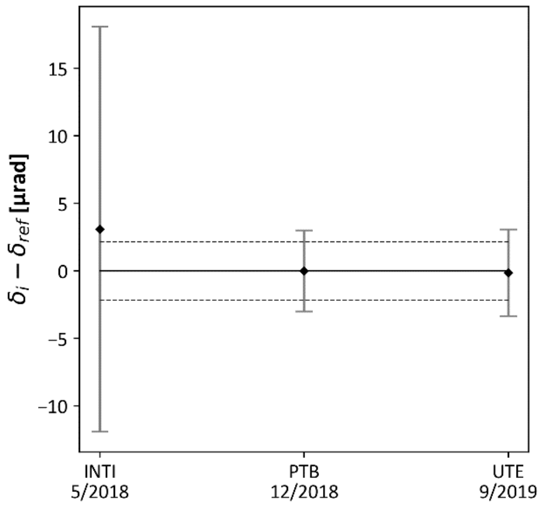

Fig. 13. Ratio 5/5, I/In = 100%, Frequency 50 Hz, Phase displacement comparison results

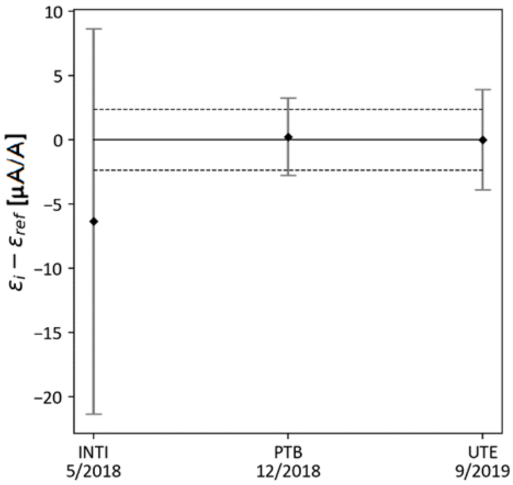

Fig. 14. Ratio 1000/5, I/In = 100%, Frequency 50 Hz, Current error comparison results

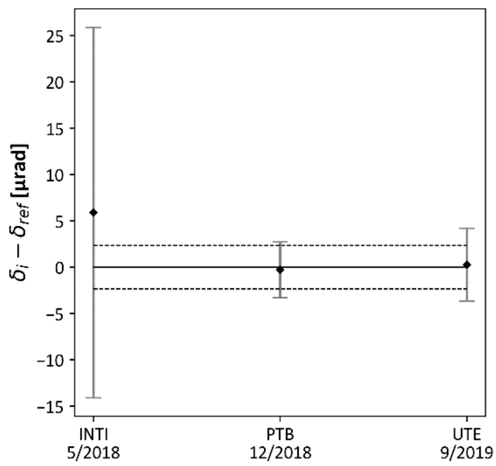

Fig. 15. Ratio 1000/5, I/In = 100%, Frequency 50 Hz, Phase displacement comparison results

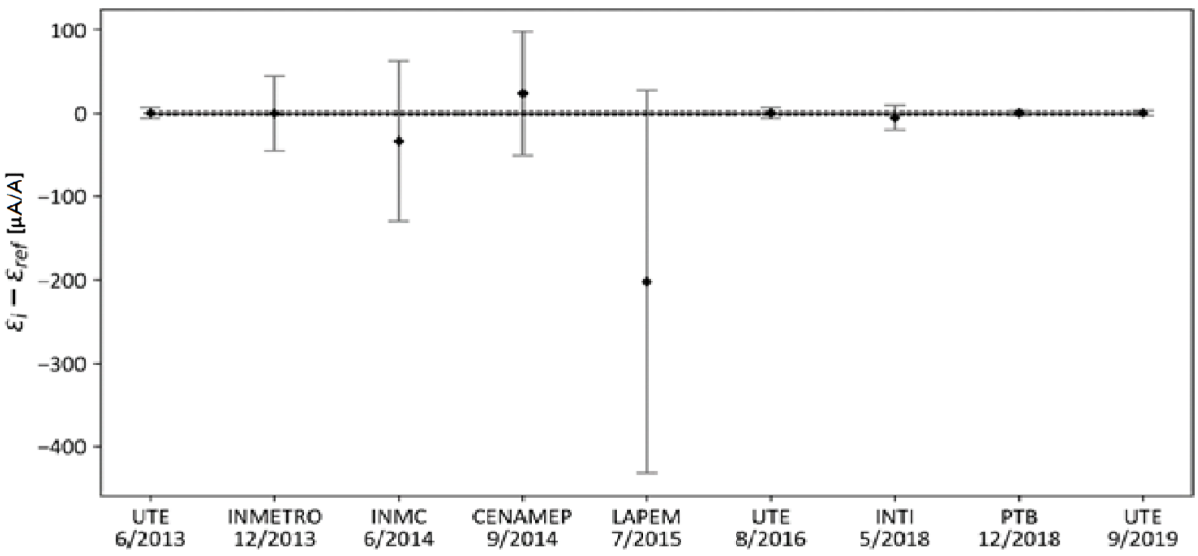

Fig. 16. Ratio 50/5, I/In = 20%, Frequency 60 Hz, Current error comparison results

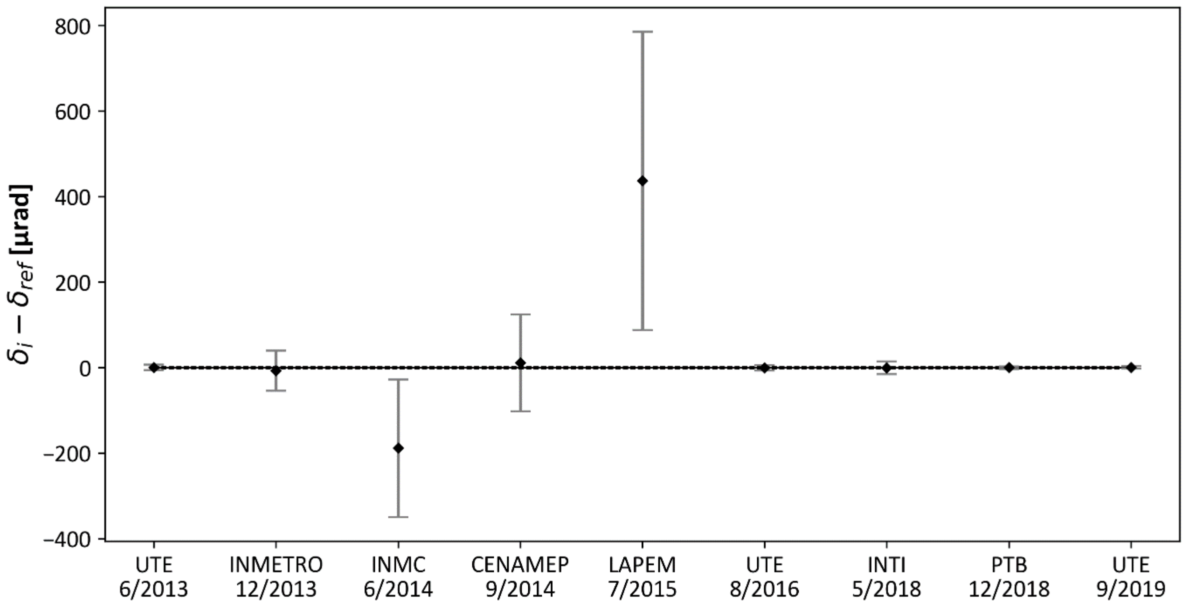

Fig. 17. Ratio 50/5, I/In = 20%, Frequency 60 Hz, Phase displacement comparison results

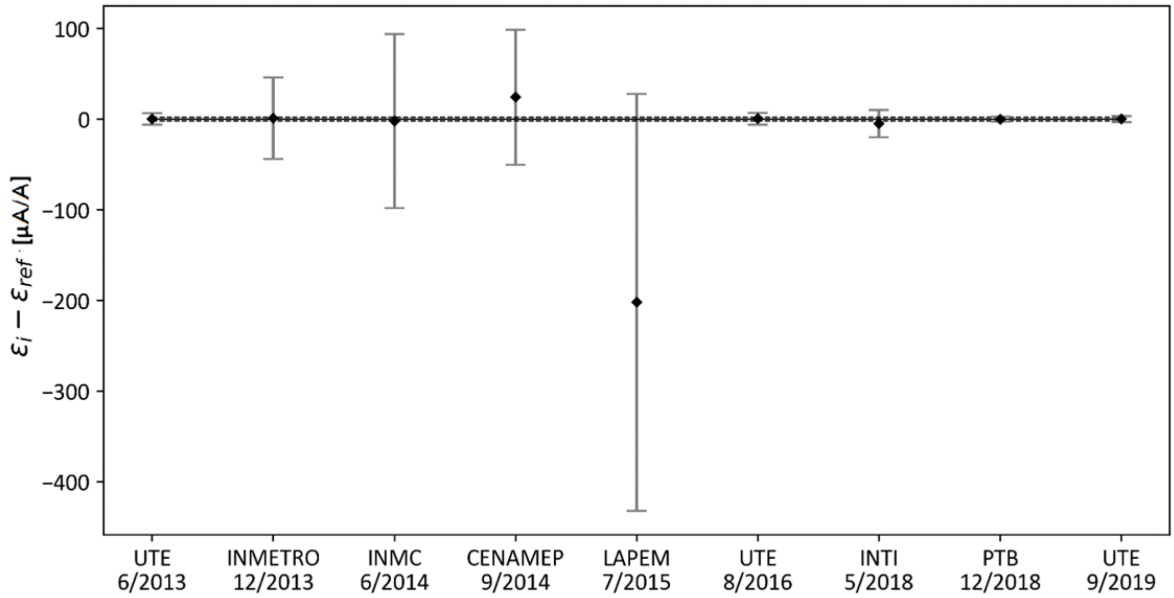

Fig. 18. Ratio 50/5, I/In = 100%, Frequency 60 Hz, Current error comparison results

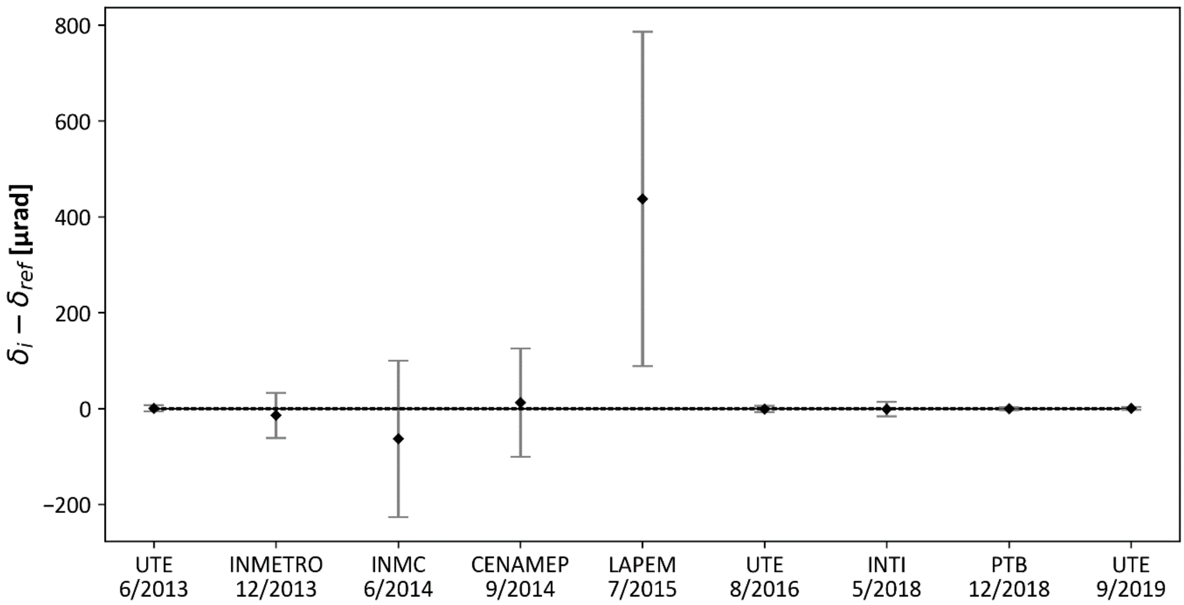

Fig. 19. Ratio 50/5, I/In = 100%, Frequency 60 Hz, Phase displacement comparison results

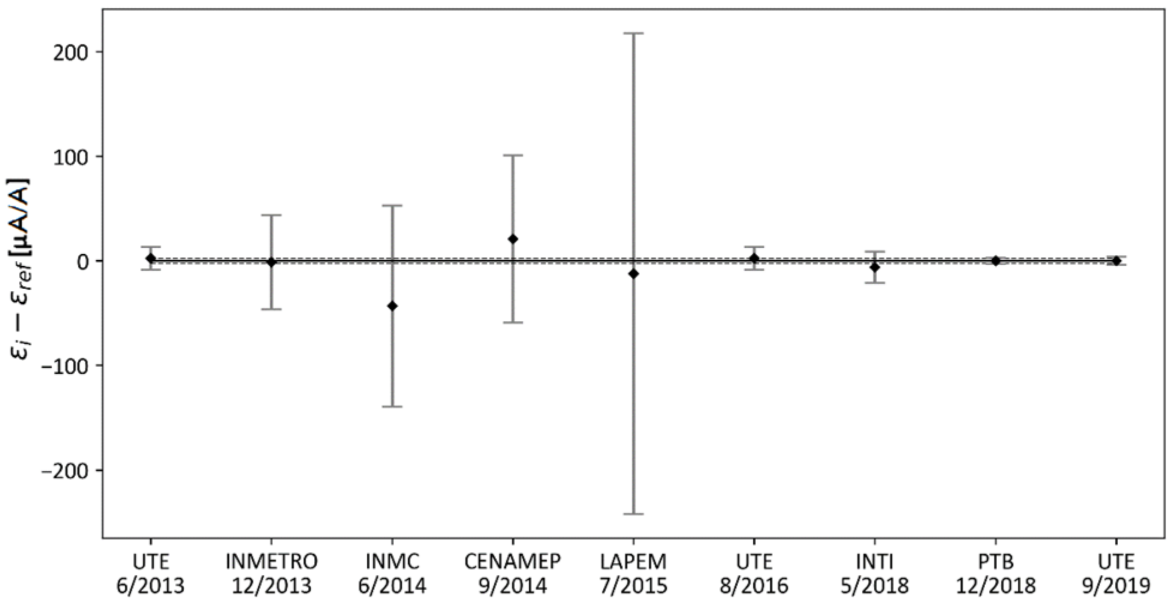

Fig. 20. Ratio 1000/5, I/In = 100%, Frequency 60 Hz, Current error comparison results

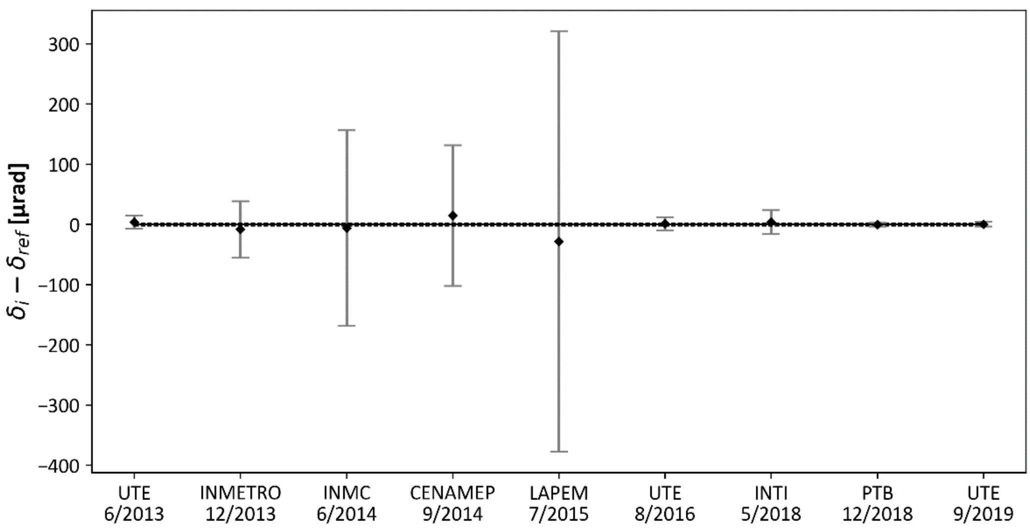

Fig. 21. Ratio 1000/5, I/In = 100%, Frequency 60 Hz, Phase displacement comparison results

8. Conclusions

A useful intercomparison of current ratio using CTs, among several laboratories, has been conducted. The ratio ranges were from 5:5 to 1000:5, at 50 Hz and 60 Hz. As methods and standards were very different for each participant, declared uncertainty values showed large dispersion. The range covers from 3 µA/A to 230 µA/A for ratio error, and from 3 µrad to 249 µrad for phase displacement.

As traveling standard, an electronically compensated CT was used. It had low dependence on ambient parameters and very stable behavior. Both characteristics were very important because of the long time required by the comparison, due to hard difficulties in customs procedures.

Results provided by the laboratories indicate very good agreement, with few exceptions. In total, there were 896 comparison values and 97% of them were compatible with the CRV. Some laboratories presented a certain amount of outlying values that suggests their measurement methods or uncertainty budget should be reevaluated. Other laboratories provided very accurate error values considering their declared uncertainties. The results of this comparison provide them the opportunity to reduce their uncertainty declarations.

The two laboratories with the lowest uncertainties showed a very good agreement. The degree of equivalences are in the order of 0.5 µA/A - µrad, with an uncertainty of 4 µA/A - µrad.

References

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Annex A - Measurement values

The measurement results, as reported by each laboratory, are shown below.

Table 17. UTE

Freq. Hz	Ratio	% In	UTE 2013 εi µA/A	UTE 2013 U(εi) µA/A	UTE 2013 δi in µrad	UTE 2013 U(δi) µrad	UTE 2016 εi µA/A	UTE 2016 U(εi) µA/A	UTE 2016 δi in µrad	UTE 2016 U(δi) µrad	UTE 2019 εi µA/A	UTE 2019 U(εi) µA/A	UTE 2019 δi in µrad	UTE 2019 U(δi) µrad
50	5/5	120	1,2	4,5	-0,3	4,5	0,5	4,5	-0,5	4,5	0,7	3,2	-0,1	3,2
50		100	1,3	4,5	-0,3	4,5	0,7	4,5	-0,6	4,5	0,7	3,2	-0,2	3,2
50		20	1,7	4,5	-0,5	4,5	1,2	4,5	-0,7	4,5	1,3	3,2	-0,2	3,2
50		5	2,7	4,5	-0,3	4,5	2,4	4,5	-0,5	4,5	2,6	3,2	0,1	3,2
50	10/5	120	1,6	4,5	-0,9	4,5	0,6	4,5	-1,6	4,5	0,7	3,2	-0,8	3,2
50		100	1,8	4,5	-0,9	4,5	0,8	4,5	-1,5	4,5	0,6	3,2	-0,7	3,2
50		20	2,1	4,5	-1,0	4,5	1,3	4,5	-2,2	4,5	2,5	3,4	-0,6	3,2
50		5	3,2	4,5	-0,7	4,5	2,3	4,5	-4,4	4,5	2,9	3,2	-0,3	3,2
50	25/5	120	1,8	4,5	1,2	4,5	2,4	4,5	0,3	4,5	2,2	3,2	1,1	3,2
50		100	1,9	4,5	1,1	4,5	2,5	4,5	0,3	4,5	2,2	3,2	1,0	3,2
50		20	2,4	4,5	1,1	4,5	2,8	4,5	0,8	4,5	3,0	3,2	1,2	3,2
50		5	4,0	4,5	1,7	4,5	5,1	4,5	1,3	4,5	5,0	3,2	2,1	3,2
50	50/5	120	2,8	6,4	-1,0	6,4	3,0	6,4	-2,1	6,4	2,5	3,2	-1,3	3,2
50		100	2,8	6,4	-1,0	6,4	3,0	6,4	-2,1	6,4	2,7	3,2	-1,3	3,2
50		20	3,3	6,4	-0,7	6,4	3,3	6,4	-1,5	6,4	3,3	3,2	-0,9	3,2
50		5	5,3	6,4	0,1	6,4	5,2	6,4	0,3	6,4	5,1	3,2	0,1	3,2
50	100/5	120	2,3	7,8	3,5	7,8	1,7	7,8	1,0	7,8	1,1	3,2	2,1	3,2
50		100	2,3	7,8	3,5	7,8	1,7	7,8	1,0	7,8	1,2	3,2	2,0	3,2
50		20	2,8	7,8	2,4	7,8	2,4	7,8	0,7	7,8	1,8	3,2	1,6	3,2
50		5	4,2	7,8	2,5	7,8	4,4	7,8	1,2	7,8	3,9	3,2	2,0	3,2
50	250/5	120	2,1	9,0	4,5	9,0	3,1	9,0	2,7	9,0	-0,2	3,2	2,0	3,2
50		100	2,1	9,0	4,5	9,0	3,1	9,0	2,7	9,0	-0,1	3,2	2,0	3,2
50		20	1,9	9,0	3,7	9,0	3,3	9,0	2,0	9,0	0,7	3,2	2,0	3,2
50		5	3,9	9,1	4,1	9,0	5,7	9,1	3,9	9,0	3,1	3,2	2,9	3,2
50	500/5	120	3,2	10,1	3,6	10,1	2,9	10,1	0,1	10,1	2,6	3,2	-1,1	3,2
50		100	3,2	10,1	3,6	10,1	2,9	10,1	0,1	10,1	2,7	3,2	-1,1	3,2
50		20	3,7	10,1	3,7	10,1	3,1	10,1	0,1	10,1	2,6	3,2	0,3	3,2
50		5	5,1	10,1	4,2	10,1	5,2	10,1	0,6	10,1	4,3	3,2	1,2	3,2
50	1000/5	120	5,0	11,1	2,8	11,1	5,4	11,1	0,0	11,1	2,3	3,9	-0,7	3,9
50		100	5,0	11,1	2,8	11,1	5,4	11,1	0,0	11,1	2,4	3,9	-0,6	3,9
50		20	4,5	11,1	3,3	11,1	4,2	11,1	1,1	11,1	2,9	3,9	1,2	3,9
50		5	5,2	11,1	3,8	11,1	4,8	11,1	1,5	11,1	4,4	4,0	2,6	3,9

Freq. Hz	Ratio	% In	UTE 2013 εi µA/A	UTE 2013 U(εi) µA/A	UTE 2013 δi in µrad	UTE 2013 U(δi) µrad	UTE 2016 εi µA/A	UTE 2016 U(εi) µA/A	UTE 2016 δi in µrad	UTE 2016 U(δi) µrad	UTE 2019 εi µA/A	UTE 2019 U(εi) µA/A	UTE 2019 δi in µrad	UTE 2019 U(δi) µrad
60	5/5	120	1,0	4,5	-0,5	4,5	0,3	4,5	-0,6	4,5	0,6	3,2	-0,1	3,2
60		100	1,1	4,5	-0,5	4,5	0,5	4,5	-0,7	4,5	0,7	3,2	-0,1	3,2
60		20	1,4	4,5	-0,6	4,5	0,9	4,5	-0,8	4,5	1,2	3,2	0,1	3,2
60		5	2,2	4,5	-0,4	4,5	1,9	4,5	-0,9	4,5	2,6	3,2	1,3	3,2
60	10/5	120	1,5	4,5	-0,9	4,5	0,2	4,5	-1,3	4,5	0,8	3,2	-0,6	3,2
60		100	1,6	4,5	-1,0	4,5	0,4	4,5	-1,3	4,5	1,0	3,2	-0,6	3,2
60		20	1,9	4,5	-1,0	4,5	0,9	4,5	-1,9	4,5	1,6	3,2	-0,4	3,2
60		5	2,7	4,5	-0,7	4,5	2,1	4,5	-3,8	4,5	2,7	3,2	0,8	3,2
60	25/5	120	1,5	4,5	1,1	4,5	2,1	4,5	0,3	4,5	2,0	3,2	1,6	3,2
60		100	1,6	4,5	1,1	4,5	2,1	4,5	0,4	4,5	2,1	3,2	1,8	3,2
60		20	1,9	4,5	1,2	4,5	2,3	4,5	0,8	4,5	2,0	3,2	2,0	3,2
60		5	3,5	4,5	1,7	4,5	4,4	4,5	1,5	4,5	4,4	3,2	3,5	3,2
60	50/5	120	2,2	6,4	-0,4	6,4	2,4	6,4	-1,9	6,4	2,0	3,2	-0,7	3,2
60		100	2,2	6,4	-0,4	6,4	2,4	6,4	-1,9	6,4	2,0	3,2	-0,6	3,2
60		20	2,7	6,4	-0,1	6,4	2,7	6,4	-1,1	6,4	2,5	3,2	-0,1	3,2
60		5	4,3	6,4	0,5	6,4	4,0	6,4	0,1	6,4	4,1	3,2	1,3	3,2
60	100/5	120	2,0	7,8	3,0	7,8	1,4	7,8	0,9	7,8	1,4	3,2	2,0	3,2
60		100	2,0	7,8	3,0	7,8	1,4	7,8	0,9	7,8	1,5	3,2	1,9	3,2
60		20	2,4	7,8	2,2	7,8	2,1	7,8	0,7	7,8	1,7	3,2	1,8	3,2
60		5	3,3	7,8	2,5	7,8	3,3	7,8	0,2	7,8	3,3	3,2	2,3	3,2
60	250/5	120	1,5	9,0	4,5	9,0	2,6	9,0	2,4	9,0	0,1	3,2	1,8	3,2
60		100	1,5	9,0	4,5	9,0	2,6	9,0	2,4	9,0	0,3	3,2	1,8	3,2
60		20	1,3	9,0	3,9	9,0	2,8	9,0	1,9	9,0	0,5	3,2	1,9	3,2
60		5	2,9	9,0	4,3	9,0	4,8	9,0	3,9	9,0	1,9	3,2	2,6	3,2
60	500/5	120	2,3	10,1	3,7	10,1	2,1	10,1	0,6	10,1	2,7	3,2	-0,8	3,2
60		100	2,3	10,1	3,7	10,1	2,1	10,1	0,6	10,1	2,8	3,2	-0,7	3,2
60		20	2,9	10,1	3,7	10,1	2,3	10,1	0,5	10,1	2,3	3,2	0,6	3,2
60		5	4,4	10,1	4,2	10,1	4,3	10,1	0,8	10,1	3,5	3,2	1,9	3,2
60	1000/5	120	4,6	11,1	3,0	11,1	4,6	11,1	0,4	11,1	2,2	3,9	-0,8	3,9
60		100	4,6	11,1	3,0	11,1	4,6	11,1	0,4	11,1	2,3	3,9	-0,6	3,9
60		20	4,4	11,1	4,1	11,1	3,7	11,1	1,4	11,1	1,7	3,9	1,0	3,9
60		5	6,2	11,1	5,6	11,1	4,5	11,1	2,0	11,1	3,1	3,9	2,5	3,9

Table 18. INMETRO

Frequency (Hz)	Burden (VA)	Ambient Temperature (℃)	Nominal ratio	Primary current (A)	Ratio error ($\times 10^{-6}$)	Ratio error uncertainty ($\times 10^{-6}$)	Phase displacement (μrad)	Phase displacement uncertainty (μrad)
60	6	23,5	5/5	0,25	-14	64	-6	70
60	6	23,5	5/5	1	-7	45	-7	47
60	6	23,5	5/5	5	-3	45	-11	47
60	6	23,5	5/5	6	-4	45	-8	47
60	6	23,5	10/5	0,5	-14	64	-8	70
60	6	23,5	10/5	2	-7	45	-8	47
60	6	23,5	10/5	10	-3	45	-13	47
60	6	23,5	10/5	12	-4	45	-10	47
60	6	23,5	20/5	1	-3	64	3	70
60	6	23,5	20/5	4	-2	45	0	47
60	6	23,5	20/5	20	-4	45	-8	47
60	6	23,5	20/5	24	-5	45	-6	47
60	6	23,5	50/5	2,5	2	64	-11	70
60	6	23,5	50/5	10	2	45	-8	47
60	6	23,5	50/5	50	3	45	-15	47
60	6	23,5	50/5	60	1	45	-13	47
60	6	23,5	100/5	5	4	64	-3	70
60	6	23,5	100/5	20	3	45	-2	47
60	6	23,5	100/5	100	2	45	-7	47
60	6	23,5	100/5	120	1	45	-5	47
60	6	23,5	250/5	12,5	0	64	-9	70
60	6	23,5	250/5	50	-2	45	-5	47
60	6	23,5	250/5	250	-4	45	-9	47
60	6	23,5	250/5	300	-5	45	-8	47
60	6	23,5	500/5	25	4	64	-1	70
60	6	23,5	500/5	100	4	45	-1	47
60	6	23,5	500/5	500	4	45	-5	47
60	6	23,5	500/5	600	3	45	-1	47
60	6	23,5	1000/5	50	1	64	-3	70
60	6	23,5	1000/5	200	1	45	-1	47
60	6	23,5	1000/5	1000	1	45	-9	47
60	6	23,5	1000/5	1200	-1	45	-7	47

Table 19. INM

Item	Date	Time		I [A]	f [Hz]	Mean Value [µA/A]	Std. Dev [µA/A]	U Comb [µA/A]	k	Degrees of Freedom	Expanded Uncertainty [µA/A]
		Start	End								
1	2014/06/03	8:00	8:45	5	60	7	5,16	47,99	2,00	341	95,98
2		8:50	9:30	5	60	6	7,07	48,01	2,00	341	96,03
3		9:45	10:35	5	60	-40	4,83	47,98	2,00	341	95,98
4		10:50	11:45	5	60	-126	4,22	53,87	2,00	341	107,75
5	2014/06/03	13:10	13:50	10	60	10	3,16	47,97	2,00	341	95,95
6		13:55	14:35	10	60	9	4,22	47,98	2,00	341	95,96
7		14:45	15:30	10	60	-23	4,71	47,98	2,00	341	95,97
8		15:45	16:55	10	60	-47	3,16	53,86	2,00	341	107,73
9	2014/06/04	8:15	9:05	25	60	-18	4,22	47,98	2,00	341	95,96
10		9:15	10:00	25	60	-19	3,16	47,97	2,00	341	95,95
11		10:10	10:55	25	60	-54	3,16	47,97	2,00	341	95,95
12		11:00	12:10	25	60	-97	4,71	53,87	2,00	341	107,76
13	2014/06/04	13:15	14:00	50	60	2	3,16	47,97	2,00	341	95,95
14		14:15	15:10	50	60	0	3,16	47,97	2,00	341	95,95
15		15:20	16:05	50	60	-31	4,22	47,98	2,00	341	95,96
16		16:15	17:10	50	60	-97	3,16	53,86	2,00	341	107,73
17	2014/06/05	8:00	9:10	100	60	-41	3,16	47,97	2,00	341	95,95
18		9:25	10:10	100	60	-39	4,83	47,98	2,00	341	95,98
19		10:20	11:15	100	60	-65	4,22	47,98	2,00	341	95,96
20		11:25	12:20	100	60	-100	4,83	53,87	2,00	341	107,76
21	2014/06/05	13:25	14:15	250	60	-40	4,22	47,98	2,00	341	95,96
22		14:25	15:10	250	60	-41	5,68	47,99	2,00	341	95,99
23		15:25	16:10	250	60	-63	4,71	47,98	2,00	341	95,97
24		16:25	17:30	250	60	-89	4,22	53,87	2,00	341	107,75
25	2014/06/06	8:10	9:05	500	60	-33	3,16	47,97	2,00	341	95,95
26		9:15	10:10	500	60	-42	4,71	47,98	2,00	341	95,97
27		10:25	11:30	500	60	-64	3,16	47,97	2,00	341	95,95
28		11:45	12:55	500	60	-89	4,22	53,87	2,00	341	107,75
29	2014/06/06	14:00	14:55	1000	60	-34	4,22	47,98	2,00	341	95,96
30		15:10	15:55	1000	60	-41	3,16	47,97	2,00	341	95,95
31		16:10	17:05	1000	60	-68	5,27	47,99	2,00	341	95,98
32		17:15	18:05	1000	60	-98	3,16	53,86	2,00	341	107,73

Item	Date	Time		I [A]	f [Hz]	Mean Value [µrad]	Std. Dev [µrad]	U Comb [µrad]	k	Degrees of Freedom	Expanded Uncertainty [µrad]
		Start	End								
1	2014/06/03	8:00	8:45	5	60	-25	52,70	81,60	2,00	341	163,23
2		8:50	9:30	5	60	-35	52,70	81,60	2,00	341	163,23
3		9:45	10:35	5	60	-176	69,92	82,88	2,00	341	165,88
4		10:50	11:45	5	60	-295	52,70	87,84	2,00	341	175,71
5	2014/06/03	13:10	13:50	10	60	-66	51,64	81,53	2,00	341	163,10
6		13:55	14:35	10	60	-85	52,70	81,60	2,00	341	163,23
7		14:45	15:30	10	60	-185	52,70	81,60	2,00	341	163,23
8		15:45	16:55	10	60	-255	52,70	87,84	2,00	341	175,71
9	2014/06/04	8:15	9:05	25	60	-16	51,64	81,53	2,00	341	163,10
10		9:15	10:00	25	60	-7	48,30	81,32	2,00	341	162,68
11		10:10	10:55	25	60	-126	51,64	81,53	2,00	341	163,10
12		11:00	12:10	25	60	-221	31,62	86,82	2,00	341	173,66
13	2014/06/04	13:15	14:00	50	60	-47	47,71	81,29	2,00	341	162,61
14		14:15	15:10	50	60	-64	51,64	81,53	2,00	341	163,10
15		15:20	16:05	50	60	-189	31,62	80,50	2,00	341	161,02
16		16:15	17:10	50	60	-323	48,30	87,59	2,00	341	175,20
17	2014/06/05	8:00	9:10	100	60	-7	48,30	81,32	2,00	341	162,68
18		9:25	10:10	100	60	-25	52,70	81,60	2,00	341	163,23
19		10:20	11:15	100	60	-97	48,30	81,32	2,00	341	162,68
20		11:25	12:20	100	60	-184	51,64	87,78	2,00	341	175,58
21	2014/06/05	13:25	14:15	250	60	-12	42,16	80,98	2,00	341	161,98
22		14:25	15:10	250	60	-26	51,64	81,53	2,00	341	163,10
23		15:25	16:10	250	60	-72	42,16	80,98	2,00	341	161,98
24		16:25	17:30	250	60	-96	51,64	87,78	2,00	341	175,58

Item	Date	Time		I [A]	f [Hz]	Mean Value [µrad]	Std. Dev [µrad]	U Comb [µrad]	k	Degrees of Freedom	Expanded Uncertainty [µrad]
		Start	End								
25	2014/06/06	8:10	9:05	500	60	-2	42,16	80,98	2,00	341	161,98
26		9:15	10:10	500	60	-9	31,62	80,50	2,00	341	161,02
27		10:25	11:30	500	60	-38	42,16	80,98	2,00	341	161,98
28		11:45	12:55	500	60	77	48,30	87,59	2,00	341	175,20
29	2014/06/06	14:00	14:55	1000	60	-4	51,64	81,53	2,00	341	163,10
30		15:10	15:55	1000	60	-7	48,30	81,32	2,00	341	162,68
31		16:10	17:05	1000	60	-36	51,64	81,53	2,00	341	163,10
32		17:15	18:05	1000	60	82	42,16	87,27	2,00	341	174,56

Table 20. CENAMEP

Frequencia	Carga Nominal	Temperatura Ambiente	Relación Nominal	Intensidad Primaria	Error de Relación	Incertidumbre del Error de Relación	Desplazamiento de Fase	Incertidumbre Desplazamiento de Fase
Hz	VA	°C	(xxx/5)	A	ppm	ppm	µrad	µrad
60,0	6,15	21	1000/5	1200	23	80	-14	117
		21		1000	23	80	-14	117
		21		200	23	80	-12	117
		21		50	20	80	-13	117
	6,14	22	500/5	600	24	80	-15	117
		21		500	24	80	-15	117
		22		100	23	80	-13	117
		22		25	20	80	-13	117
	6,17	21	250/5	300,0	24	75	-12	113
		21		250,0	24	75	-12	113
		21		50,0	25	75	-11	113
		21		12,5	23	75	-12	113
	6,15	21	100/5	120	28	75	-15	113
		21		100	28	75	-15	113
		21		20	28	75	-13	113
		21		5	28	75	-13	113
	6,13	21	50/5	60,0	26	75	-12	113
		21		50,0	26	75	-12	113
		21		10,0	26	75	-11	113
		21		2,5	26	75	-11	113
	6,15	21	25/5	30,0	21	75	-14	113
		21		25,0	21	75	-15	113
		21		5,0	21	75	-13	113
		21		1,25	21	75	-13	113
	6,15	21	10/5	12,0	19	75	-14	113
		21		10,0	20	75	-14	113
		21		2,0	20	75	-12	113
		21		0,5	22	75	-8	113
	6,15	21	5/5	6,0	20	75	-14	113
		21		5,0	20	75	-14	113
		21		1,0	21	75	-11	113
		21		0,25	24	75	-3	113

Table 21. CFE LAPEM

Corriente de Cal.		Clase Exactitud		Lectura Patrón		Incertidumbre		Tolerancia	
Amperes	% In	Relación	Carga VA	% Error Relación	Error Fase (min)	Fase min.	Relación (%)	Fase min.	Relación (%)
0.25	5	5:5 A	100 %	-0.017	1.3	1.2	0.023		
1.00	20			-0.018	1.3	1.2	0.023		
5.00	100			-0.018	1.4	1.2	0.023		
6.00	120			-0.018	1.4	1.2	0.023		
0.5	5	10:5 A	100 %	-0.018	1.4	1.2	0.023		
2.0	20			-0.020	1.6	1.2	0.023		
10.0	100			-0.020	1.6	1.2	0.023		
12.0	120			-0.021	1.6	1.2	0.023		
1.3	5	25:5 A	100 %	-0.021	1.7	1.2	0.023		
5.0	20			-0.020	1.6	1.2	0.023		
25.0	100			-0.019	1.5	1.2	0.023		
30.0	120			-0.019	1.5	1.2	0.023		
2.5	5	50:5 A	100 %	-0.019	1.5	1.2	0.023		
10.0	20			-0.020	1.5	1.2	0.023		
50.0	100			-0.020	1.5	1.2	0.023		
60.0	120			-0.020	1.6	1.2	0.023		
5	5	100:5 A	100 %	-0.017	1.6	1.2	0.023		
20	20			-0.017	1.1	1.2	0.023		
100	100			-0.018	1.1	1.2	0.023		
120	120			-0.018	1.2	1.2	0.023		
12.5	5	250:5 A	100 %	-0.022	1.2	1.2	0.023		
50.0	20			-0.014	0.9	1.2	0.023		
250.0	100			-0.007	0.4	1.2	0.023		
300.0	120			-0.002	0.0	1.2	0.023		
25	5	500:5 A	100 %	0.003	-0.4	1.2	0.023		
100	20			0.001	-0.3	1.2	0.023		
500	100			0.000	-0.2	1.2	0.023		
600	120			-0.001	-0.2	1.2	0.023		
50	5	1 000:5 A	100 %	-0.002	-0.2	1.2	0.023		
200	20			-0.001	-0.2	1.2	0.023		
1 000	100			-0.001	-0.1	1.2	0.023		
1 200	120			-0.001	-0.1	1.2	0.023		

Table 22. INTI

Frequency [Hz]	Burden [VA] Cos φ:1	T [ºC]	Nominal Ratio	Primary Current [A]	Ratio Error [x10^{-6}]	Ratio Error Uncertainty [x10^{-6}]	Phase Displacement [urad]	Phase Displacement Uncertainty [urad]
50	6	23 ± 1	5/5	6	-1	15	3	15
50	6	23 ± 1	5/5	5	-1	15	3	15
50	6	23 ± 1	5/5	1	1	15	3	15
50	6	23 ± 1	5/5	0.25	2	15	4	15
50	6	23 ± 1	10/5	12	-1	15	-3	15
50	6	23 ± 1	10/5	10	-1	15	-3	15
50	6	23 ± 1	10/5	2	1	15	-2	15
50	6	23 ± 1	10/5	0.5	2	15	0	15
50	6	23 ± 1	25/5	30	-1	15	-3	15
50	6	23 ± 1	25/5	25	-1	15	-3	15
50	6	23 ± 1	25/5	5	0	15	-2	15
50	6	23 ± 1	25/5	1.25	2	15	0	15
50	6	23 ± 1	50/5	60	-2	15	-2	15
50	6	23 ± 1	50/5	50	-3	15	-2	15
50	6	23 ± 1	50/5	10	-1	15	-2	15
50	6	23 ± 1	50/5	2.5	0	15	0	15
50	6	23 ± 1	100/5	120	-3	15	6	15
50	6	23 ± 1	100/5	100	-3	15	8	15
50	6	23 ± 1	100/5	20	-1	15	13	15
50	6	23 ± 1	100/5	5	2	15	13	15
50	6	23 ± 1	250/5	300	-6	15	11	20
50	6	23 ± 1	250/5	250	-6	15	10	20
50	6	23 ± 1	250/5	50	-5	15	9	20
50	6	23 ± 1	250/5	12.5	-3	15	10	20
50	6	23 ± 1	500/5	600	1	15	-1	20
50	6	23 ± 1	500/5	500	1	15	-1	20
50	6	23 ± 1	500/5	100	1	15	0	20
50	6	23 ± 1	500/5	25	2	15	2	20
50	6	23 ± 1	1000/5	1200	-3	15	5	20
50	6	23 ± 1	1000/5	1000	-4	15	5	20
50	6	23 ± 1	1000/5	200	-4	15	7	20
50	6	23 ± 1	1000/5	50	-3	15	7	20

Frequency [Hz]	Burden [VA] Cos φ:1	T [ºC]	Nominal Ratio	Primary Current [A]	Ratio Error [x10^{-6}]	Ratio Error Uncertainty [x10^{-6}]	Phase Displacement [urad]	Phase Displacement Uncertainty [urad]
60	6	23 ± 1	5/5	6	-2	15	3	15
60	6	23 ± 1	5/5	5	-2	15	3	15
60	6	23 ± 1	5/5	1	-1	15	4	15
60	6	23 ± 1	5/5	0.25	0	15	4	15
60	6	23 ± 1	10/5	12	-2	15	-2	15
60	6	23 ± 1	10/5	10	-2	15	-2	15
60	6	23 ± 1	10/5	2	-1	15	-1	15
60	6	23 ± 1	10/5	0.5	0	15	0	15
60	6	23 ± 1	25/5	30	-2	15	-1	15
60	6	23 ± 1	25/5	25	-2	15	-1	15
60	6	23 ± 1	25/5	5	-2	15	0	15
60	6	23 ± 1	25/5	1.25	0	15	1	15
60	6	23 ± 1	50/5	60	-3	15	-2	15
60	6	23 ± 1	50/5	50	-3	15	-2	15
60	6	23 ± 1	50/5	10	-3	15	-1	15
60	6	23 ± 1	50/5	2.5	-1	15	0	15
60	6	23 ± 1	100/5	120	-4	15	9	15
60	6	23 ± 1	100/5	100	-4	15	12	15
60	6	23 ± 1	100/5	20	-3	15	14	15
60	6	23 ± 1	100/5	5	-1	15	13	15
60	6	23 ± 1	250/5	300	-6	15	13	20
60	6	23 ± 1	250/5	250	-5	15	14	20
60	6	23 ± 1	250/5	50	-5	15	13	20
60	6	23 ± 1	250/5	12.5	-3	15	13	20
60	6	23 ± 1	500/5	600	1	15	-3	20
60	6	23 ± 1	500/5	500	1	15	-3	20
60	6	23 ± 1	500/5	100	0	15	-3	20
60	6	23 ± 1	500/5	25	2	15	-1	20
60	6	23 ± 1	1000/5	1200	-4	15	3	20
60	6	23 ± 1	1000/5	1000	-4	15	3	20
60	6	23 ± 1	1000/5	200	-4	15	5	20
60	6	23 ± 1	1000/5	50	-3	15	4	20

Table 23. PTB

f in Hz	Burden in VA	T in °C	Kn (xxx A/5 A)	I_p in A	ε_i in 10^{-6}	$U(\varepsilon_i)$ in 10^{-6}	δ_i in µrad	$U(\delta_i)$ µrad
50	6,0	23	5	6,02	0,6	3,0	0,1	3,0
50	6,0	23	5	5,01	0,7	3,0	-0,1	3,0
50	6,0	23	5	1,00	1,3	3,0	0,1	3,0
50	6,0	23	5	0,25	2,8	3,0	0,8	3,0
60	6,0	23	5	6,00	0,5	3,0	-0,1	3,0
60	6,0	23	5	5,00	0,7	3,0	-0,1	3,0
60	6,0	23	5	1,00	1,2	3,0	0,0	3,0
60	6,0	23	5	0,24	2,6	3,0	0,5	3,0
50	6,0	23	10	12,01	0,8	3,0	-0,4	3,0
50	6,0	23	10	9,99	1,1	3,0	-0,6	3,0
50	6,0	23	10	1,99	1,5	3,0	0,1	3,0
50	6,0	23	10	0,49	2,9	3,0	0,5	3,0
60	6,0	23	10	12,00	0,7	3,0	-0,5	3,0
60	6,0	23	10	9,98	0,8	3,0	-0,6	3,0
60	6,0	23	10	1,99	1,3	3,0	-0,3	3,0
60	6,0	23	10	0,49	2,5	3,0	0,4	3,0
50	6,0	23	25	30,03	1,7	3,0	0,8	3,0
50	6,0	23	25	24,97	1,8	3,0	0,6	3,0
50	6,0	23	25	4,95	2,4	3,0	0,9	3,0
50	6,0	23	25	1,24	4,0	3,0	2,1	3,0
60	6,0	23	25	30,04	1,7	3,0	0,7	3,0
60	6,0	23	25	25,02	1,8	3,0	0,7	3,0
60	6,0	23	25	4,94	2,1	3,0	0,9	3,0
60	6,0	23	25	1,24	3,5	3,0	1,8	3,0
50	6,0	23	50	60,04	2,1	3,0	-1,5	3,0
50	6,0	23	50	50,00	2,1	3,0	-1,5	3,0
50	6,0	23	50	10,00	2,6	3,0	-1,0	3,0
50	6,0	23	50	2,49	4,6	3,0	0,0	3,0
60	6,0	23	50	60,04	2,0	3,0	-1,3	3,0
60	6,0	23	50	50,02	2,0	3,0	-1,2	3,0
60	6,0	23	50	10,01	2,4	3,0	-0,9	3,0
60	6,0	23	50	2,55	3,8	3,0	0,1	3,0
50	6,0	23	100	120,11	1,6	3,0	1,8	3,0
50	6,0	23	100	99,91	1,7	3,0	1,8	3,0
50	6,0	23	100	20,12	2,1	3,0	1,4	3,0
50	6,0	23	100	4,96	3,6	3,0	2,1	3,0
60	6,0	23	100	120,18	1,5	3,0	1,6	3,0
60	6,0	23	100	100,06	1,7	3,0	1,5	3,0
60	6,0	23	100	19,84	2,0	3,0	1,3	3,0
60	6,0	23	100	4,88	3,2	3,0	1,8	3,0
50	6,0	23	250	300,23	0,4	3,0	2,1	3,0

50	6,0	23	250	250,23	0,4	3,0	2,2	3,0
50	6,0	23	250	49,60	1,0	3,0	2,2	3,0
50	6,0	23	250	12,45	2,9	3,0	3,3	3,0
60	6,0	23	250	300,11	0,5	3,0	2,1	3,0
60	6,0	23	250	250,21	0,4	3,0	2,0	3,0
60	6,0	23	250	49,86	0,9	3,0	2,1	3,0
60	6,0	23	250	12,34	2,5	3,0	2,9	3,0
50	6,0	23	500	600,92	2,8	3,0	-1,1	3,0
50	6,0	23	500	500,38	2,8	3,0	-0,8	3,0
50	6,0	23	500	99,90	2,2	3,0	0,5	3,0
50	6,0	23	500	25,37	3,7	3,0	1,3	3,0
60	6,0	23	500	601,50	2,5	3,0	-0,8	3,0
60	6,0	23	500	500,30	2,5	3,0	-0,6	3,0
60	6,0	23	500	99,17	2,0	3,0	0,4	3,0
60	6,0	23	500	24,78	3,1	3,0	1,5	3,0
50	6,0	23	1000	1201,86	3,0	3,0	-1,3	3,0
50	6,0	23	1000	999,66	2,6	3,0	-1,2	3,0
50	6,0	23	1000	199,52	1,3	3,0	0,1	3,0
50	6,0	23	1000	49,28	3,0	3,0	1,2	3,0
60	6,0	23	1000	1200,51	2,9	3,0	-1,1	3,0
60	6,0	23	1000	1001,10	2,3	3,0	-1,1	3,0
60	6,0	23	1000	199,55	1,0	3,0	0,1	3,0
60	6,0	23	1000	49,29	2,6	3,0	1,1	3,0

Annex B - Uncertainty Budgets

Summaries of the uncertainty budget calculations, as reported by each laboratory, are shown below.

Table 24. UTE 2013 and 2016.

Uncertainty Budget for ratio error at a 25/5 ratio and In = 100%

Quantity *Xi*	Standard uncertainty *u(xi) ppm*	Probability distribution	Sensitivity coefficient *ci*	Uncertainty contribution *ui(y) ppm*
Bridge deviaion Δp_c	0,5	Normal	1	0,5
Measurement setup δs	2,2	Normal	1	2,2
Bridge reading p	0,0	3	1	0,0
Bridge resolution δp_r	0,1	Rectangular	1	0,1
Standard CT E_N	0	Normal	1	0
Burden variation Δ_B	0,1	Normal	1	0,1
Standard uncertainty Ξ_x				2,3
Rounded expanded measurement uncertainty (k = 2)				4,5

Uncertainty Budget for phase displacement at a 25/5 ratio and In = 100%

Quantity *Xi*	Standard uncertainty *u(xi) µrad*	Probability distribution	Sensitivity coefficient *ci*	Uncertainty contribution *ui(y) µrad*
Bridge deviaion Δp_c	0,5	Normal	1	0,5
Measurement setup δs	2,2	Normal	1	2,2
Bridge reading p	0,0	3	1	0,0
Bridge resolution δp_r	0,1	Rectangular	1	0,1
Standard CT E_N	0	Normal	1	0
Burden variation Δ_B	0,1	Normal	1	0,1
Standard uncertainty Ξ_x				2,3
Rounded expanded measurement uncertainty (k = 2)				4,5

Uncertainty Budget for ratio error at a 1000/5 ratio and In = 100%

Quantity *Xi*	Standard uncertainty *u(xi) ppm*	Probability distribution	Sensitivity coefficient *ci*	Uncertainty contribution *ui(y) ppm*
Bridge deviaion Δp_c	0,5	Normal	1	0,5
Measurement setup δ*s*	2,2	Normal	1	2,2
Bridge reading p	0	3	1	0,0
Bridge resolution δp_r	0,1	Rectangular	1	0,1
Standard CT E_N	5,0	Normal	1	5,0
Burden variation Δ_B	0,1	Normal	1	0,1
Standard uncertainty Ξ_x				5,5
Rounded expanded measurement uncertainty (k = 2)				11,1

Uncertainty Budget for phase displacement at a 1000/5 ratio and In = 100%

Quantity *Xi*	Standard uncertainty *u(xi) µrad*	Probability distribution	Sensitivity coefficient *ci*	Uncertainty contribution *ui(y) µrad*
Bridge deviaion Δp_c	0,5	Normal	1	0,5
Measurement setup δ*s*	2,2	Normal	1	2,2
Bridge reading p	0	3	1	0,0
Bridge resolution δp_r	0,1	Rectangular	1	0,1
Standard CT E_N	5,0	Normal	1	5,0
Burden variation Δ_B	0,1	Normal	1	0,1
Standard uncertainty Ξ_x				5,5
Rounded expanded measurement uncertainty (k = 2)				11,1

Table 25. UTE 2019

Uncertainty Budget for ratio error at a 25/5 ratio and In = 100%

Quantity *Xi*	Standard uncertainty *u(xi) ppm*	Probability distribution	Sensitivity coefficient *ci*	Uncertainty contribution *ui(y) ppm*
Bridge deviaion Δp_c	0,5	Normal	1	0,5
Measurement setup δs	1	Normal	1	1
Bridge reading p	0,1	3	1	0,1
Bridge resolution δp_r	0,1	Rectangular	1	0,1
Standard CT E_N	1,1	Normal	1	1,1
Burden variation Δ_B	0,1	Normal	1	0,1
Standard uncertainty Ξ_x				1,6
Rounded expanded measurement uncertainty (k = 2)				3,2

Uncertainty Budget for phase displacement at a 25/5 ratio and In = 100%

Quantity *Xi*	Standard uncertainty *u(xi) μrad*	Probability distribution	Sensitivity coefficient *ci*	Uncertainty contribution *ui(y) μrad*
Bridge deviaion Δp_c	0,5	Normal	1	0,5
Measurement setup δs	1	Normal	1	1
Bridge reading p	0,1	3	1	0,1
Bridge resolution δp_r	0,1	Rectangular	1	0,1
Standard CT E_N	1,1	Normal	1	1,1
Burden variation Δ_B	0,1	Normal	1	0,1
Standard uncertainty Ξ_x				1,6
Rounded expanded measurement uncertainty (k = 2)				3,2

Uncertainty Budget for ratio error at a 1000/5 ratio and In = 100%

Quantity *Xi*	Standard uncertainty *u(xi) ppm*	Probability distribution	Sensitivity coefficient *ci*	Uncertainty contribution *ui(y) ppm*
Bridge deviaion Δp_c	0,5	Normal	1	0,5
Measurement setup δs	1	Normal	1	1
Bridge reading p	0,1	3	1	0,1
Bridge resolution δp_r	0,1	Rectangular	1	0,1
Standard CT E_N	1,6	Normal	1	1,6
Burden variation Δ_B	0,1	Normal	1	0,1
Standard uncertainty Ξ_x				2,0
Rounded expanded measurement uncertainty (k = 2)				3,9

Uncertainty Budget for phase displacement at a 1000/5 ratio and In = 100%

Quantity *Xi*	Standard uncertainty *u(xi) μrad*	Probability distribution	Sensitivity coefficient *ci*	Uncertainty contribution *ui(y) μrad*
Bridge deviaion Δp_c	0,5	Normal	1	0,5
Measurement setup δs	1	Normal	1	1
Bridge reading p	0,1	3	1	0,1
Bridge resolution δp_r	0,1	Rectangular	1	0,1
Standard CT E_N	1,6	Normal	1	1,6
Burden variation Δ_B	0,1	Normal	1	0,1
Standard uncertainty Ξ_x				2,0
Rounded expanded measurement uncertainty (k = 2)				3,9

Table 26. INMETRO

Uncertainty budget (5 % of In):

Source of uncertainty	Value of standard uncertainty u(xi)×10-6	Type (A,B)	Prob. distribution	ci=df/dxi	ui=ci.u(xi) ×10-6	Degree of freedom
Measurement standard	32	B	Normal	1	32	∞
Repeatability	1	A	Normal	1	1	4
Combined uncertainty	32					
Expanded uncertainty (k=2)	64					

Source of uncertainty	Value of standard uncertainty μrad	Type (A,B)	Prob. distribution	ci=df/dxi	ui=ci.u(xi) ×10-6	Degree of freedom
Measurement standard	35	B	Normal	1	35	∞
Repeatability	1	A	Normal	1	1	4
Combined uncertainty	35					
Expanded uncertainty (k=2)	70					

Uncertainty budget (20 % to 120 % of In):

Source of uncertainty	Value of standard uncertainty u(xi)×10-6	Type (A,B)	Prob. distribution	ci=df/dxi	ui=ci.u(xi) ×10-6	Degree of freedom
Measurement standard	22,5	B	Normal	1	22,5	∞
Repeatability	0	A	Normal	1	0	4
Combined uncertainty	22,5					
Expanded uncertainty (k=2)	45					

Source of uncertainty	Value of standard uncertainty µrad	Type (A,B)	Prob. distribution	ci=df/dxi	ui=ci.u(xi) ×10-6	Degree of freedom
Measurement standard	23,3	B	Normal	1	23,3	∞
Repeatability	0	A	Normal	1	0	4
Combined uncertainty	23,3					
Expanded uncertainty (k=2)	47					

Table 27. INM
Ratio 50:5, 20% In

Measurement 15. [µA/A]

Main uncertainty components y_i	Standard uncertainty $u(y_i)$	Type method A or B of evaluation/probability distribution function	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degrees of freedom n_i
1) Standard deviation of the readings of the traveling standard	4,22/√10	Type A Normal	1	1,33	241
2) Uncertainty components of the reference standard of the participant	50/2	Type B Rectangular	1	25,00	241
3) Uncertainty components of the current transformer test set	50/√3	Type B Rectangular	1	28,87	241
4) Uncertainty components of drift	50/√3	Type B Rectangular	1	28,87	241
5) Uncertainty components of resolution	10/√12	Type B Rectangular	1	2,89	∞
Root square sum of Type A standard uncertainties and effective degrees of freedom				1,33	241
Root square sum of Type B standard uncertainties and effective degrees of freedom				47,96	241
Combined standard uncertainty and effective degrees of freedom				47,98	340,8
Expanded uncertainty (95,45 % coverage factor)				95,95	

Measurement 15. [µrad]

Main uncertainty components y_i	Standard uncertainty $u(y_i)$	Type method A or B of evaluation/probability distribution function	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$	Degrees of freedom n_i
1) Standard deviation of the readings of the traveling standard	31,62/√10	Type A Normal	1	10,00	241
2) Uncertainty components of the reference standard of the participant	11,64/2	Type B Rectangular	1	29,09	241
3) Uncertainty components of the current transformer test set	83,97/√3	Type B Rectangular	1	48,48	241
4) Uncertainty components of drift	83,97/√3	Type B Rectangular	1	48,48	241
5) Uncertainty components of resolution	100/√12	Type B Rectangular	1	28,87	∞
Root square sum of Type A standard uncertainties and effective degrees of freedom				10,00	241
Root square sum of Type B standard uncertainties and effective degrees of freedom				79,88	241
Combined standard uncertainty and effective degrees of freedom				80,50	340,8
Expanded uncertainty (95,45 % coverage factor)				161,00	

Table 28. CENAMEP

RELACIÓN 1000/5

120 % In

Fuentes de Incertidumbre	Incertidumbre Estándar u(xi)x10^6	Tipo	Distribución	Coef. Sensibilidad (ci)	ui=ci. u(xi)x10^6	Grados de libertad
Especificación transformador patrón (U1)	28,87	B	Rectangular	1	28,87	500
Comparador de corriente (U2)	17,32	B	Rectangular	1	17,32	100
Especificación multímetro maestro (U3)	5,77	B	Rectangular	1	5,77	500
Especificación multímetro esclavo (U4)	5,77	B	Rectangular	1	5,77	500
Afectación por carga (U5)	5,77	B	Rectangular	1	5,77	100
Afectación por temperatura (U6)	11,55	B	Rectangular	1	11,55	500
Afectación por conexiones (U7)	17,32	B	Rectangular	1	17,32	100
Mediciones (U8)	0,04	A	Normal	1	0,04	4
Incertidumbre Combinada	41			Grados efectivos		857
Incertidumbre Expandida k=2	80			Factor de cobertura		1,96

Same uncertainties are for ratio error (in µA/A) and for phase displacement (in µrad).

Table 29. INTI

Ejemplo de balance de incertidumbre en error de relación para la relación 5/5:

Fuente de Incertidumbre	Simbolo	Tipo	C_i	u_X [ppm]	Distribución	Factor A	V_i	$U_i = u_x/A$	$C_i^2 . U_i^2$
Tipo A	u_A	A	1	0.4	N	1	9	0.4	0.16
TI Patrón	u_{F_N}	B	1	5	N	1	50	5	25
setup de medición	u_P	B	1	4	N	1	50	4	16
Resolución	u_{R_P}	B	1	1	R	1.732	50	0,58	0,34
Corriente I_P	u_{I_P}	B	1	2	N	1	50	2	4
Variación carga	u_B	B	1	2	N	1	50	2	4
Temperatura	u_t	B	1	1	N	1	50	1	1
Frecuencia	u_f	B	1	1	N	1	50	1	1
Incertidumbre combinada	u_c								7.2
Incertidumbre expandida (K=2)	U				N(95%)	2			15 [ppm]

Ejemplo de balance de incertidumbre en error de desplazamiento de fase para la relación 5/5:

Fuente de Incertidumbre	Simbolo	Tipo	C_i	u_X [µrad]	Distribución	Factor A	V_i	$U_i = u_x/A$	$C_i^2 . U_i^2$
Tipo A	u_A	A	1	0.4	N	1	9	0.4	0.16
TI Patrón	u_{F_N}	B	1	5	N	1	50	5	25
setup de medición	u_P	B	1	4	N	1	50	4	16
Resolución	u_{R_P}	B	1	1	R	1.732	50	0,58	0,34
Corriente I_P	u_{I_P}	B	1	2	N	1	50	2	4
Variación carga	u_B	B	1	2	N	1	50	2	4
Temperatura	u_t	B	1	1	N	1	50	1	1
Frecuencia	u_f	B	1	1	N	1	50	1	1
Incertidumbre combinada	u_c								7.2
Incertidumbre expandida (K=2)	U				N(95%)	2			15 [µrad]

Table 30. PTB

uncertainty budget (traveling CT)		PTB Braunschweig		
50/60 Hz; (5A - 1kA) / 5A; I_p / $I_{p,r}$ = 5%... 120%		WG 2.31 Instrument Tranformers and Sensors		
current ratio error ε_x				
quantity x_i	**limits in µA / A**	**type**	**distribution**	**standard uncertainty** $u(x_i)$
$s(\varepsilon_X)$ (SEKAM IV; n = 20)	4	A	normal	0,46
ε_{Bridge} (SEKAM IV)	0,5	B	normal	0,25
ε_N (standard CT - IW51)	1	B	normal	0,50
ε_B (influence of burden)	1,5	B	rectangular	0,87
ε_F (influence of frequency)	0,2	B	rectangular	0,12
ε_{repro} (reproducibility; day to day)	0,2	B	rectangular	0,12
			standard uncertainty $u(\varepsilon_x)$ =	**1,14 µA / A**
			round off - expanded measurement uncertainty (k = 2) $U_{PTB}(\varepsilon_x)$ =	**3,0 µA / A**
phase displacement δ_x				
quantity x_i	**limits in µrad**	**type**	**distribution**	**standard uncertainty** $u(x_i)$
$s(\delta_X)$ (SEKAM IV; n = 20)	4	A	normal	0,46
δ_{Bridge} (SEKAM IV)	0,5	B	normal	0,25
δ_N (standard CT - IW51)	1,5	B	normal	0,75
δ_B (influence of burden)	1,5	B	rectangular	0,87
δ_F (influence of frequency)	0,2	B	rectangular	0,12
δ_{repro} (reproducibility; day to day)	0,2	B	rectangular	0,12
			standard uncertainty $u(\delta_x)$ =	**1,27 µrad**
			round off - expanded measurement uncertainty (k = 2) $U_{PTB}(\delta_x)$ =	**3,0 µrad**

Annex C - Description of measurement equipment as reported by laboratories.

a. UTE

The comparison between the traveling CT and the laboratory standard CT was made by a bridge which schematic is shown in figure 22. The power source can be set at 50 Hz or 60 Hz. The primary current is adjusted by a regulating transformer with a step-down transformer. A variable resistor and a capacitor allow to get close to null voltage at the connection point between both CTs (Pi-P1).

The self-calibrated current comparator is described in [1]. Its output is connected to a lock-in amplifier with two multimeters, one indicating the in-phase error and the other, the phase shift error.

Two UTE laboratory standard CTs were used, one in the 2013-2016 calibrations, and other in 2019 calibrations. Both were of two-stage type with electronic compensators, calibrated by self-calibration procedures. The first one (CONIMED, TI 1205) was calibrated by a step-up method [2]. The second one (LABUTE 201809) is a self-development that has its primary windings separated in sectors to allow series-parallel configurations [3]. The 5:5-ratio was self-calibrated. Higher ranges relate their errors to the first one by changing its series-parallel primary configurations. Using this last CT, a lower uncertainty was achieved.

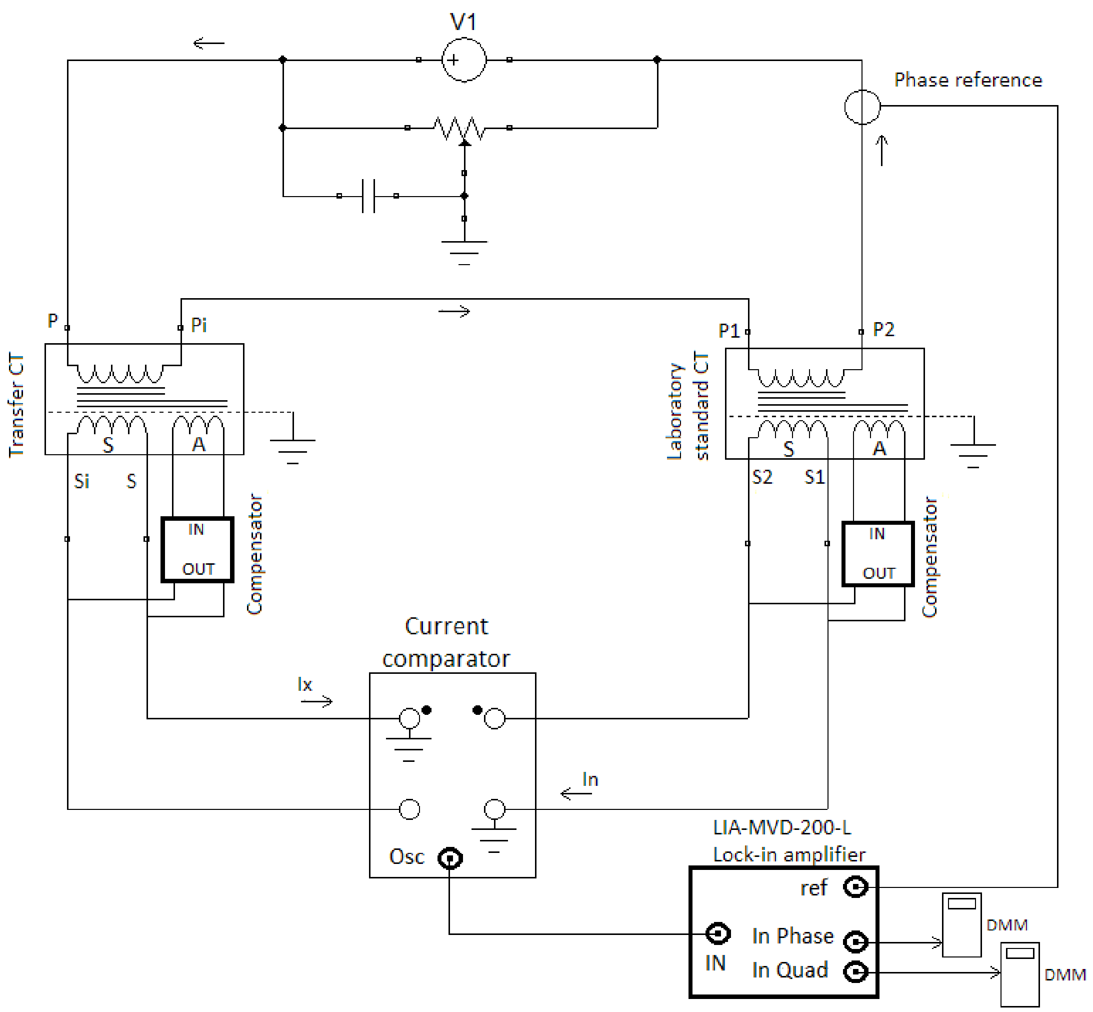

Fig. 22. UTE measurement equipment.

b. INMETRO

Calibration was performed by the comparison method (same method declared in CMC's), using a standard CT and a standard CT bridge. Measurements were performed at a frequency of 60 Hz, referenced to the standards listed below:

Current Transformer PR 008.

Measurement bridge PR 046.

c. INM

The comparison method is shown in figure 23.

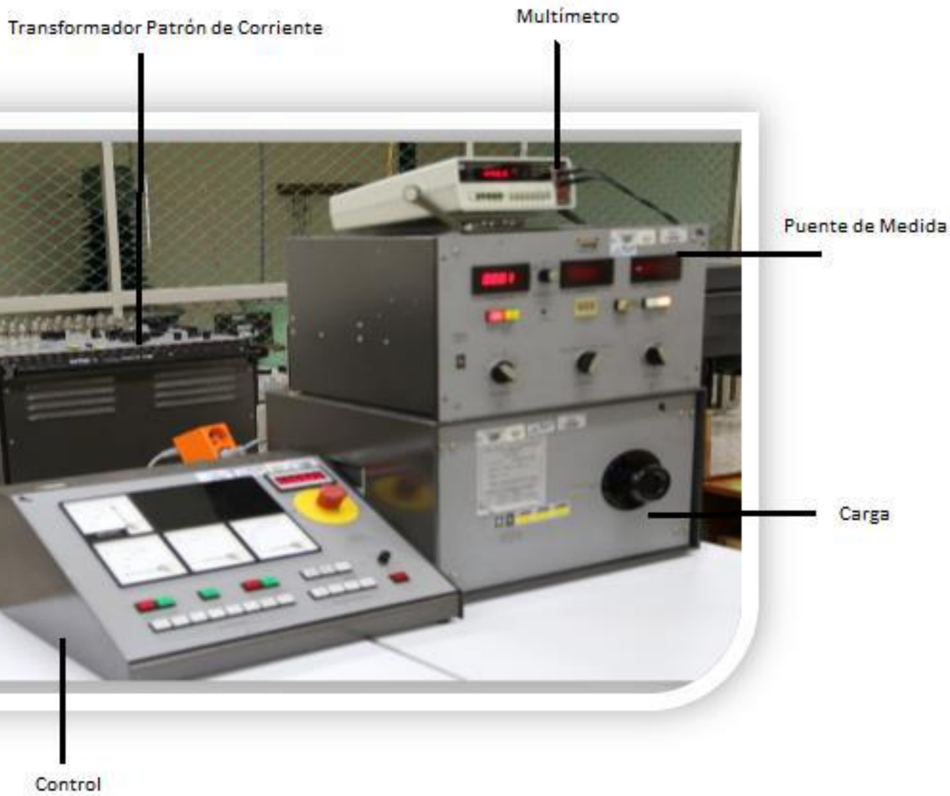

Fig. 23. Measurement set up of INM.

d. CENAMEP

The direct comparison method was used. That is, the traveling transformer was compared against a current transformer of equal class. The measurement system for the calibration of current measurement transformers, shown in figure 24, consists of:

Current transformer standard. This transformer is of two stages type, and constitutes the reference of our measurement system. It has an accuracy of 0.005 % and 0.5' for currents between 1 % and 120 % of the rated current.

Current measurement transformer comparator. It is of the differential type, it allows to compare our reference transformer with the one you want to test, by means of two voltage output signals (reference and difference), which can be visualized and processed with certain display equipment. Digital multimeters: configured as master and slave, the signals coming from the comparator are connected, they digitize the voltage signals using Swerlein algorithm.

Variable current source: two current injector modules that by induction generate the current that circulates through the primary transformers.

Data:
Current transformer standard: CONIMED, TI 1205.
Current comparator: CONIMED, CTI-CT3.
Digital multimeters: AGILENT, 3458 A.

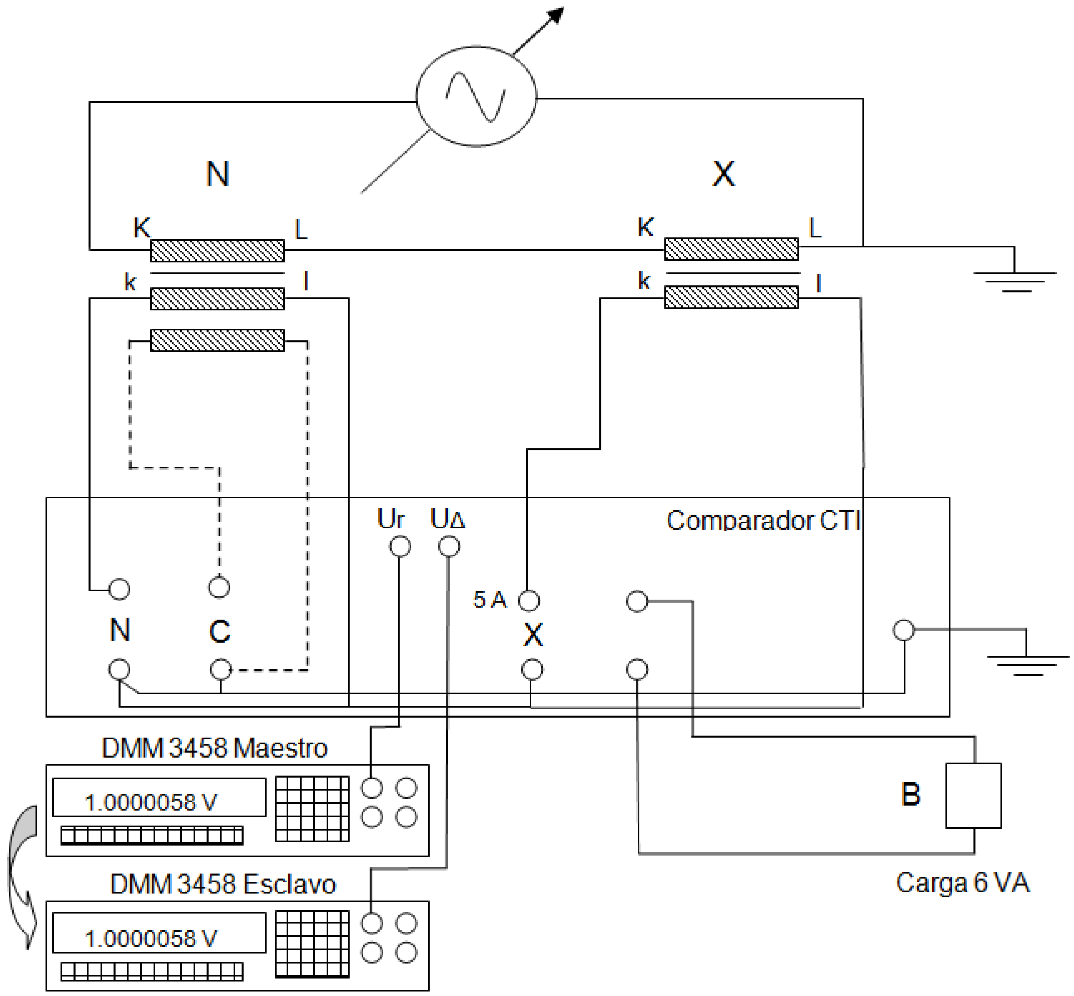

Fig. 24. CENAMEP measurement equipment.

e. CFE

The direct comparison method was used. Table 31 shows the measurement equipment used.

Table 31. Measurement equipment used by CFE.

DATOS	PATRÓN EMPLEADO	PATRÓN EMPLEADO	PATRÓN EMPLEADO	INSTRUMENTO
Nombre	Puente de TC's			Transformador de Corriente
Marca	ZERA			CONIMED
Modelo	SCT 6000-120			TI 1205
No. Serie y/o Id.	2/09/0984			11023
Clase de Exactitud	±(0,02%rel 1 min. fase			±(0.005% rel 0.5 min. fase)
Folio del patrón	20101063			
Vigencia	2015-02-27			n.a.

f. INTI

Figure 25 shows the measurement scheme based on a differential method using a current comparator. The difference signal provides the error and it is read with a lock in amplifier, and processed by specially designed software.

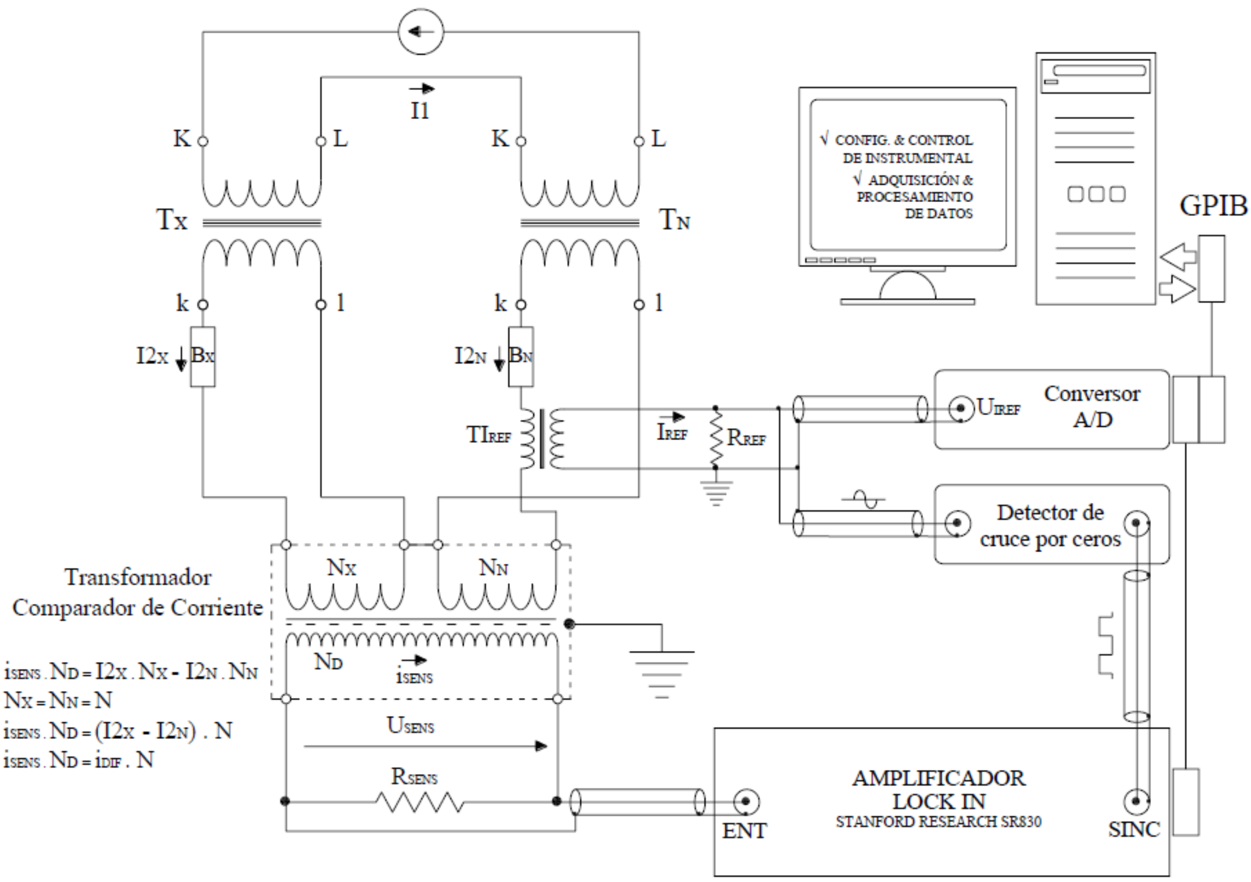

Fig. 25. INTI measurement equipment.

g. PTB

The CT measurement system consists mainly of an electronically compensated current comparator T_N (Std.: “IW 51”) and a self-calibrating current transformer test set (Std.: “SEKAM IV”) based on the ratiometric method [4], [5]. Fig. 26 shows the simplified setup of the test set for calibrating the CT T_X against the standard CT T_N using the high accurate dual current-to-voltage converter module SEKAM IV with a sampling-based two-channel ratio measurement system [6]. A waveform generator with a high power amplifier and associated range transformers is used to generate the test current I_p. The output of the current source is connected to the reference T_N and the CT under test T_X. Each secondary of both CTs is connected to the self-calibrated current-to-voltage converters of the subsequently arranged bridge. The bridge SEKAM IV consists of two identical transformer-based current-to-voltage converters with several primary windings for rated currents from 100 mA to 5 A, error correction amplifiers, and active, i.e., amplifier aided, measuring resistors. This setup ensures a very precise ratio of the output voltage and the input currents of the so defined bridge paths N and X.

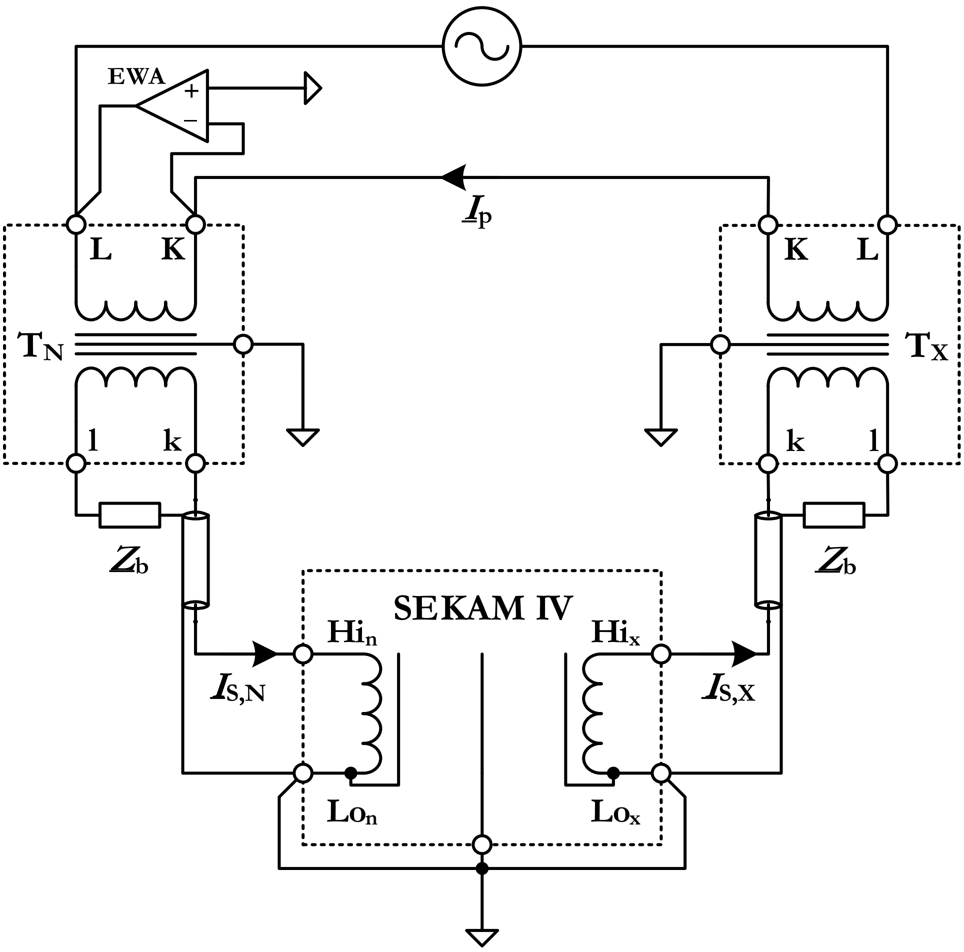

Fig. 26. Circuit diagram of PTB.