CMI
Czech Republic

BIM, NCM
Bulgaria

Supplementary comparison of measurements of current transformers
EURAMET.EM-S30

Final report

EURAMET Project No 1081

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Table of contents

1. Introduction

A supplementary comparison was organized between CMI, Czech Republic and BIM, Bulgaria, in the field of current transformer ratio measurements. This comparison is registered as EURAMET project nr. 1081 and EURAMET.EM-S30 in the BIPM key comparison database.

The aim of the comparison was to demonstrate the improvement and extension of the calibration and measurement capabilities (CMC's) of BIM in this working field and to support the submission of an improved and extended CMC for BIM in Appendix C of the CIPM mutual recognition arrangement (MRA).

This comparison was organized in the framework of Phare project BG 2005/017-353.02.02, Lot 1, and was financed in this framework by the EU. This project run from March 2008 to the end of February 2009.

2. Participants and organisation of the comparison

2.1. List of participants

Participants:

Name:	Czech Metrology Institute	
Acronym:	CMI	
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Country:	Czech Republic	
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Name:	Bulgarian Institute of Metrology, National Centre of Metrology	
Acronym:	BIM	
Address:	General Directorate "National Centre of Metrology" Section "Electric Energy Measurements" 52-B G.M. Dimitrov Blvd. 1040 Sofia	
Country:	Bulgaria	
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Comparison coordinator:
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2.2. Comparison schedule

The travelling standards were circulated in a schedule A-B-A, as shown in the tables below. The behaviour of the travelling CMI transformers during the comparison was determined from the measurements of CMI. The behaviour of the travelling BIM transformer during the comparison was determined from the measurements of BIM.

In the original schedule, each participant was allowed two weeks to perform the measurements and to ship the standards to the other participant. However, it appeared that more time was required to complete the measurements. The actual schedules are given here below.

CMI transformers		
Participant	Measurements from	to
CMI	21-10-2008	18-11-2008
BIM	04-12-2008	06-01-2009
CMI	30-01-2009	09-02-2009

BIM transformer		
Participant	Measurements from	to
BIM	30-10-2008	14-11-2008
CMI	07-12-2008	21-01-2009
BIM	03-02-2009	03-02-2009

The transport of the travelling standards was arranged by door-to-door parcel service.

3. Travelling standard and measurement instructions

3.1. Description of the standard(s)

Description, relevant technical data:

1. Tettex 4720 – for ratios (0.1; 1; 5 and 100) A/5 A; burden max. 5 VA; accuracy ± 0.01 % and ± 0.5 min
   Serial number: 116 426
   Owner: CMI

2. CLA 2.2 – 500 A/5 A; class 0.2; burden 5 VA
   Serial number: 269954/08
   Owner: CMI

3. CLA 3.2 – 1000 A/5 A; class 0.1; burden 5 VA
   Serial number: 269955/08
   Owner: CMI

4. CLB 10 – 2000 A/5 A; class 0.1; burden 5 VA
   Serial number: 269956/08
   Owner: CMI

5. I 523 – 4000 A/5 A; class 0.05; nominal burden 15 VA
   Serial number: 18/1981
   Owner: BIM

Figure 1. CMI Tettex transformer

Figure 2. CMI Tettex transformer

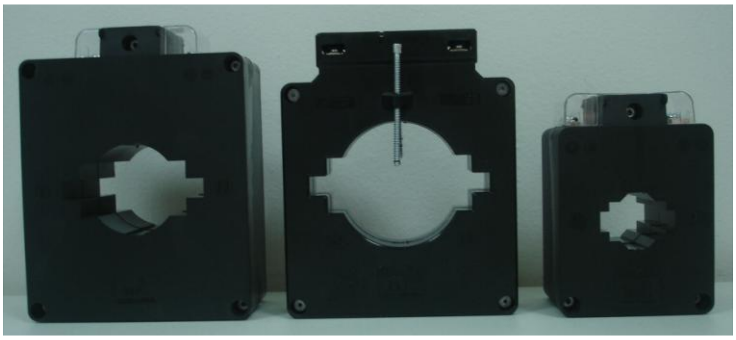


Figure 3. CMI transformers
(from left to right CLA 3.2, CLB 10 and CLA 2.2)

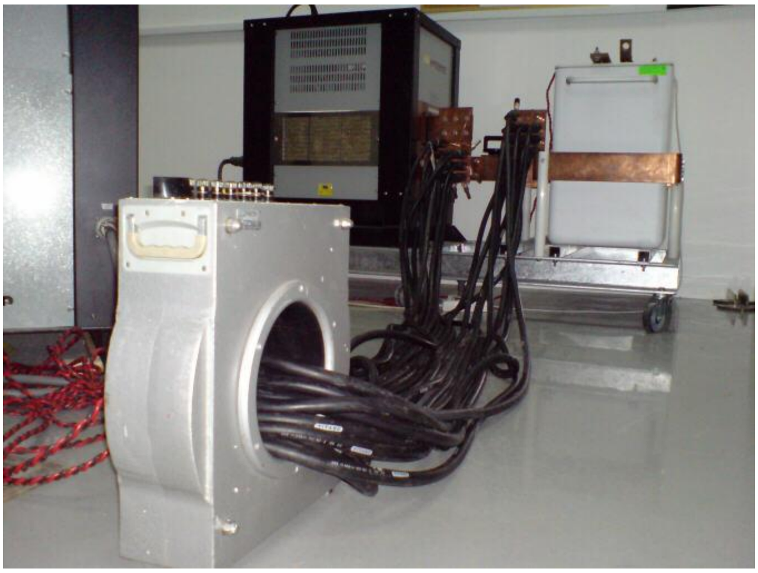


Figure 4. BIM transformer: I 523

Figure 5. CMI transformers

3.2. Quantities to be measured and conditions of measurement

The quantities to be measured are the current error and the phase displacement.

ε_X Current error: The error which a transformer introduces into the measurement of a current and which arises from the fact that the actual transformation ratio is not equal to the rated transformation ratio. The current error expressed in ppm is given by the formula:

ε_X (ppm) = $10^6 \cdot (K_n I_s - I_p) / I_p$

K_n Rated transformation ratio.
I_p Actual primary current.
I_s Actual secondary current when I_p is flowing under the conditions of measurement.
I/I_n Excitation current, expressed in percent of rated current.

δ_X Phase displacement: The difference in phase, expressed in minutes, between the primary and secondary current vectors, the direction of the vectors being chosen in such a way that the angle is zero for a perfect transformer. The phase displacement is said to be positive when the secondary current vector leads the primary current vector.

The measurements were to be performed at a frequency of 50 Hz.

The measurements were to be performed at an ambient temperature of (23 ± 1) ºC.

The comparison was made by measuring the following ratios: primary (4000, 2000, 1000, 500, 100, 5, 1 and 0.5) A / secondary 5 A. All ratios had to be measured with a burden of 5 VA at unity power factor. The measurements were performed at 120 %, 100 %, 20 % and 5 % of the rated current. For ratios with primary current less than 5 A, the point at 5 % was replaced by 10 %.

3.3. Measurement instructions

The participants were asked to follow their usual measurement procedure corresponding to their best measurement capabilities.

3.4. Deviations from the protocol

- The protocol listed the ratio 0.1 A/ 5A as one of the points to be measured. However, CMI was not ready to perform this measurement. Therefore, it was decided to replace this measurement with 0.5 A/5 A.
- There was some deviation from the original schedule in the protocol. The actual schedule of measurements is given in section 2.2 of this report.

4. Methods of measurement

4.1. Method of CMI

Comparison against standard current comparator Tettex 4764 (for range of primary current 5 A up to 4 kA) or Tettex 4761 (for range of primary current 1 A and 0,5 A). Errors were measured by a commercial test set Tettex 2767; used burden Tettex 3691 (set value 5 VA real).
The reference values for both standards (current comparators) can be linked to the results of the international comparison EUROMET.EM-S11 (EUROMET project nr. 612).

4.2. Method of BIM

Comparison against standard current transformer with errors measured on commercial test set Tettex 2767.

- For the the 5 A to 4000 A ratio, the BIM reference standard was an electronically compensated current comparator Tettex 4764.
- For the 0.5 A to 1 A ratio, the BIM reference standard was a passive current transformer MWB type NJ 0.5b.
- Both reference standards were calibrated at PTB in 2006.

5. Measurement results

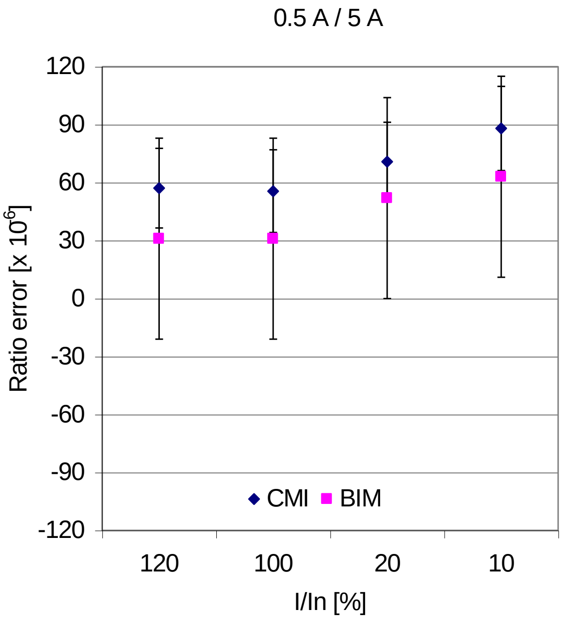
5.1. Results of the participating institutes

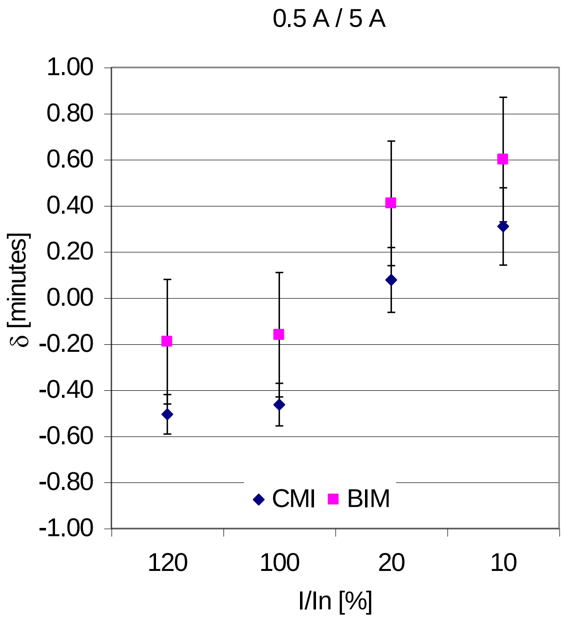
Reported ambient conditions:

	Temperature °C	Relative Humidity %
BIM	23.0 ± 1.0	45 ± 5
CMI	23.0 ± 0.5	40 ± 5

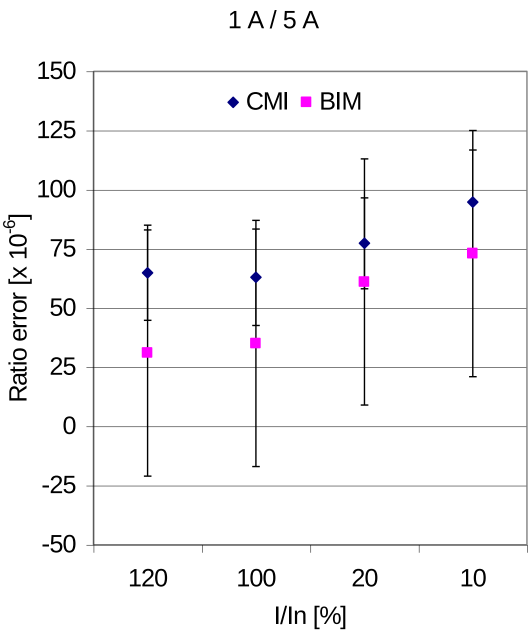
Burden: 5 VA; cos ϕ = 1
Frequency: 50 Hz

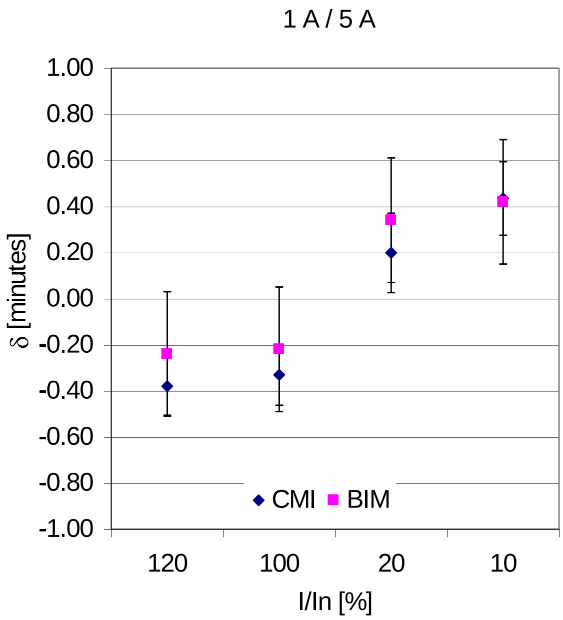
The reported results from both laboratories are given in the graphs and tables on the following pages.



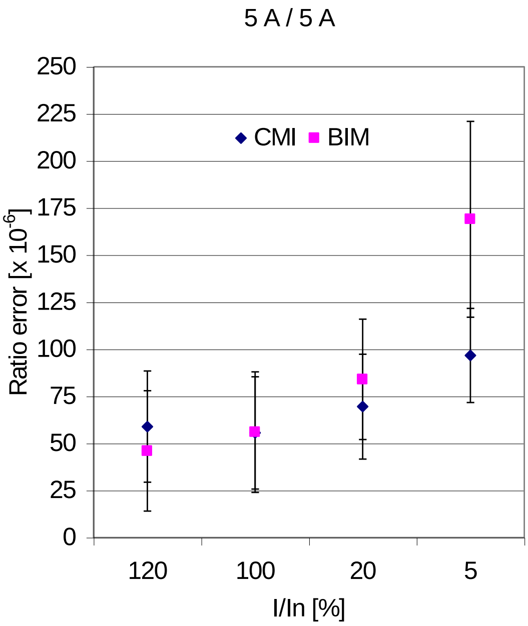


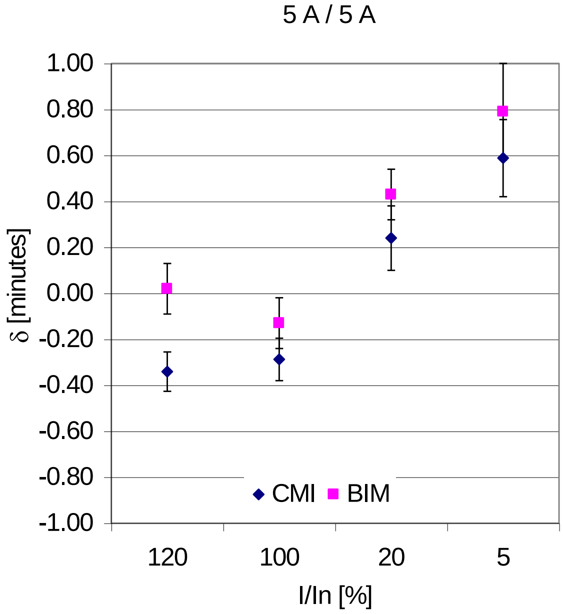
		CMI		**CMI**		**BIM**		**BIM**	
k (A/A)	I/I_n (%)	ε ($x10^{-6}$)	$U(\varepsilon)$ ($x10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)	ε ($x10^{-6}$)	$U(\varepsilon)$ ($x10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)
0.5/5	120	57	21	-0.51	0.09	31	52	-0.19	0.27
0.5/5	100	56	21	-0.46	0.09	31	52	-0.16	0.27
0.5/5	20	71	20	0.08	0.14	52	52	0.41	0.27
0.5/5	10	88	22	0.31	0.17	63	52	0.60	0.27



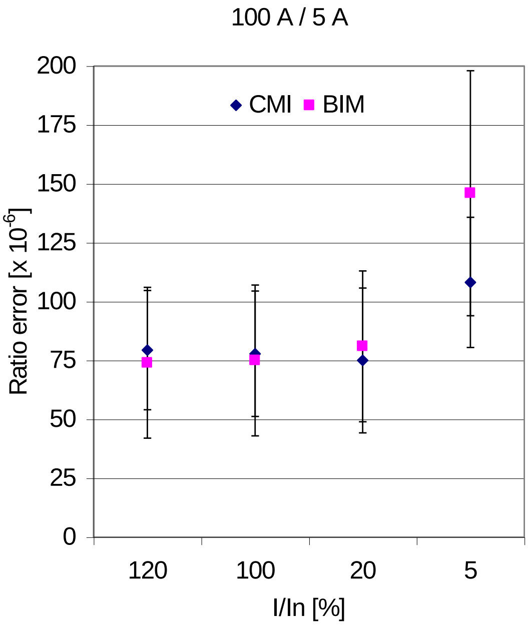


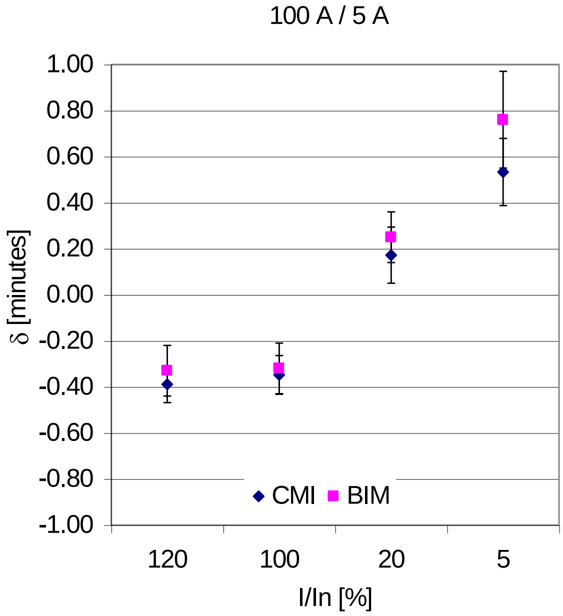
		CMI		CMI		BIM		BIM	
k (A/A)	I/I_n (%)	ε ($x10^{-6}$)	$U(\varepsilon)$ ($x10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)	ε ($x10^{-6}$)	$U(\varepsilon)$ ($x10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)
1/5	120	65	20	-0.38	0.13	31	52	-0.24	0.27
1/5	100	63	20	-0.33	0.13	35	52	-0.22	0.27
1/5	20	77	19	0.20	0.17	61	52	0.34	0.27
1/5	10	95	22	0.43	0.16	73	52	0.42	0.27



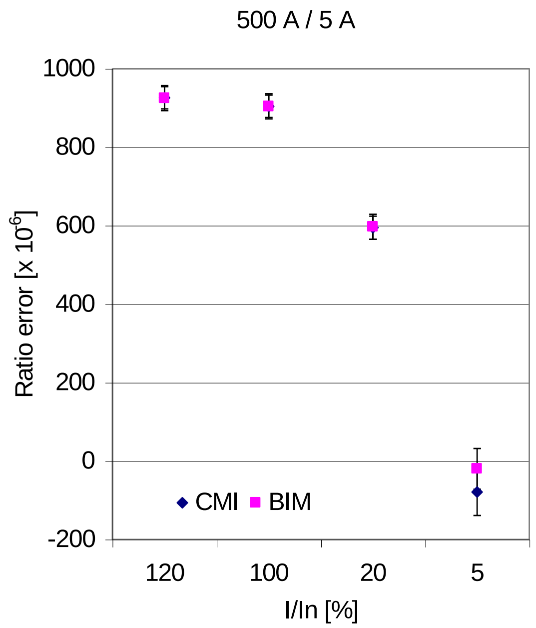


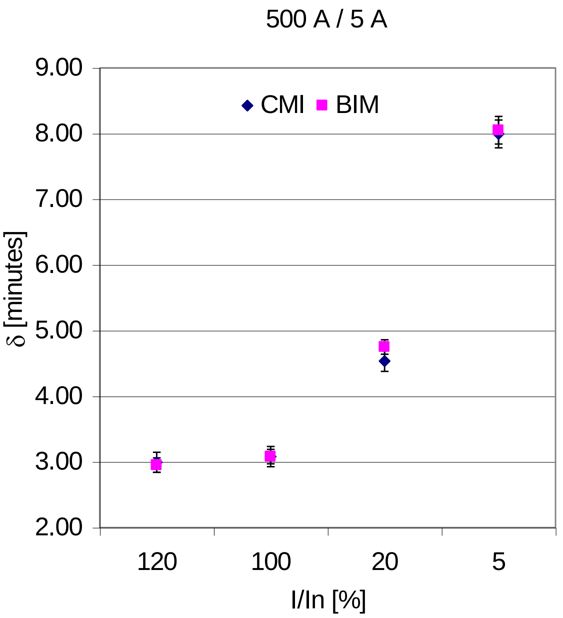
		CMI		CMI		BIM		BIM	
k (A/A)	I/I_n (%)	ε ($\times 10^{-6}$)	$U(\varepsilon)$ ($\times 10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)	ε ($\times 10^{-6}$)	$U(\varepsilon)$ ($\times 10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)
5/5	120	59	30	-0.34	0.09	46	32	0.02	0.11
5/5	100	56	30	-0.29	0.09	56	32	-0.13	0.11
5/5	20	70	28	0.24	0.14	84	32	0.43	0.11
5/5	5	97	25	0.59	0.17	169	52	0.79	0.21



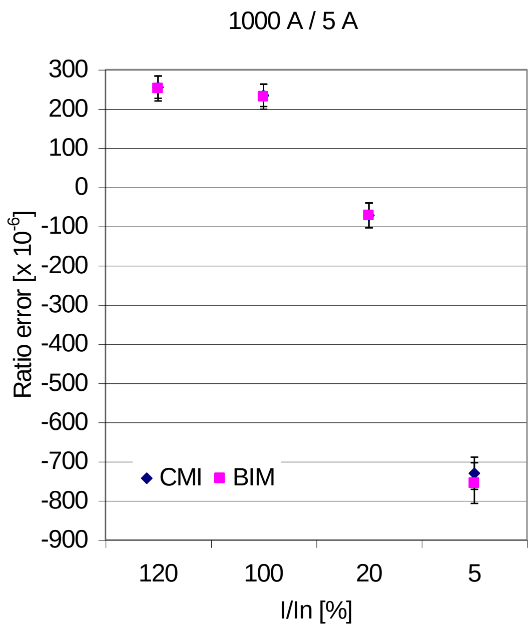


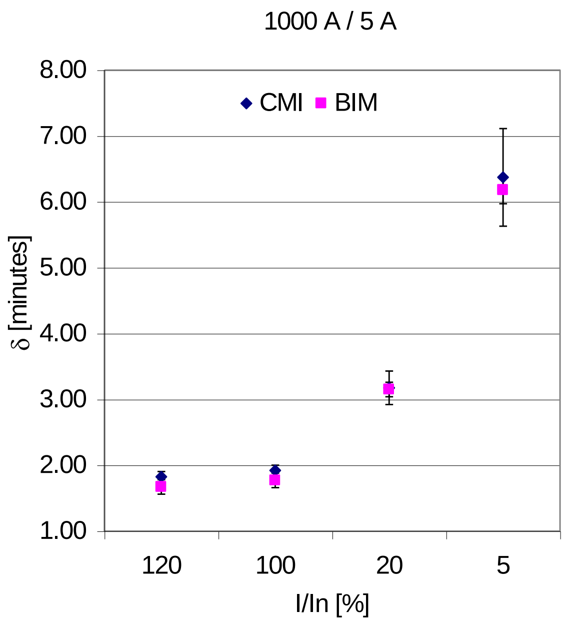
		CMI		CMI		BIM		BIM	
k (A/A)	I/I_n (%)	ε ($\times 10^{-6}$)	$U(\varepsilon)$ ($\times 10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)	ε ($\times 10^{-6}$)	$U(\varepsilon)$ ($\times 10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)
100/5	120	79	25	-0.39	0.08	74	32	-0.33	0.11
100/5	100	78	27	-0.35	0.08	75	32	-0.32	0.11
100/5	20	75	31	0.17	0.12	81	32	0.25	0.11
100/5	5	108	28	0.53	0.15	146	52	0.76	0.21



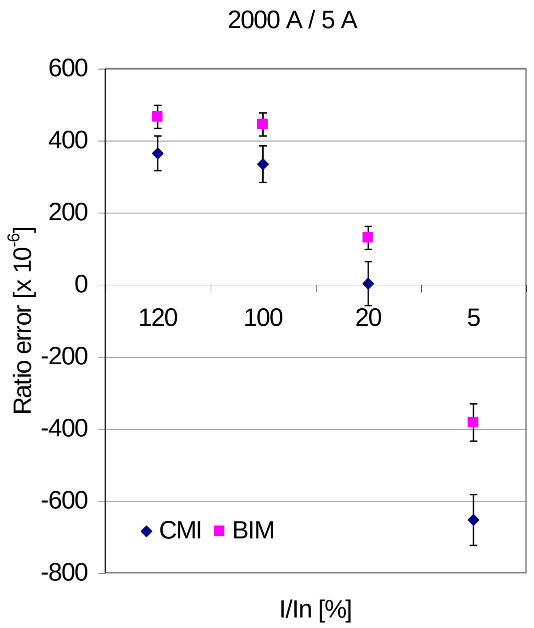


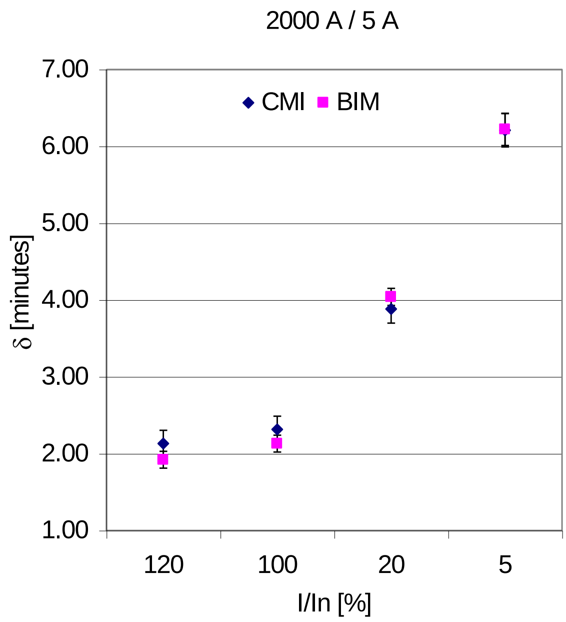
		CMI		CMI		BIM		BIM	
k (A/A)	I/I_n (%)	ε (x10^{-6})	$U(\varepsilon)$ (x10^{-6})	δ (minutes)	$U(\delta)$ (minutes)	ε (x10^{-6})	$U(\varepsilon)$ (x10^{-6})	δ (minutes)	$U(\delta)$ (minutes)
500/5	120	926	28	2.99	0.15	925	32	2.95	0.11
500/5	100	904	29	3.08	0.15	904	32	3.08	0.11
500/5	20	595	29	4.54	0.16	597	32	4.75	0.11
500/5	5	-79	60	7.99	0.21	-20	52	8.05	0.21



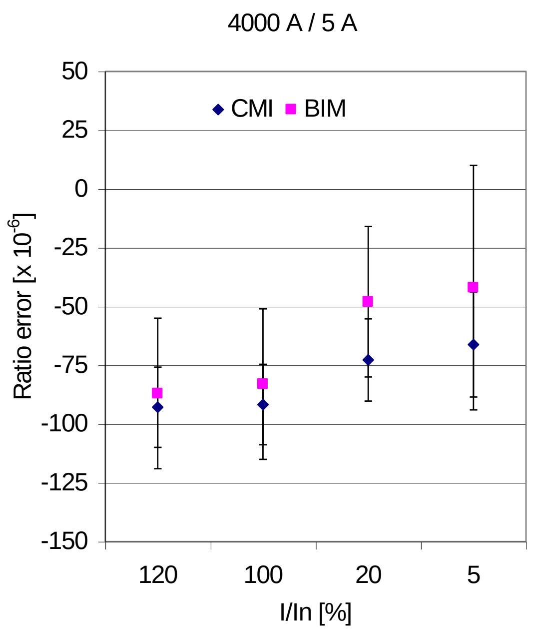


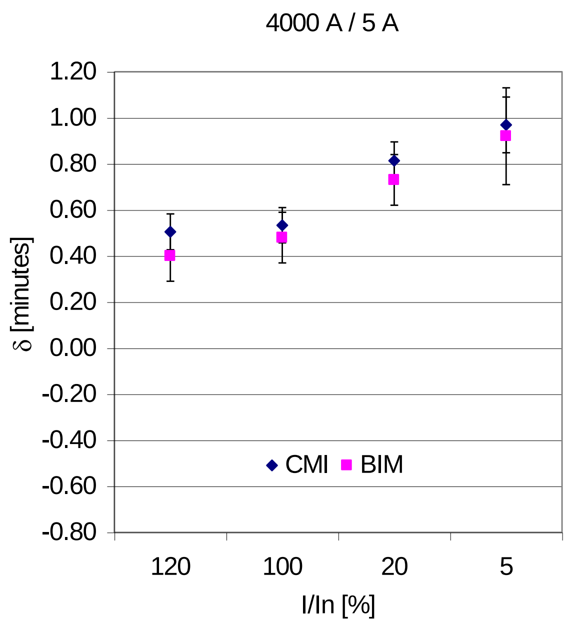
		CMI		CMI		BIM		BIM	
k (A/A)	I/I_n (%)	ε (x10^{-6})	$U(\varepsilon)$ (x10^{-6})	δ (minutes)	$U(\delta)$ (minutes)	ε (x10^{-6})	$U(\varepsilon)$ (x10^{-6})	δ (minutes)	$U(\delta)$ (minutes)
1 000/5	120	255	28	1.82	0.08	252	32	1.67	0.11
1 000/5	100	234	28	1.92	0.08	231	32	1.77	0.11
1 000/5	20	-72	31	3.18	0.25	-72	32	3.15	0.11
1 000/5	5	-730	41	6.37	0.74	-755	52	6.18	0.21





		CMI		CMI		BIM		BIM	
k (A/A)	I/I_n (%)	ε ($\times10^{-6}$)	$U(\varepsilon)$ ($\times10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)	ε ($\times10^{-6}$)	$U(\varepsilon)$ ($\times10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)
2 000/5	120	365	48	2.13	0.17	466	32	1.92	0.11
2 000/5	100	335	51	2.32	0.17	445	32	2.13	0.11
2 000/5	20	3	61	3.88	0.19	130	32	4.04	0.11
2 000/5	5	-654	70	6.21	0.22	-383	52	6.22	0.21





		CMI		CMI		BIM		BIM	
k (A/A)	I/I_n (%)	ε ($\times10^{-6}$)	$U(\varepsilon)$ ($\times10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)	ε ($\times10^{-6}$)	$U(\varepsilon)$ ($\times10^{-6}$)	δ (minutes)	$U(\delta)$ (minutes)
4 000/5	120	-93	17	0.50	0.08	-87	32	0.40	0.11
4 000/5	100	-92	17	0.53	0.08	-83	32	0.48	0.11
4 000/5	20	-73	18	0.81	0.08	-48	32	0.73	0.11
4 000/5	5	-66	22	0.97	0.12	-42	52	0.92	0.21

5.2. Calculation of the reference value and its uncertainty

For the current ratios in the range from 1/5 A/A to 1000/5 A/A, CMI participated in the supplementary comparison EUROMET.EM-S11 with 15 participants. To allow a comparison of the BIM results with the results of the participants in EUROMET.EM-S11, the BIM results are, thus, referred to the reference value of this comparison, as described in Sect. 5.3 below.

For the current ratios 0.5/5 A/A, 2000/5 A/A and 4000/5 A/A, there are no results available from previous comparisons. For this reason, only the degree of equivalence between the two laboratories are determined for these ratios.

5.3. Degrees of equivalence

The degree of equivalence (D_{ij}) (*i* is for rated transformation ratio and *j* is excitation current) of BIM, NCM with respect to the reference values of the comparison EUROMET.EM-S11 is found from the difference between the BIM result and the CMI result, corrected for the difference of the CMI results to the reference values of EUROMET.EM-S11, for both the ratio error ε and the phase displacement δ:

$$D_{ij}(\varepsilon) = \varepsilon_{BIM} - \varepsilon_{CMI} + \chi_{\varepsilon CMI}$$
$$D_{ij}(\delta) = \delta_{BIM} - \delta_{CMI} + \chi_{\delta CMI}$$

where

$\chi_{\varepsilon CMI}$ ($\chi_{\delta CMI}$) is ε_{CMI} (δ_{CMI}) deviation from the comparison reference values of EUROMET.EM-S11.

The relevant uncertainties $u(D_{ij})$ (k=1) are given by:

$$u(D_{ij}(\varepsilon)) = \sqrt{(u(\varepsilon_{BIM}))^2 + (u(\varepsilon_{CMI}))^2 + (u(\varepsilon_{CMI S11}))^2}$$
$$u(D_{ij}(\delta)) = \sqrt{(u(\delta_{BIM}))^2 + (u(\delta_{CMI}))^2 + (u(\delta_{CMI S11}))^2}$$

where it is assumed that there is no significant correlation between the results of BIM and the results of CMI.

The expanded uncertainties $U(D_{ij})$ (k=2) are:

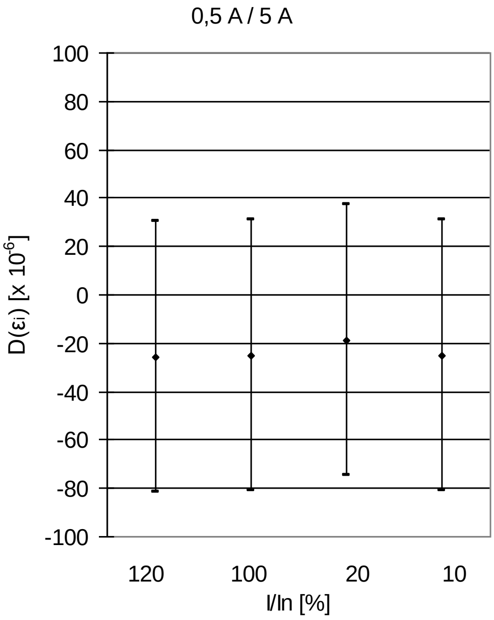
$$U(D_{ij}(\varepsilon)) = 2 \cdot u(D_{ij}(\varepsilon))$$
$$U(D_{ij}(\delta)) = 2 \cdot u(D_{ij}(\delta))$$

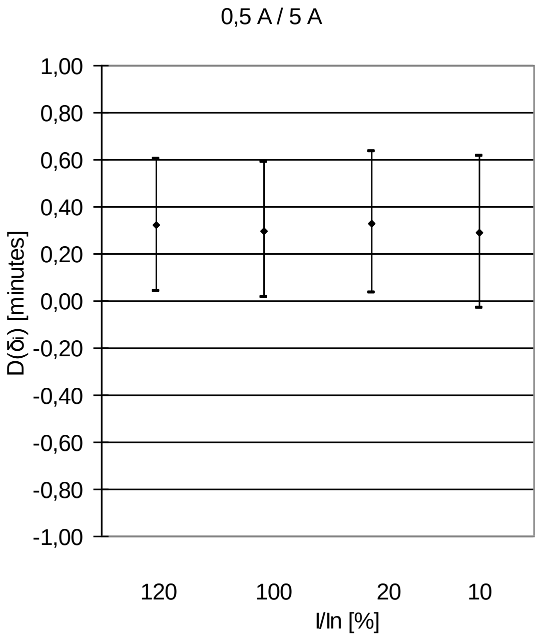
For the current ratios 0.5/5 A/A, 2000/5 A/A and 4000/5 A/A the degree of equivalence (D_{ij}) are:

$$D_{ij}(\varepsilon) = \varepsilon_{BIM} - \varepsilon_{CMI}$$

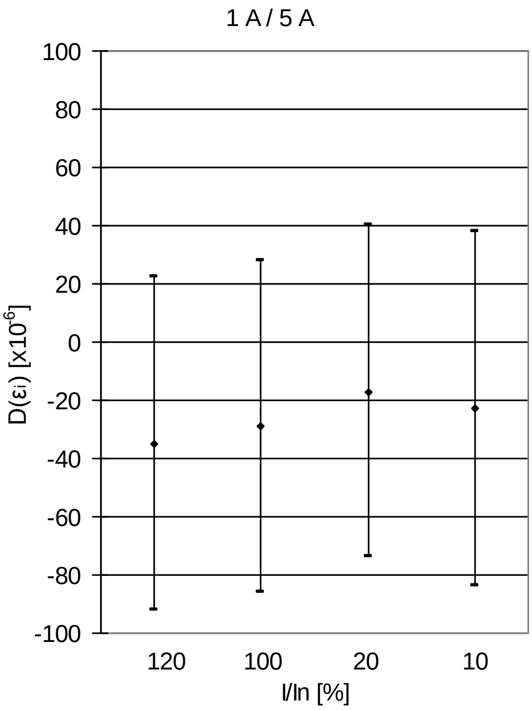
$$D_{ij}(\delta) = \delta_{BIM} - \delta_{CMI}\,.$$

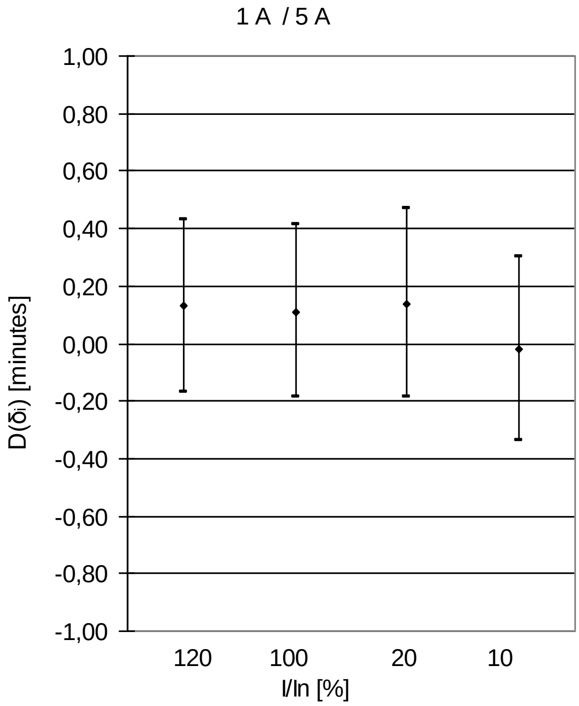
The degrees of equivalence are given in the tables and graphs on the following pages.



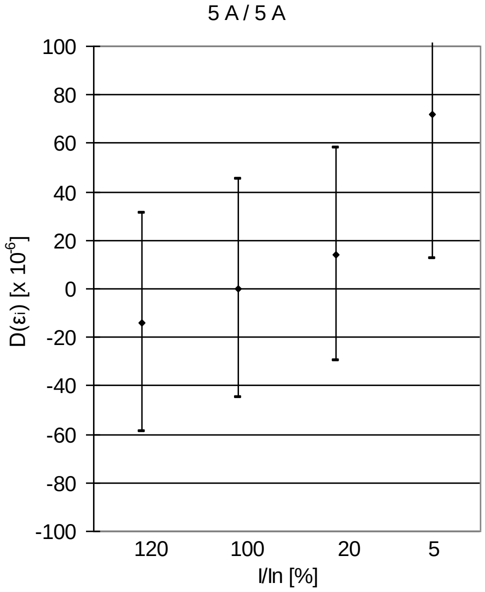


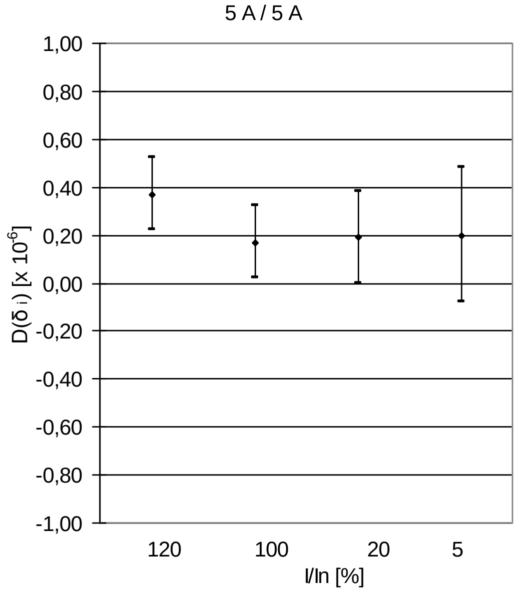
k (A/A)	I/I_n (%)	$D(\varepsilon)$ ($x10^{-6}$)	$U(D(\varepsilon))$ ($x10^{-6}$)	$D(\delta)$ (minutes)	$U(D(\delta))$ (minutes)
0.5/5	120	-26	56	0.32	0.28
0.5/5	100	-25	56	0.30	0.29
0.5/5	20	-19	56	0.33	0.30
0.5/5	10	-25	56	0.29	0.32



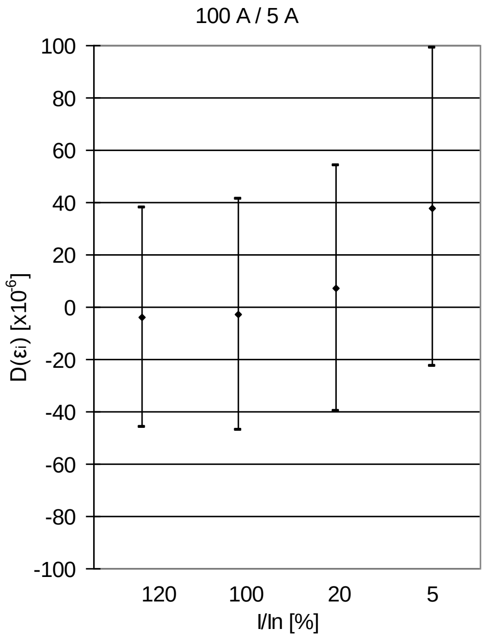


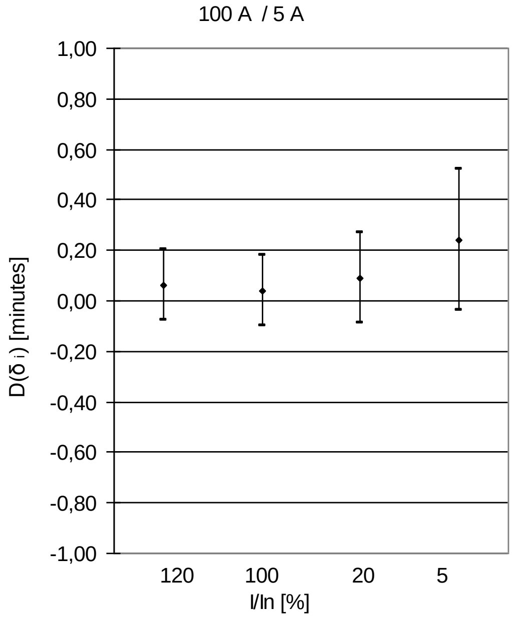
k (A/A)	I/I_n (%)	$D(\varepsilon)$ ($x10^{-6}$)	$U(D(\varepsilon))$ ($x10^{-6}$)	$D(\delta)$ (minutes)	$U(D(\delta))$ (minutes)
1/5	120	-35	57	0.13	0.30
1/5	100	-29	57	0.11	0.30
1/5	20	-17	57	0.14	0.33
1/5	10	-23	61	-0.02	0.32



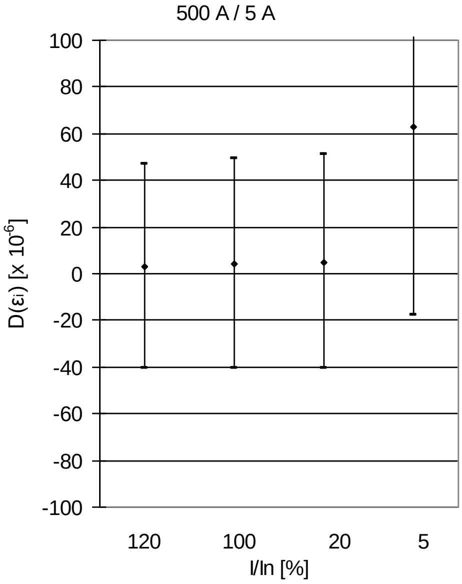


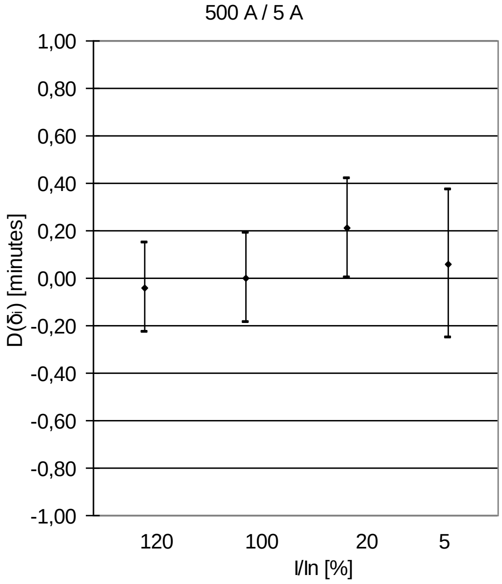
k (A/A)	I/I_n (%)	$D(\varepsilon)$ (x10^{-6})	$U(D(\varepsilon))$ (x10^{-6})	$D(\delta)$ (minutes)	$U(D(\delta))$ (minutes)
5/5	120	-14	45	0.37	0.15
5/5	100	0	45	0.17	0.15
5/5	20	14	44	0.19	0.19
5/5	5	72	60	0.20	0.28



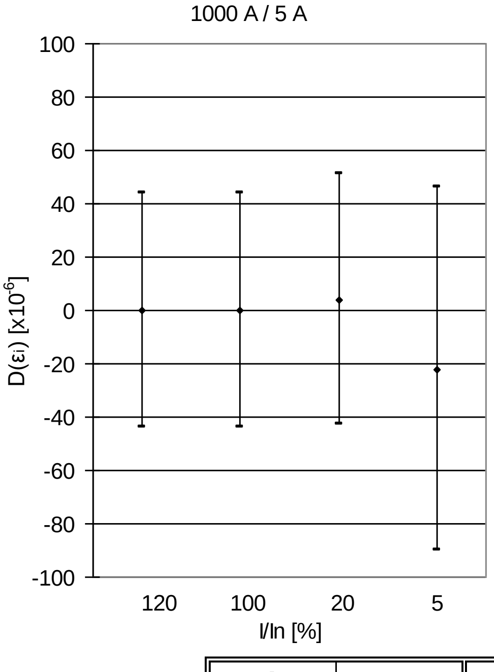


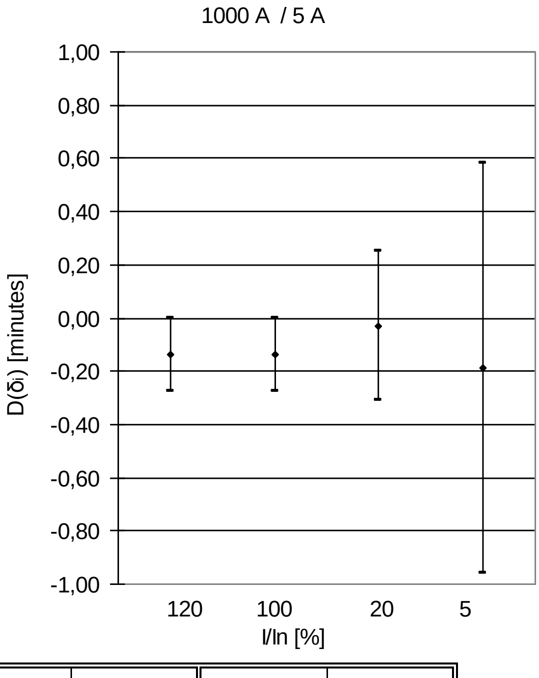
k (A/A)	I/I_n (%)	$D(\varepsilon)$ (x10^{-6})	$U(D(\varepsilon))$ (x10^{-6})	$D(\delta)$ (minutes)	$U(D(\delta))$ (minutes)
100/5	120	-4	42	0.06	0.14
100/5	100	-3	44	0.04	0.14
100/5	20	7	47	0.09	0.18
100/5	5	38	61	0.24	0.28



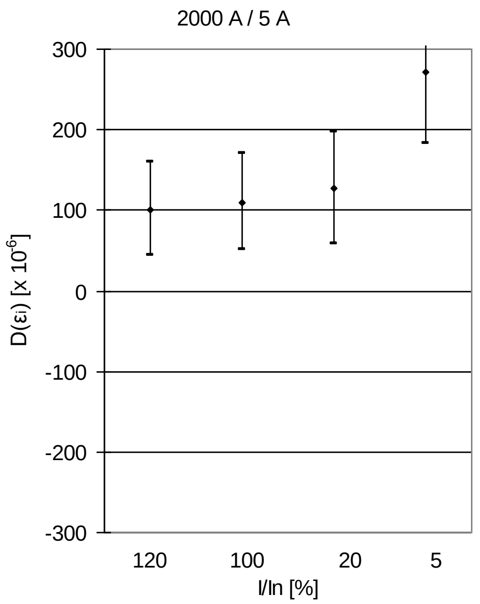


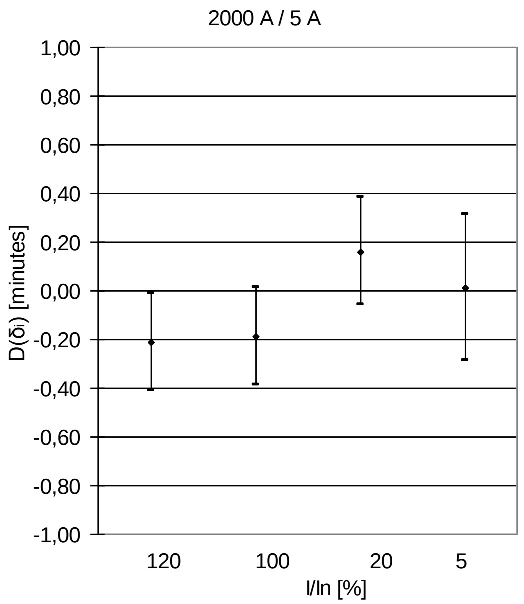
k (A/A)	I/I_n (%)	$D(\varepsilon)$ ($x10^{-6}$)	$U(D(\varepsilon))$ ($x10^{-6}$)	$D(\delta)$ (minutes)	$U(D(\delta))$ (minutes)
500/5	120	3	44	-0.04	0.19
500/5	100	4	45	0.00	0.19
500/5	20	5	46	0.21	0.21
500/5	5	63	81	0.06	0.31



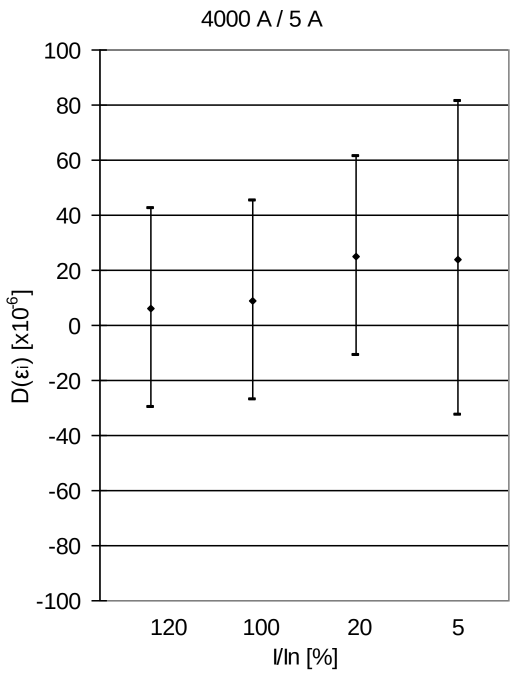


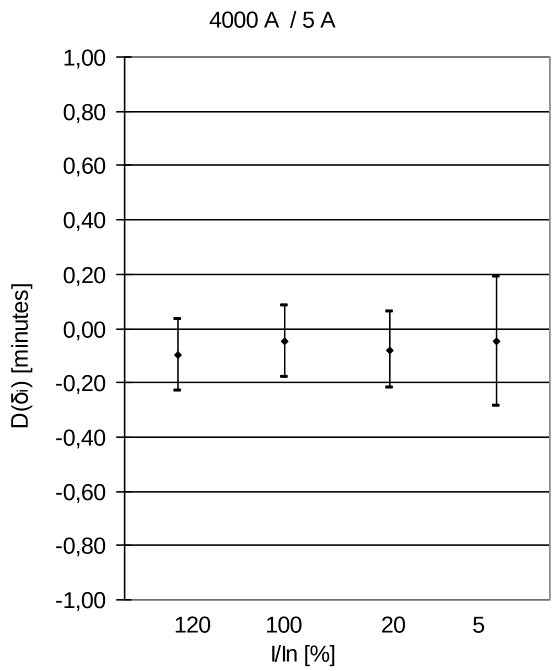
k (A/A)	I/I_n (%)	$D(\varepsilon)$ ($x10^{-6}$)	$U(D(\varepsilon))$ ($x10^{-6}$)	$D(\delta)$ (minutes)	$U(D(\delta))$ (minutes)
1 000/5	120	0	44	-0.14	0.14
1 000/5	100	0	44	-0.14	0.14
1 000/5	20	4	47	-0.03	0.28
1 000/5	5	-22	68	-0.19	0.77





k (A/A)	I/I_n (%)	$D(\varepsilon)$ ($x10^{-6}$)	$U(D(\varepsilon))$ ($x10^{-6}$)	$D(\delta)$ (minutes)	$U(D(\delta))$ (minutes)
2 000/5	120	101	58	-0.21	0.20
2 000/5	100	110	60	-0.19	0.20
2 000/5	20	127	69	0.16	0.22
2 000/5	5	271	88	0.01	0.30





k (A/A)	I/I_n (%)	$D(\varepsilon)$ ($x10^{-6}$)	$U(D(\varepsilon))$ ($x10^{-6}$)	$D(\delta)$ (minutes)	$U(D(\delta))$ (minutes)
4 000/5	120	6	36	-0.10	0.13
4 000/5	100	9	36	-0.05	0.13
4 000/5	20	25	36	-0.08	0.14
4 000/5	5	24	57	-0.05	0.24

6. Summary and conclusions

For all of the current ratio error measurements, except for the measurements at 2 kA, there is a good agreement between BIM, NCM (Bulgaria) and CMI (Czech Republic). The cause of this significant discrepancy was investigated through additional measurements provided by CMI. The results of these measurements are given in Annex D.

For the current phase displacement measurements, the agreement on several measurement points is marginal or there are even small discrepancies. This should also be investigated in further detail.

7. References

[1] IEC 60044-1:2002 Edition 1.2 Instrument Transformers – Part 1: Current Transformers

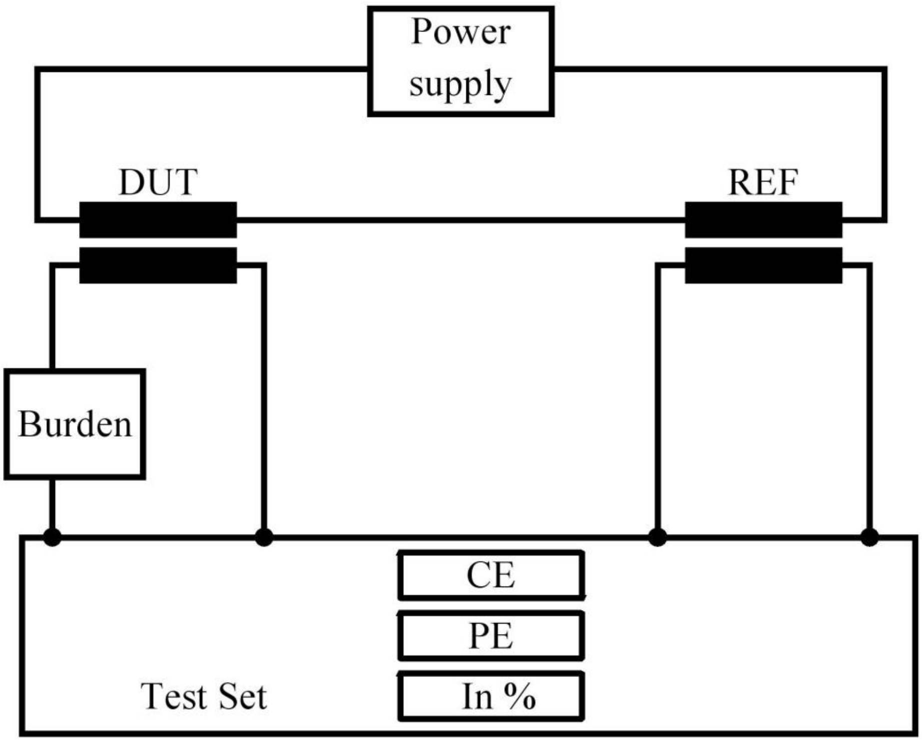
[2] BIPM, IEC, IFCC, ISO,IUPAP, OIML, Guide to the Expression of Uncertainty in Measurement, International Organization for Standardization, Geneva, First Edition 1993

[3] EUROMET.EM-S11: EUROMET Projects 473 and 612 – Comparison of the measurement of current transformers (CTs). Final report.

Annex A. Methods of measurement

A.1 Detailed description of the BIM measurement set-up and method of measurement

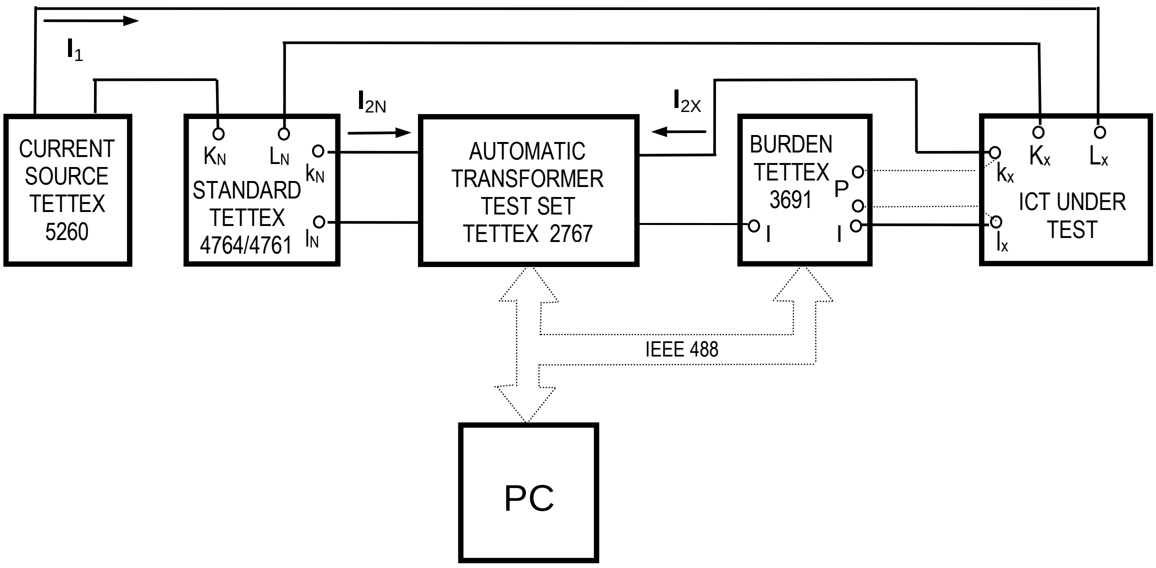
The measurements were performed using an electronic measurement system. The transformer test set measures the transfer standard (marked as DUT) errors by dividing the differential current into two components. These values are evaluated automatically as current error (CE) and phase displacement (PE) by the test set electronics. The display "In %" on the test set indicates the percentage of the nominal ratio.
The burden used is an electronic current burden which compensates the ohmic resistance of the measurement circuit.
A schematic diagram is given below.



Schematic diagram of the BIM set-up

The power supply runs for 6 minutes and must then be switched off for 24 minutes.
Within the 6 minutes, a series of 10 measurements is performed.
This cycle of 30 minutes has been repeated 10 times for each ratio.

A.2 Detailed description of the CMI measurement set-up and method of measurement



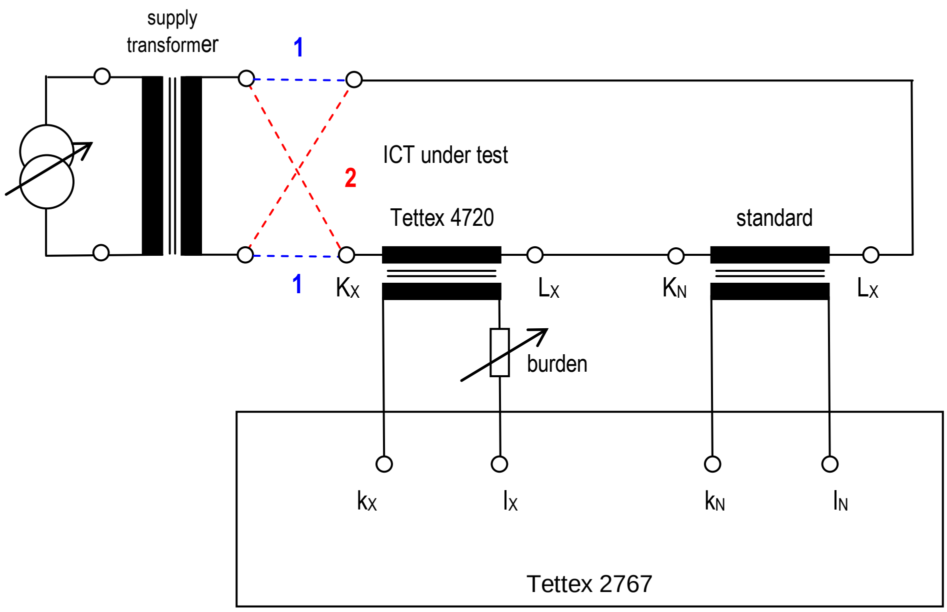
Basic calibration layout in CMI

In above shown connection a set of SEVERAL measurments was performed.

For the CLA, CLB and Tettex transformers:

3 sets in October - November, 2 sets in January - February

For the transfer standard Tettex 4720 each measurement was performed twice, at first at the position "1" and then at the position "2" (with commutated primary current) – see figure below. Resuts of these two measurements were averaged and this mean value was taken as a result of one measurement.



Principle of primary current commutation by measurement of the Tettex 4720 transformer

For the I523 transformer a set of 10 measurements was performed.

Annex B. Uncertainty budgets

B.1 Detailed uncertainty budget for BIM

Uncertainty Budget: Current error in percent 0,5A/5A 100%

	Source of uncertainty	Distribution	*Value*	*Type*	$u(x_i)$	ν_i	c_i	$u_i(y)$
1	repeatability	Normal	-0.00786	A	6.56E-05	9	1	6.56E-05
2	calibration of the reference standard	Normal	0.011	B	0.0025	50	1	0.0025
3	error in the bridge	Rectangular	0	B	0.000187	infinity	1	0.000187
4	drift of the reference standard	Rectangular	0	B	0.000289	infinity	1	0.000289
5	resolution of test set	Rectangular	0	B	2.89E-05	infinity	1	2.89E-05
6	error due to burden setting	Rectangular	0	B	5.77E-05	infinity	1	5.77E-05
7	error due to current setting	Rectangular	0	B	7.22E-05	infinity	1	7.22E-05
8	circuit and temperature influence	Rectangular	0	B	5.77E-05	infinity	1	5.77E-05
y		Normal	0.00314		0.002527	52.18759		
					k =	2.0491		
		Result =	0.0031		*U* =	0.0052		

Uncertainty Budget:Phase displacement in minutes 0,5A/5A 100%

i	Source of uncertainty	Distribution	*Value*	*Type*	$u(x_i)$	ν_i	c_i	$u_i(y)$
1	repeatability	Normal	-0.3611	A	0.0002161	9	1	0.000216
2	calibration of the reference standard	Normal	0.2	B	0.1	50	1	0.1
3	error in the bridge	Rectangular	0	B	0.006399	infinity	1	0.006399
4	drift of the reference standard	Rectangular	0	B	0.0866	infinity	1	0.0866
5	resolution of test set	Rectangular	0	B	0.00289	infinity	1	0.00289
6	error due to burden setting	Rectangular	0	B	0.00204	infinity	1	0.00204
7	error due to current setting	Rectangular	0	B	0.002448	infinity	1	0.002448
8	circuit and temperature influence	Rectangular	0	B	0.00204	infinity	1	0.00204
y		Normal	-0.1611		0.1325263	infinity		
					k =	2.0000		
		Result =	-0.16		*U* =	0.27		

Uncertainty Budget: **Current error in percent 1kA/5A 100%**

	Source of uncertainty	Distribution	*Value*	*Type*	$u(x_i)$	ν_i	c_i	$u_i(y)$
1	repeatability	Normal	0.023101	A	3.82E-06	9	1	3.82E-06
2	calibration of the reference standard	Normal	0	B	0.0015	50	1	0.0015
3	error in the bridge	Rectangular	0	B	0.000213	infinity	1	0.000213
4	drift of the reference standard	Rectangular	0	B	0.00031	infinity	1	0.00031
5	resolution of test set	Rectangular	0	B	2.89E-05	infinity	1	2.89E-05
6	error due to burden setting	Rectangular	0	B	5.77E-05	infinity	1	5.77E-05
7	error due to current setting	Rectangular	0	B	7.22E-05	infinity	1	7.22E-05
8	circuit and temperature influence	Rectangular	0	B	5.77E-05	infinity	1	5.77E-05
y		Normal	0.023101		0.001551	57.08771		
					k =	2.0448		
		Result =	0.0231		*U* =	0.0032		

Uncertainty Budget:Phase displacement in minutes 1kA/5A 100%

i	Source of uncertainty	Distribution	*Value*	*Type*	$u(x_i)$	ν_i	c_i	$u_i(y)$
1	repeatability	Normal	1.77407	A	0.0002458	9	1	0.000246
2	calibration of the reference standard	Normal	0	B	0.05	50	1	0.05
3	error in the bridge	Rectangular	0	B	0.008846	infinity	1	0.008846
4	drift of the reference standard	Rectangular	0	B	0.0154	infinity	1	0.0154
5	resolution of test set	Rectangular	0	B	0.00289	infinity	1	0.00289
6	error due to burden setting	Rectangular	0	B	0.00204	infinity	1	0.00204
7	error due to current setting	Rectangular	0	B	0.002448	infinity	1	0.002448
8	circuit and temperature influence	Rectangular	0	B	0.00204	infinity	1	0.00204
y		Normal	1.77407		0.0532742	64.4403153		
					k =	2.0395		
		Result =	1.77		*U* =	0.11		

Uncertainty Budget: Current error in percent 4kA/5A 100%

i	Source of uncertainty	Distribution	Value	Type	$u(x_i)$	ν_i	c_i	$u_i(y)$
1	repeatability	Normal	-0.00827	A	8.37E-06	9	1	8.37E-06
2	calibration of the reference standard	Normal	0	B	0.0015	50	1	0.0015
3	error in the bridge	Rectangular	0	B	0.000188	infinity	1	0.000188
4	drift of the reference standard	Rectangular	0	B	0.00031	infinity	1	0.00031
5	resolution of test set	Rectangular	0	B	2.89E-05	infinity	1	2.89E-05
6	error due to burden setting	Rectangular	0	B	5.77E-05	infinity	1	5.77E-05
7	error due to current setting	Rectangular	0	B	7.22E-05	infinity	1	7.22E-05
8	circuit and temperature influence	Rectangular	0	B	5.77E-05	infinity	1	5.77E-05
y		Normal	-0.00827		0.001547	56.61524		
					k =	2.0451		
		Result =	-0.0083		*U* =	0.0032		

Uncertainty Budget:Phase displacement in minutes 4kA/5A 100%

i	Source of uncertainty	Distribution	Value	Type	$u(x_i)$	ν_i	c_i	$u_i(y)$
1	repeatability	Normal	0.47874	A	0.0009608	9	1	0.000961
2	calibration of the reference standard	Normal	0	B	0.05	50	1	0.05
3	error in the bridge	Rectangular	0	B	0.006603	infinity	1	0.006603
4	drift of the reference standard	Rectangular	0	B	0.0154	infinity	1	0.0154
5	resolution of test set	Rectangular	0	B	0.00289	infinity	1	0.00289
6	error due to burden setting	Rectangular	0	B	0.00204	infinity	1	0.00204
7	error due to current setting	Rectangular	0	B	0.002448	infinity	1	0.002448
8	circuit and temperature influence	Rectangular	0	B	0.00204	infinity	1	0.00204
y		Normal	0.47874		0.0529561	62.9150174		
					k =	2.0405		
		Result =	0.48		*U* =	0.11		

B.2 Detailed uncertainty budget for CMI

Uncertainty budget was calculated for current transformer I523, Ser. No. 18 1981, transformation ratio 4 kA/5 A

Transformation ratio: 4 kA/5 A

Burden: 5 VA real

Point of measurement: I_1 = 100 % I_N

Used standards: Current comparator Tettex 4764, Ser. No. 143 473

Errors: ±10 ppm and ±0,05 '

Automatic transformer test set Tettex 2767, Ser. No. 141 727

Limits of errors:

Ratio error: ± 0,5 % RDG ± (0,5 % FS or 10 ppm) - greater of both values applies

Used range: 0,1999 %

Phase displacement: ± 0,5 % RDG ± (0,5 % FS or 0,034') - greater of both values applies

Used range: 1,999' and 19,99'

Programmable electronic current burden Tettex 3691, Ser. No. 141 474

Ratio error uncertainty

Source of uncertainty	value (ppm)	type	probable distribution	divisor	C_i	u_i (ppm)	V_i
standard current comparator	10	B	rectangular	√3	1	5.8	∞
transformer test set	11	B	rectangular	√3	1	6.1	∞
Burden	2	B	rectangular	√3	1	1.2	∞
circuit configuration	2	B	rectangular	√3	1	1.2	∞
repeatability	1	A	normal	1	1	0.9	9
combined uncertainty						8.6	
expanded uncertainty, k = 2				**U (ε_I) (ppm)**		**17.2**	

Phase displacement uncertainty

Source of uncertainty	value (')	type	probable distribution	divisor	C_i	u_i (')	V_i
standard current comparator	0.050	B	rectangular	√3	1	0.03	∞
transformer test set	0.037	B	rectangular	√3	1	0.02	∞
Burden	0.010	B	rectangular	√3	1	0.01	∞
circuit configuration	0.010	B	rectangular	√3	1	0.01	∞
repeatability	0.011	A	normal	1	1	0.01	9
combined uncertainty						0.04	
expanded uncertainty, k = 2				**U(δ_I) (′)**		**0.08**	

Explanatory notes:

C_i sensitivity coefficient

u_i standard uncertainty

V_i degrees of freedom

Annex C. Comparison protocol

Comparison of the measurements of current transformers (CTs)

Introduction

This comparison is organized in the framework of, and financed by:
Phare project BG 2005/017-353.02.02, LOT 1.
This project runs from March 2008 to the end of February 2009.

Current transformer measurements made by the participating NMIs support a large number of measurements made in the electrical generation, supply and distribution industries in their own countries. They also support many transformer manufacturers.

Participants

BIM - NCM, Sofia, Bulgaria
Address:
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General Directorate "National Centre of Metrology"
Section "Electric Energy Measurements"
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Emil Dimitrov
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CMI, Czech Metrological Institute, Prague, Czech Republic
Address:
Czech Metrology Institute
Laboratory of Instrument Transformers
V Botanice 4
CZ-150 72 Prague 5
Renata Styblíková
Tel: +420 257 288 335
rstyblikova@cmi.cz

Quantities to be measured

ε_X Current error: The error which a transformer introduces into the measurement of a current and which arises from the fact that the actual transformation ratio is not equal to the rated transformation ratio. The current error expressed in ppm is given by the formula:

$$\text{Current error (ppm)} = 10^6.(K_n I_s - I_p) / I_p$$

K_n Rated transformation ratio.
I_p Actual primary current.
I_s Actual secondary current when I_p is flowing under the conditions of measurement.
I/I_n Excitation current, expressed in percent of rated current.

δ_X Phase displacement: The difference in phase, expressed in minutes, between the primary and secondary current vectors, the direction of the vectors being so chosen that the angle is zero for a perfect transformer. The phase displacement is said to be positive when the secondary current vector leads the primary current vector.

Co-ordinator

The co-ordinator of this comparison in the Phare project is:
Erik Dierikx
NMI Van Swinden Laboratorium BV
Tel: +31 15 269 1688
edierikx@nmi.nl

Support group of the comparison

The support group of this comparison consists of:
The contact persons from the participating laboratories and the co-ordinator of the comparison.

Travelling standards

1. Tettex 4720 – for ratios (0.1; 1; 5 and 100) A/5 A; burden max. 5 VA; accuracy ± 0.01 % and ± 0.5 min
   Serial number: 116 426
   Owner: CMI

2. CLA 2.2 – 500 A/5 A; class 0.2; burden 5 VA
   Serial number: 269954/08
   Owner: CMI

3. CLA 3.2 – 1000 A/5 A; class 0.1; burden 5 VA
   Serial number: 269955/08
   Owner: CMI

4. CLB 10 – 2000 A/5 A; class 0.1; burden 5 VA
   Serial number: 269956/08
   Owner: CMI

   The insurance value of CMI owned transformers is 1 500 EUR

5. I 523 – 4000 A/5 A; class 0.05; nominal burden 15 VA
   Serial number: 18/1981
   Insurance value: 1 000 EUR
   Owner: NCM

Transportation information

CMI and NCM will be responsible for arranging transportation to each other. CMI and NCM should inform each other when the travelling standards are sent.
Each laboratory is responsible for proper insurance of the standards during the stay in its laboratory and during transport to the other laboratory.

Circulation scheme and timetable

Including time for transportation:

For the CMI transformers:

Laboratory	**Period of measurements**
CMI, Czech Republic	20 October 2008 to 10 November 2008
NCM, Bulgaria	10 November 2008 to 1 December 2008
CMI, Czech Republic	1 December 2008 to 7 December 2008

For the NCM transformer:

Laboratory	**Period of measurements**
NCM, Bulgaria	20 October 2008 to 10 November 2008
CMI, Czech Republic	10 November 2008 to 1 December 2008
NCM, Bulgaria	1 December 2008 to 7 December 2008

Measurements

Measurements should be made at frequency 50 Hz.

Measurements should be made at (23 ± 1) ºC.

Comparison will be made by measuring following ratios: 4000, 2000, 1000, 500, 100, 5, 1 & 0.1/ secondary 5 A. All ratios should be measured with a burden 5 VA at unity power factor. Measurements will be performed with the following % of rated current: 120, 100, 20 and 5. For ratios with primary current less than 5 A the point 5 % should be replaced with 10 %.

Report

The report should be sent to the co-ordinator as soon as possible (or at least within 6 weeks) after completing the measurements. In addition to the results, the report should contain a brief description of the measurement technique and all relevant conditions.

The report should contain an uncertainty budget. The uncertainty calculations should comply with the requirements of the GUM for the calculation of the uncertainty of measurement. The report should include the degrees of freedom and the complete budget of uncertainty.

The co-ordinator, as independent party, will collect all the measurement reports and will keep them confidential until all reports have been received. When all reports have been collected, they will be sent to NCM who will do the data analysis and who will prepare the final report. The co-ordinator will observe that the original data (including uncertainties) are not changed anymore.

,by the end of January 2009, the Report - Draft A, will be prepared. The Draft B Report has to be completed before the end of the project, which is 28 February 2009.

Computation of the reference value

The reference values in this comparison will be the results from the linking laboratory. Therefore, for most of the measurements, CMI will be the linking laboratory. Only for the ratio 0.1 A/ 5 A, NCM will be the linking laboratory.

Emil Dimitrov
September 2008

Annex A

Uncertainty budget table

Annex B

Summary of results form (Table)

Annex D. Optional measurements

The CLB 10, k_I = 2 kA/5 A at a burden 5 VA real is measured in November 2008 and in February 2009.

After result processing in VSL pilot lab CMI tried to explore a source of big result differences between CMI and BIM. It has emerged that values and measured errors depend strongly on primary cable position in the transformer opening. For this reason in March an error dependence on primary cable position has been explored (see Fig. 1, CMI primary conductor was formed by two round parallel cables).

Results of these measurements are given in Table 1. Results for the "position 0" are given partly by results measured in February and partly by supplementary results measured later in March.

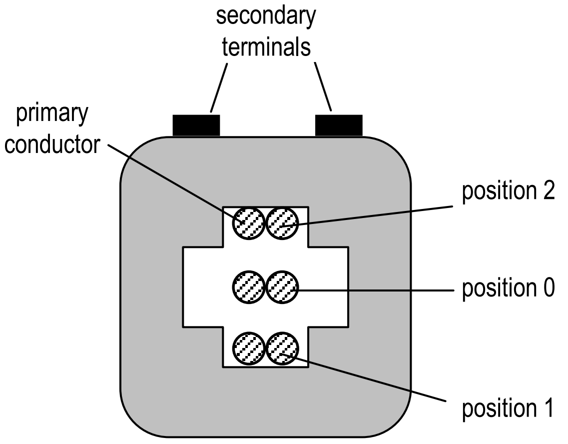

Fig. 1

It can be assumed from results that by the measurements performed in CMI in November the primary conductor was placed probably in the top part of the transformer opening. The results of BIM (the last column in Table 1) correspond rather to the "position 1" – primary cables on the bottom of the transformer opening which was confirmed by BIM laboratory that CLB 10 measurements was performed with copper bus placed on the bottom of the transformer opening.

We assume that the error dependence on primary conductor position depends on small cross section of the transformer core (toroidal core dimensions: Ø = 123/108 mm, h = 15 mm).

	CMI			BIM
	position 0	position 1	position 2	
I [%]	ε_I (ppm)	ε_I (ppm)	ε_I (ppm)	ε_I (ppm)
120	397	467	355	466
100	369	441	319	445
20	45	188	-14	130
5	-602	-390	-645	-383

I [%]	δ_I (′)	δ_I (′)	δ_I (′)	δ_I (′)
120	2,23	2,25	1,70	1,92
100	2,42	2,45	1,88	2,13
20	3,97	3,93	3,37	4,04
5	6,35	6,15	5,45	6,22

Table 1.