State Enterprise "All-Ukrainian state research and production center
of standardization, metrology, certification consumers' right protection"
(SE "Ukrmetrteststandard")

Approved by the chairman of TC 1.3 COOMET
Chairman of TC 1.3 COOMET
_______________ T. Kolomiets

Final report
on COOMET 344/UA/05
Supplementary Comparison of 50/60 Hz Power
(COOMET.EM-S2)

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Participants in the comparisons:
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BelGIM, Republic of Belarus
BIM, Bulgaria

Kyiv, Ukraine

Abstract
To support the Calibration and Measurement Capabilities (CMCs) declared by members of COOMET in the framework of the CIPM-MRA, the COOMET Supplementary Comparison was organized. Electrical standard of low-frequency (50/53 Hz*) power were compared at 3 National Metrology Institutes (NMIs) of COOMET to establish the relationship between the electrical units of AC power at these laboratories.*
The results of this comparison are described. The differences between almost all laboratory's values and the reference values were within the expanded measurement uncertainties at a coverage factor k=2 [1].

Table of Content

1 Introduction

The COOMET supplementary comparison of the electrical power standard in range of frequencies 50 Hz and 53 Hz (comparison number in KCDB – COOMET.EM-S2) which conducted under the COOMET 344/UA/05.
This project is the comparison of National standards of electrical power and power factor between the countries – participants of the regional metrological organization COOMET. In these comparison took part three national metrology institutes: SE "Ukrmetrteststandard" (Ukraine), BelGIM (Belarus), BIM (Bulgaria). Relevance of the comparison results are expected at the level of better than 0.005%.
The SE "Ukrmeterteststandard" (UMTS) was selected as the pilot laboratory, which is responsible for providing travelling standard, coordinating the schedule, collecting and analyzing the comparison data, and preparing the draft report.

2 Participants and organization of the comparison
2.1 Participants

There are 3 participants in this comparison. The acronyms of the laboratories and their countries are given in Table 1.

Table 1 List of participants, in the sequence of measurements performed

№	NMI	Abbreviation of NMI	Address	Contact person	e-mail, phone, fax
1	State Enterprise "All-Ukrainian state research and production center of standardization, metrology, certification consumers' right protection" (SE "Ukrmetrteststandard")	UMTS	4, Metrologichna Str., 03680, Kyiv, Ukraine	O. Velychko, O. Akhmadov	ermatec@ukrcsm.kiev.ua Tel./Fax: +38 044 526 5568
2	Belarusian State Institute of Metrology	BelGIM	93 Starovilensky Ave, 220053, Minsk, Belarus	A. Volkodatov	volkodatov@belgim.by Tel.: +375 17 2331510 Fax: +375 17 233 5799
3	Bulgarian Institute of Metrology	BIM	21 6-th September Str, 1000, Sofia, Bulgaria	A.G. Yovcheva	a.yovcheva@bim.government.bg Tel.: (+3592) 9702 98 Fax: (+3592) 9702 735

2.2 Organization of the comparison

The participants had one month for conducting measurements and returning travelling standard to the pilot laboratory. The approximate period for measurement conducting are 2 weeks, the rest time (2 weeks) is available for transportation of travelling standard [2].
In the case of unexpected delays, the coordinator of the comparison and the next participant should be notified by fax or by e-mail. The list of dates of measurements is given in Table 2.

Table 2 The list of dates of measurements

Laboratory	Dates of measurements	Date of report
UMTS	January 2008	–
BelGIM	February 2009	May 2009
UMTS	June 2009 – April 2010	–
BIM	May 2011 – June 2011	July 2011
UMTS	November 2011	December 2011

3. Travelling standard and measurement instruction

3.1. Description of the travelling standard

Selected travelling standard is Radian Research RM 15-04 precision electric power standard s/n 4418 (RM 15-04). RM 15-04 is the most versatile portable standard available for providing as many as 16 different measurement functions which are configured by special way.

RM 15-04 is capable for measuring electrical active power. With the help of button “SELECT” can be selected the measured value: Wh/kW, VAh/kVA, VARh/kVAR, mVh/V, mAh/A. In Supplementary Comparison of 50/60 Hz Power was measured electrical active power so it had to be selected kilo Watt (kW) in the menu of button “SELECT” and the constant of the frequency output is 100 000 000 pulse/kWs. The measure process of measuring active power is fully automatically with the help of connector output count number of pulses which is directly proportional to the measured active power. The output frequency of RM 15-04 is 50 000 pulse/s.

RM 15-04 is well-suited for test applications that require multiple measurements with high accuracy and stability. In addition to its auto ranging capabilities, RM 15-04 features three summing current inputs which can be used to perform closed link testing. A test current of 150 amps maximum can be used by applying 50 amps to each of the inputs. All errors are in percent of reading at any combination of the normal operating conditions.

Note: Stability is included within the maximum accuracy specifications for all measurement functions. All other measurement functions other than Watt hours and VAR hours have an accuracy of ± 0.1% maximum. Power factor is referenced to Watt hours and it is also assumed that voltage is the reference vector.

Appearance of RM 15-04 is shown on Figure 1.

Figure 1 Travelling standard RM 15-04

Travelling standard RM 15-04 is single-phase electric power meter, works on principles of digital processing of electrical current and voltage signals.

Main characteristics of travelling standard RM 15-04:

– input voltage: 60…600 V (RMS);

– input current: 0,2…50 A (RMS);

– frequency of the input voltage and current signals: 48…62 Hz;

– constant of the frequency output: 100 000 000 pulse/kWs;

– supply voltage: 80…600 V (RMS);
– working range of the temperature: 10 °C…–40 °C;
– keeping range of the temperature: 0 °C...+60 °C;
– working range of the humidity: 0...85%;
– dimensions: 140×140×195 mm;
– weight: 3 kg.

Physical dimension of the travelling standard RM 15-04 is shown on Figure 2.

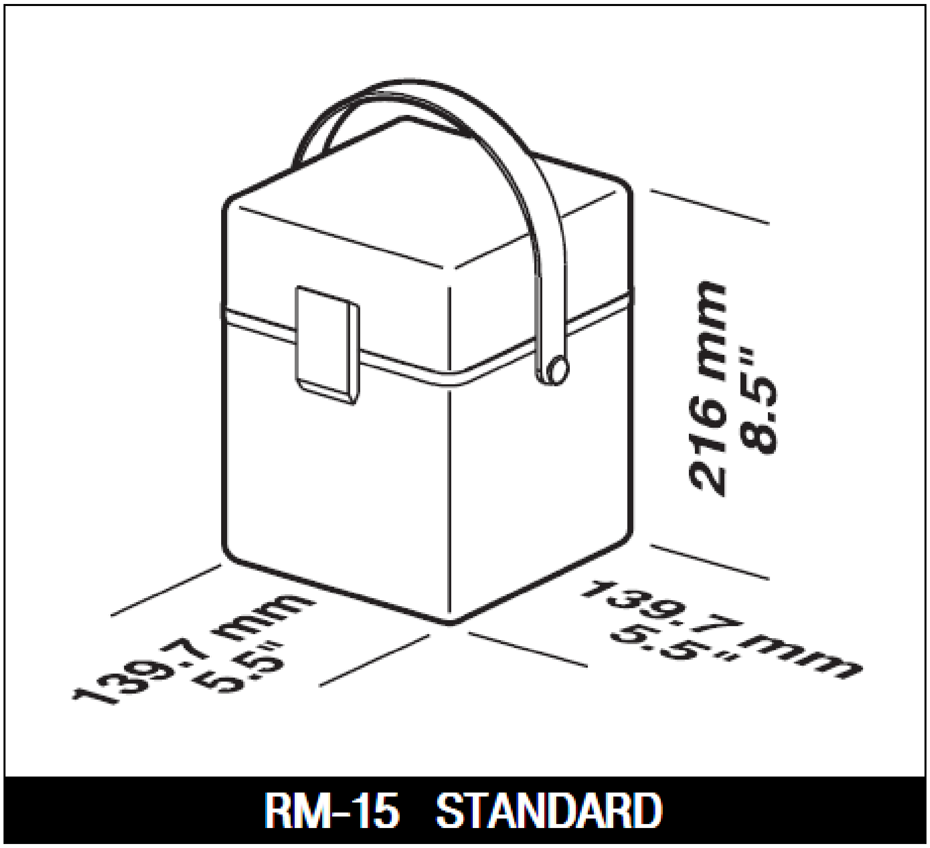


Figure 2 Physical dimension of travelling standard RM 15-04

User manual for travelling standard is attached. The participants of the comparison should have learned the documentation before comparison conducting.

3.2 Unpacking and packing

Travelling standard will be transported in a container, which is designed for safe transportation of the standard. Upon arrival, participants should check the container and make sure that all parts are present according to the list. After the measurement model should be carefully packed back into the container, in which it has arrived. Linear dimensions of container: 700 mm x 520 mm x 220 mm. The weight of container (with the content) is about 20 kg.
If the damage of the container is detected, travelling standard should be packed in new containers, which will provide the necessary protection during transportation.
Upon receipt of travelling standard it is necessary to check the container for external damage and verify the completeness of travelling standard in accordance with the attached list.

The copy of the technical description of RM 15-04 is attached. It is necessary to familiarize with the features of travelling standard before starting the measurement. It must be carefully removed from the container.
Opening the corpus of RM 15-04 is strictly prohibited. If some defects of travelling standard are found, the participating laboratory should have immediately to inform the pilot laboratory by fax or e-mail. If the repair of travelling standard is needed, the participant of comparisons should send travelling standard in a pilot laboratory.
Participants must inform the pilot laboratory by fax or e-mail about the arrival of travelling standard by using the form shown on Figure 3 [2].

Confirmation note for receipt		
Date of arrival		
NMI		
Name of responsible person		
The travel standard	□ Damaged	□ Not Damaged
Additional notes:		

Figure 3 Sample form for the information of arrival of travelling standard RM 15-04

The participating laboratory should inform the pilot laboratory about departure of travelling standard by using the form shown on Figure 4 [2].

Confirmation note for dispatch	
Date of shipment	
NMI	
Name of responsible person	
Shipment information (company name etc.)	
Additional notes:	

Figure 4 Sample form for the information of departure of travelling standard RM 15-04

After the measurements, each participant of comparison must send the travelling standard to the pilot laboratory.
The laboratories participating in the comparison are responsible for arranging shipment of travelling standard to the pilot laboratory.

4. Description of the method of measurement
4.1 Operations before measurements

Before the measurements, it is necessary to familiarize design features and work principles of travelling standard by using technical description (user manual) of RM 15-04. Connection travelling standard in accordance with the scheme is shown on Figure 5.

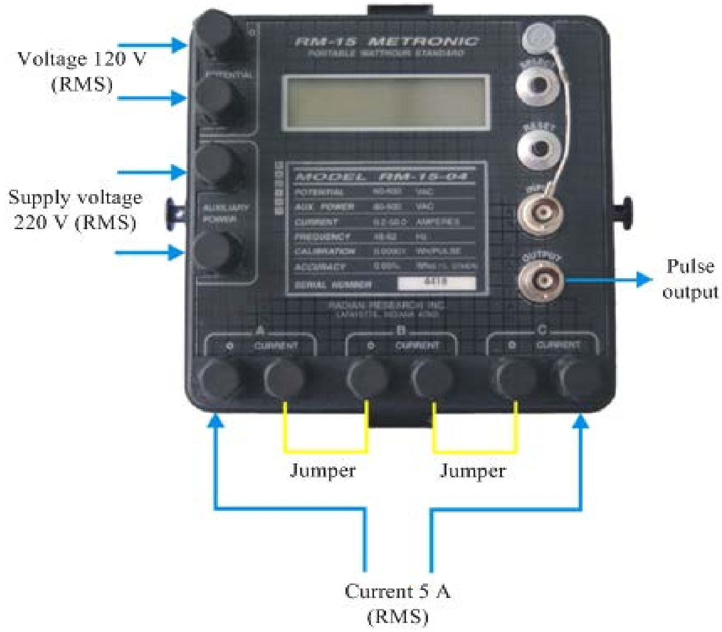


Figure 5 Connection scheme for travelling standard RM 15-04

4.2 Measurements

Before the measurements of active power in the RM 15-04 by measuring the output pulses it must be warmed up for 24 hours (connected to the main power supply). Current and voltage signals must be connected for 4 ho urs before measurement. Following these procedures, short-term shutdown signal current or voltage from travelling standard will not lead to loss of the standard's characteristics. But if the power supply of travelling standard will be turned off, then the procedure of warming up must be made over again.

Main measurements should be performed with the input signals and environmental conditions such as:

Voltage:	120 V ± 0.2 %;
Current:	5 A ± 0.2 %;
Power factor:	1.0, 0.5 Lag, 0.5 Lead deviation from the nominal value not exceeding ± 0.002%;
Frequency:	50 Hz ± 0.05 Hz and 53 Hz ± 0.05 Hz;
Temperature:	23 °C ± 1 °C;
Humidity:	20 % – 70 %;
Supply voltage:	220 V ± 5 %;
Frequency of the supply voltage:	50 Hz ± 0.1 Hz.

4.3 Uncertainty of the measurements

Uncertainty of the measurements should be calculated according to the GUM (Guide to the expression of uncertainty in measurement JCGM 100:2008 [3] (GUM 1995 with minor corrections)), JCGM 101:2008 [4]. With the results of measurements should be given a model that describes how the measurement result was obtained considering all influencing quantities (voltages, currents, etc.).

For each of the influencing quantities should be given the description of the source of uncertainty and an assessment of this uncertainty. All influencing quantities, their uncertainties, influencing coefficients, degrees of freedom and levels of confidence should be given in the budget of the uncertainty.

The budget of the uncertainty should include such number of influencing quantities and their uncertainties, which ensures the highest level measurements of electrical power for each of the laboratories.

5. Behavior of travelling standard

Travelling standard RM 15-04 model provides extreme linearity coupled with extreme stability. In addition, high resolution and repeatability permits rapid and accurate single revolution testing both in the field and in the lab with the appropriate optical pickup.

The RM-15 is well-suited for test applications that require multiple measurements with high accuracy and stability.

The first day of starting comparison was 8 January 2008. Comparison finished 29 December 2011.UMTS has performed repeated measurements on travelling standard for 35 months.

During the course of this comparison the drift effect is calculated. From these measurements after analyzing specified that the behavior of travelling standard is the linear fit and can be seen in Figures 6–11.

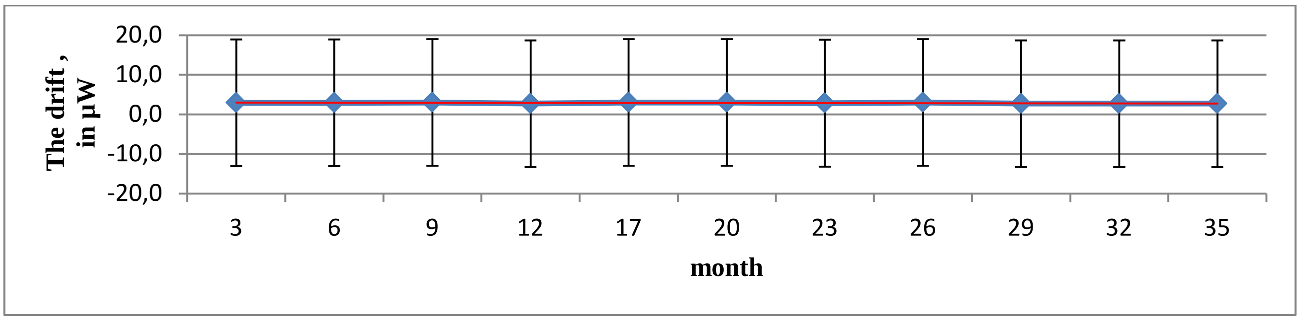


Figure 6 Behavior of the travelling standard for PF=1.0 and *f*=50 Hz

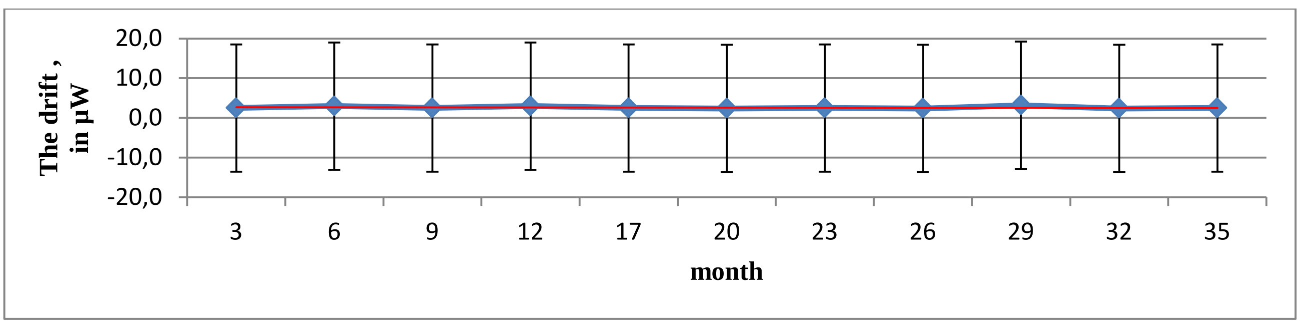


Figure 7 Behavior of the travelling standard for PF=1.0 and *f*=53 Hz

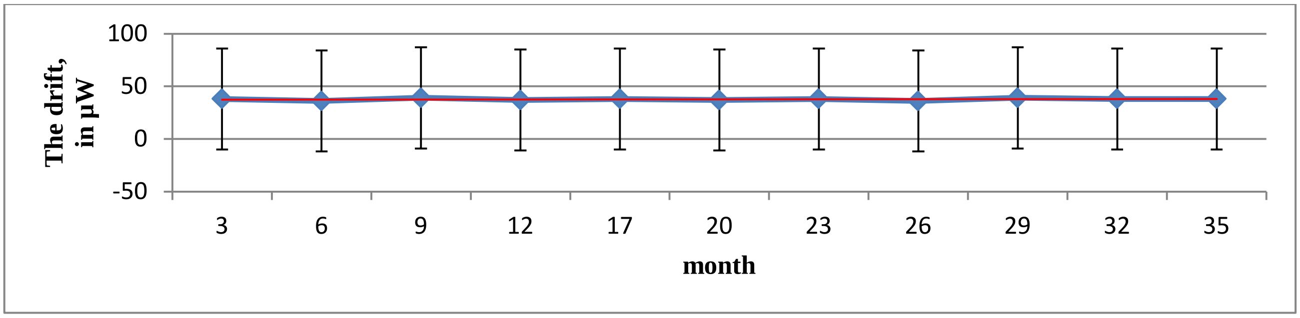


Figure 8 Behavior of the travelling standard for PF=0.5 Lag (ind) and *f*=50 Hz

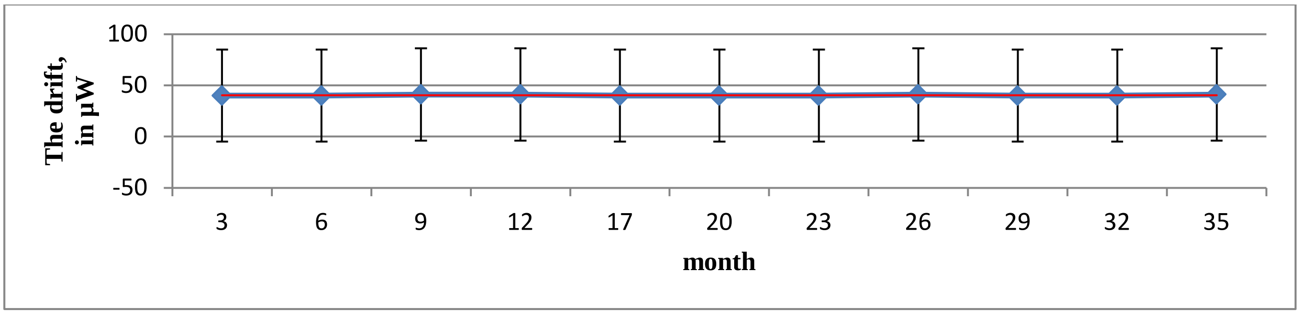


Figure 9 Behavior of the travelling standard for PF=0.5 Lag (ind) and *f*=53 Hz

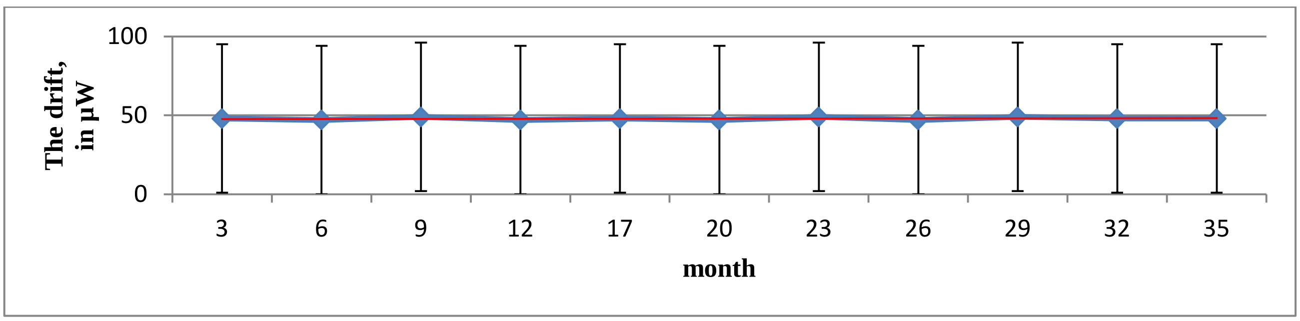


Figure 10 Behavior of the travelling standards (PF=0.5 Lead (cap), *f*=50 Hz)

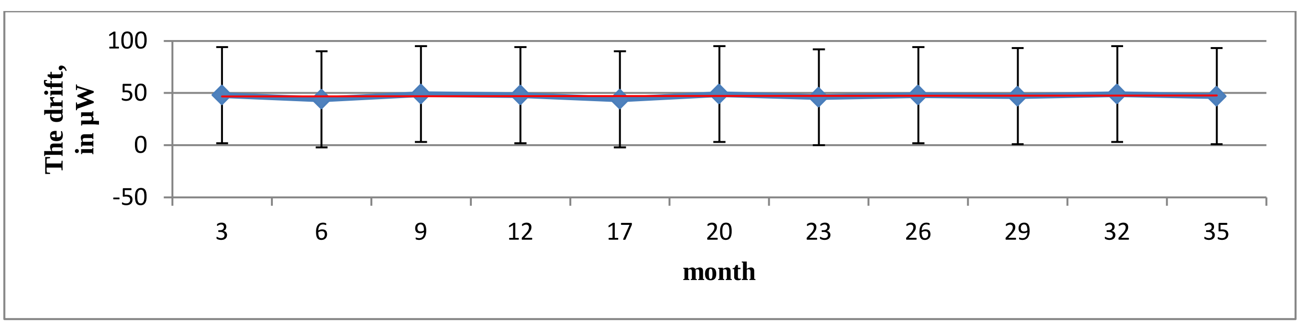


Figure 11 Behavior of the travelling standard for PF=0.5 Lead (cap) and *f*=53 Hz)

The correction values δP_{drift} together with their corresponding uncertainties $u(\delta P_{drift})$ are given in the table below.

Table 3 Correction values and Uncertainties

Travelling standard	Power factor PF	δP_{drift} μW/(VA)	$u(\delta P_{drift})$ μW/(VA)
RM 15-04	1.0 (50 Hz)	0.1	0.3
	1.0 (53 Hz)	0.2	0.5
	0.5 Lag (50 Hz)	1.5	4.5
	0.5 Lag (53 Hz)	1.7	5.0
	0.5 Lead (50 Hz)	1.9	5.8
	0.5 Lead (53 Hz)	2.2	6.5

The linear fit is given by:

$$x - \overline{x} = m \cdot (y_i - \overline{y}) \quad (1)$$

Where:

y_i (month) – the given date;

$\overline{y}$ (month) – the average date of the UMTS measurements on the travelling standard;

x (μW/VA) – the active power value given by the linear fit on date y_i;

$\overline{x}$ (μW/VA) – the average active power value of UMTS measurements on the travelling standard;

m (μW/VA/month) – the drift of the inductance value per month.

6. Measurement results of the supplementary comparison

6.1. Results of the participating institutes

Each laboratory which participates in the comparison should provide a report within 6 weeks from the date of departure travelling standard. The report should be send to the pilot laboratory by e-mail: ermatec@ukrcsm.kiev.ua.

The report must contain:

– description of the method of measurement;

– description of the measuring scheme;

– confirmation of the traceability of measurements performed (if participating laboratories does not have realization system of the unit of electrical power, must provide proof of traceability from another laboratory);

– temperature and humidity in the laboratory during the measurements;

– measurements: the values of amendments for the travel standard (6 values) for the frequencies of 50 Hz, 53 Hz and power factor: 1.0, 0.5 Lag, 0.5 Lead;

– values of the corresponding standard uncertainties, the effective values of the degrees of freedom and expanded uncertainty;

– detailed budget of the uncertainty, which will be included in the report of the comparisons.

The participating laboratory will be informed if the significant difference between its results of measurements and preliminary reference value will be found. Other information about the measurement results will not be reported. Appendix A1 is presented the methods of measurement and the measuring schemes of NMIs.

The active power values x_i and their expanded uncertainties $u(x_i)$ reported by the participants are given in Table 4. Detailed uncertainty budgets from all participants are given in Appendix A2. Each of the x_i values has been corrected for the drift of the travelling standard. The correction values δP_{drift} and the corrected active power values P_{corr} are also given in the tables below, together with their corresponding uncertainties $u(\delta P_{drift})$ and $u(P_{corr})$.

$$P_{corr} = x_i + \delta P_{drift}, \quad (2)$$

$$u(P_{corr}) = \sqrt{(u(x_i))^2 + (u(\delta P_{drift}))^2} \quad (3)$$

Note: For the UMTS results, it is to be expected that there is a correlation between $u(x_i)$ and $u(\delta P_{drift})$. For reasons of simplicity, these correlation have been ignored, which may result in a slightly overestimated values of $u(P_{corr})$.

Table 4 Measurement results with drift corrections on travelling standard
(the reported uncertainties are combined uncertainties)

Laboratory	x_i μW/(VA)	$u(x_i)$ μW/(VA)	δP_{drift} μW/(VA)	$u(\delta P_{drift})$ μW/(VA)	P_{corr} μW/(VA)	$u(P_{corr})$ μW/(VA)
PF 1.0 (50 Hz)						
BelGIM	28.1	36.0	0.1	0.3	28.2	36.0
UMTS	2.7	16.1	0.1	0.3	2.8	16.1
BIM	–8.8	7.3	0.1	0.3	–8.7	7.3
PF 1.0 (53 Hz)						
BelGIM	20.0	28.0	0.2	0.5	20.2	28.0
UMTS	2.4	15.9	0.2	0.5	2.6	15.9
BIM	1.7	7.4	0.2	0.5	1.9	7.4
PF 0.5 Lag (50 Hz)						
BelGIM	–7.1	58.0	1.5	4.5	–5.6	58.2
UMTS	–38.2	44.1	1.5	4.5	–36.7	44.3
BIM	–70.2	11.5	1.5	4.5	–68.7	12.4
PF 0.5 Lag (53 Hz)						
BelGIM	–31.1	58.0	1.7	5.0	–29.4	58.2
UMTS	–40.1	45.0	1.7	5.0	–38.4	45.3
BIM	–65.0	11.8	1.7	5.0	–63.3	12.8
PF 0.5 Lead (50 Hz)						
BelGIM	31.2	58.0	1.9	5.8	33.1	58.3
UMTS	48.0	45.1	1.9	5.8	49.9	45.5
BIM	50.9	11.4	1.9	5.8	52.8	12.7
PF 0.5 Lead (53 Hz)						
BelGIM	19.0	58.0	2.2	6.5	21.2	58.4
UMTS	47.0	45.6	2.2	6.5	49.2	46.1
BIM	56.3	11.5	2.2	6.5	58.5	13.2

6.2 Reference values

According to the recommendation COOMET R/GM/19 [5] on the basis of measurement results and associated uncertainties $\{x_i, u(x_i)\}, i = 1,\ldots,n$ presented by participants of comparison, calculate the value of the criterion χ^2.

$$\chi^2 = \sum_{i=1}^{n} \frac{(x_i - \bar{x}_{ref})^2}{u^2(x_i)} \quad (4)$$

where:

$$\bar{x}_{ref} = \frac{\sum_{i=1}^{n} \frac{x_i}{u^2(x_i)}}{\sum_{i=1}^{n} \frac{1}{u^2(x_i)}} \qquad (5)$$

$\bar{x}_{ref}$ – reference value,

$$u^2(\bar{x}_{ref}) = \frac{1}{\sum_{i=1}^{n} \frac{1}{u^2(x_i)}} \qquad (6)$$

$u^2(\bar{x}_{ref})$ – the uncertainty of the Reference Value.

To checks consistency of comparisons were used criterion value, calculated from data provided by the NMI does not exceed the critical value χ^2 for confidence level 0.95 and the number of degrees of freedom *n*-1

$$\chi^2 \prec \chi^2_{0,95}(n\text{-}1) \qquad (7)$$

Values for criterion χ^2 are given in Table 5.

Table 5 Values for criterion χ^2

Power factor PF	χ^2	$\chi^2_{0,95}(n\text{-}1)$
1.0 (50 Hz)	1.3341	5.9915
1.0 (53 Hz)	0.4001	
0.5 Lag (50 Hz)	1.5620	
0.5 Lag (53 Hz)	0.5850	
0.5 Lead (50 Hz)	0.1133	
0.5 Lead (53 Hz)	0.4261	

Data from different NMIs may be deemed agreed that is an objective confirmation of the stated uncertainties. Reference Values and Uncertainties are given in Table 6.

Table 6 Reference Values and Uncertainties

Travelling standard	Power factor PF	Reference Value RV µW/(VA)	Uncertainties of Reference Value *u*(RV) µW/(VA)
RM 15-04	1.0 (50 Hz)	-5.7	6.5
	1.0 (53 Hz)	2.8	6.5
	0.5 Lag (50 Hz)	-66.0	10.9
	0.5 Lag (53 Hz)	-62.2	11.1
	0.5 Lead (50 Hz)	50.1	10.8
	0.5 Lead (53 Hz)	54.4	11.0

The corrected values are also presented in the graphs in Figures 12–17.
UMTS result in this comparison is the average value of the individual results reported by UMTS for travelling standard.

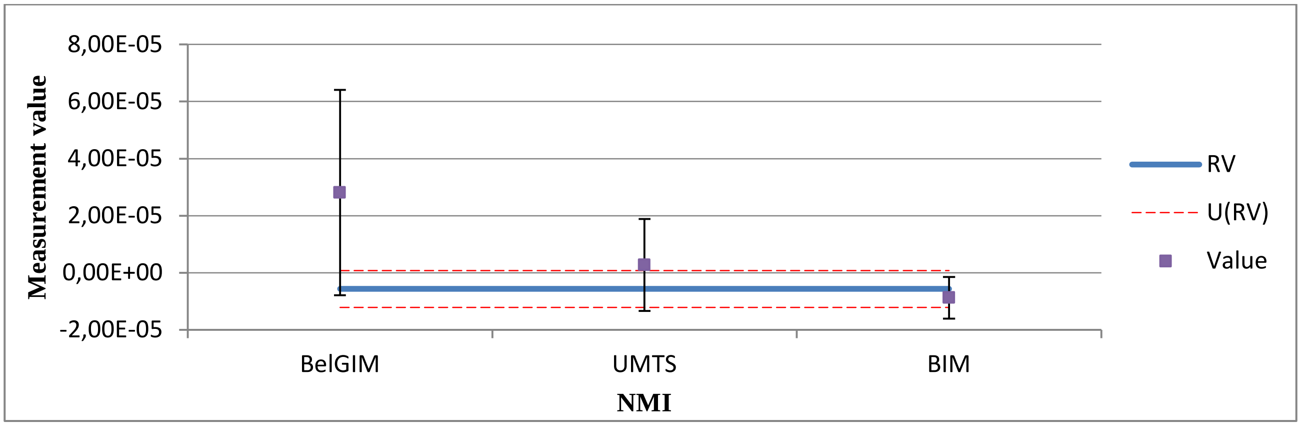


Figure 12 Active power values measured by the participants and corrected for drift of travelling standard for PF=1.0 and *f*=50 Hz

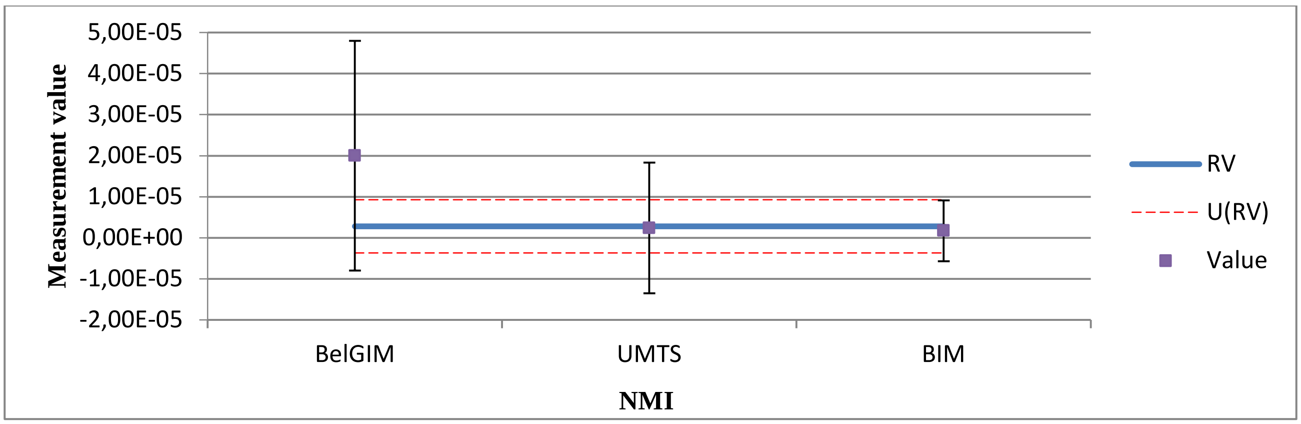


Figure 13 Active power values measured by the participants and corrected for drift of travelling standard for PF=1.0 and *f*=53 Hz

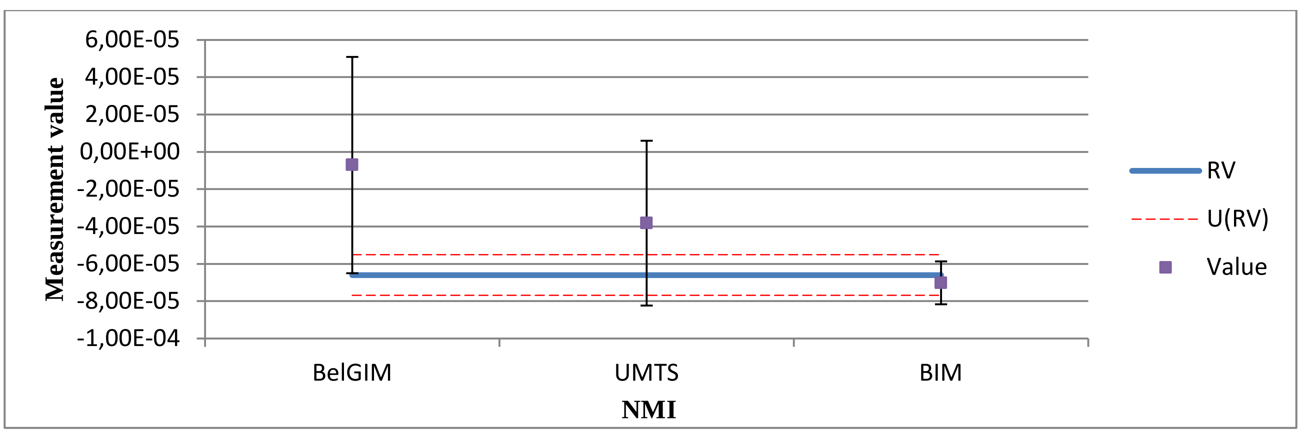


Figure 14 Active power values measured by the participants and corrected for drift of travelling standard for PF=0.5 Lag and *f*=50 Hz

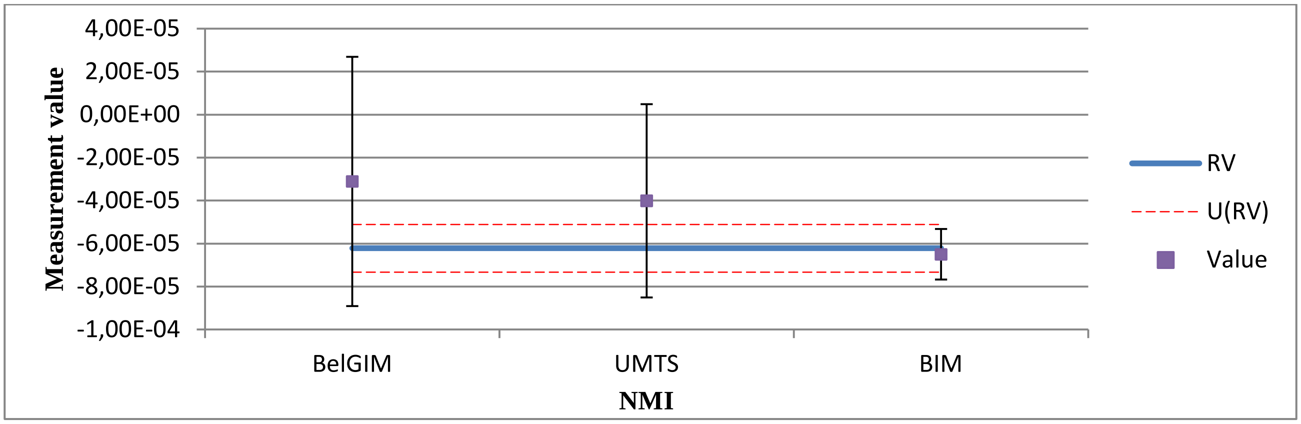


Figure 15 Active power values measured by the participants and corrected for drift of travelling standard for PF=0.5 Lag and *f*=53 Hz

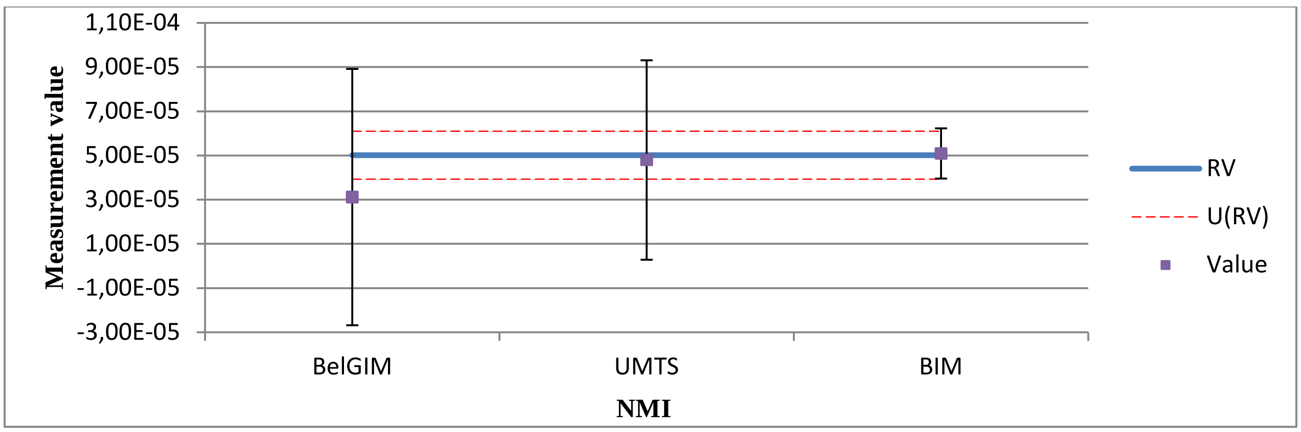


Figure 16 Active power values measured by the participants and corrected for drift of travelling standard for PF=0.5 Lead and *f*=50 Hz

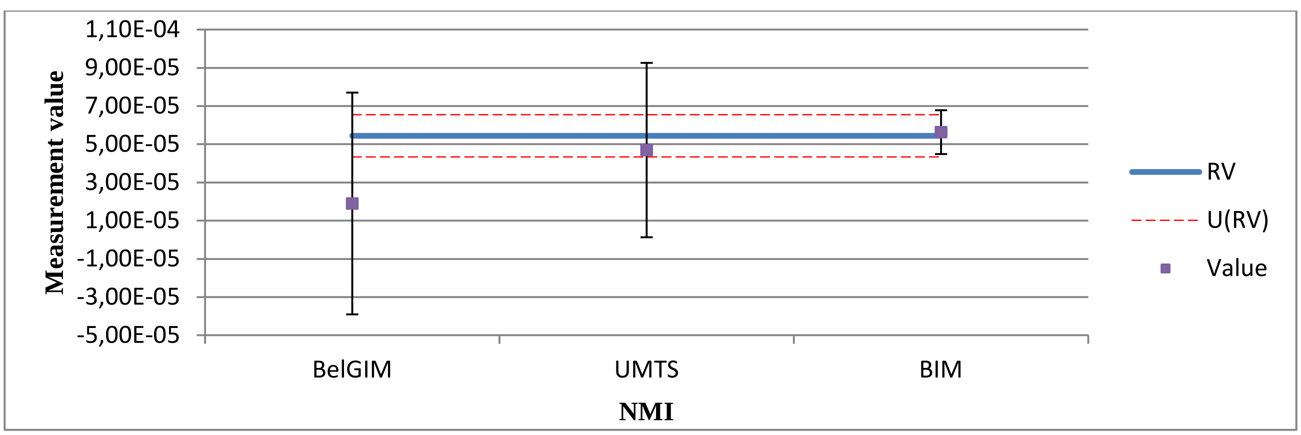


Figure 17 Active power values measured by the participants and corrected for drift of travelling standard for PF=0.5 Lead and *f*=53 Hz

6.3 Degrees of equivalence

For each participant *i*, the degree of equivalence D_i with respect to the reference value is determined as:

$$D_i = P_{corr\,i} - \mathrm{RV}_i \tag{8}$$

with the corresponding uncertainty $u(D_i)$:

$$u(D_i) = \sqrt{(u(P_{corr\,i}))^2 + (u(\mathrm{RV}_i))^2 - 2 \cdot r_i \cdot u(P_{corr\,i}) \cdot u(\mathrm{RV}_i)} \tag{9}$$

where r_i is the correlation coefficient between laboratory result and the RV.

Correlations between the results from the laboratories and the reference value have been ignored (r_i = 0) in the computation of $u(D_i)$, except for the case of UMTS

$$u(D_i) = \sqrt{(u(P_{corr\,i}))^2 + (u(\mathrm{RV}_i))^2} \tag{10}$$

Additionally, the performance indicator E_n is calculated as:

$$E_n = \frac{|D_i|}{u(D_i)} \tag{11}$$

All degrees of equivalence and the E_n values are given in Table 7.

Table 7 Degrees of equivalence (D_i) and E_n values

Laboratory	D_i µW/(VA)	$u(D_i)$ µW/(VA)	E_n
1	2	3	4
PF 1.0 (50 Hz)			
BelGIM	33.9	36.6	0.9269
UMTS	8.5	17.4	0.4899
BIM	–3.0	9.8	0.3051
PF 1.0 (53 Hz)			
BelGIM	17.3	28.7	0.6035
UMTS	–0.3	17.2	0.0146
BIM	–1.0	9.9	0.0965
PF 0.5 Lag (50 Hz)			
BelGIM	60.4	59.2	0.1021
UMTS	29.3	45.7	0.6421
BIM	–2.7	16.5	0.1627

1	2	3	4
PF 0.5 Lag (53 Hz)			
BelGIM	32.8	59.3	0.5527
UMTS	23.8	46.6	0.5096
BIM	–1.2	16.9	0.0679
PF 0.5 Lead (50 Hz)			
BelGIM	–17.0	59.3	0.2863
UMTS	–0.2	46.7	0.0037
BIM	2.7	16.7	0.1634
PF 0.5 Lead (53 Hz)			
BelGIM	–33.2	59.4	0.5596
UMTS	–5.2	47.4	0.1105
BIM	4.1	17.2	0.2365

The values of D_i with the uncertainties are also plotted in Figures 18–23.

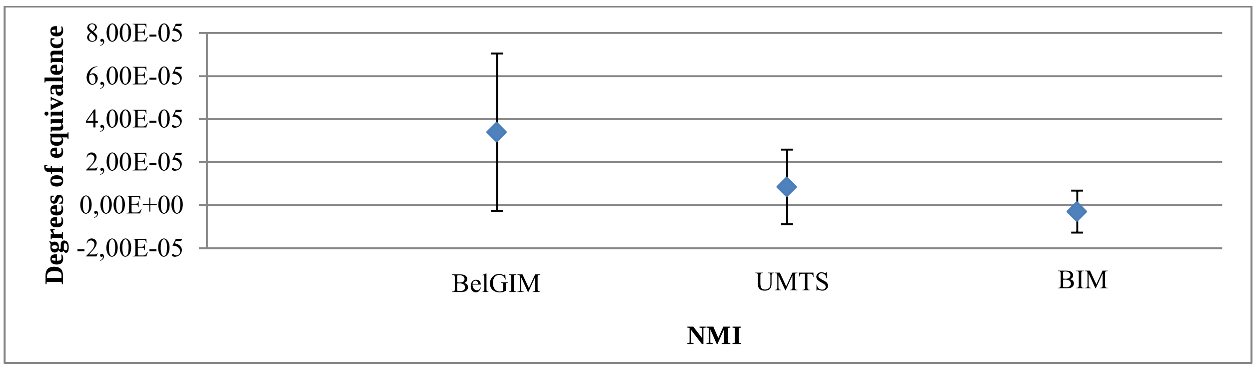


Figure 18 Degrees of equivalence for PF=1.0 and *f*=50 Hz

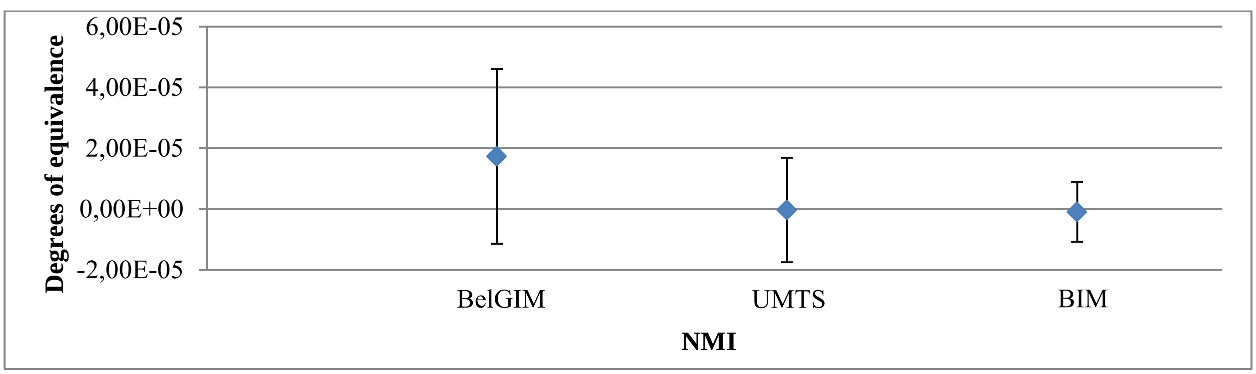


Figure 19 Degrees of equivalence for PF=1.0 and *f*=53 Hz

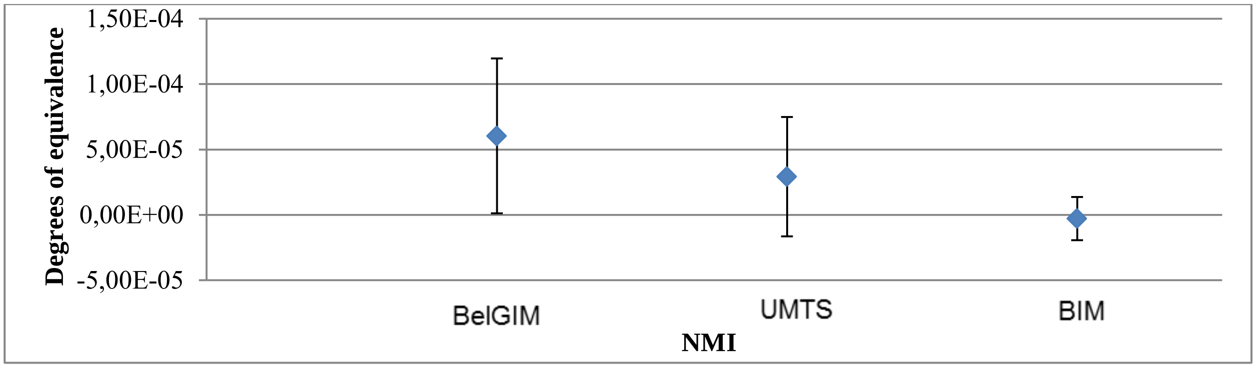


Figure 20 Degrees of equivalence for PF=0.5 Lag and *f*=50 Hz

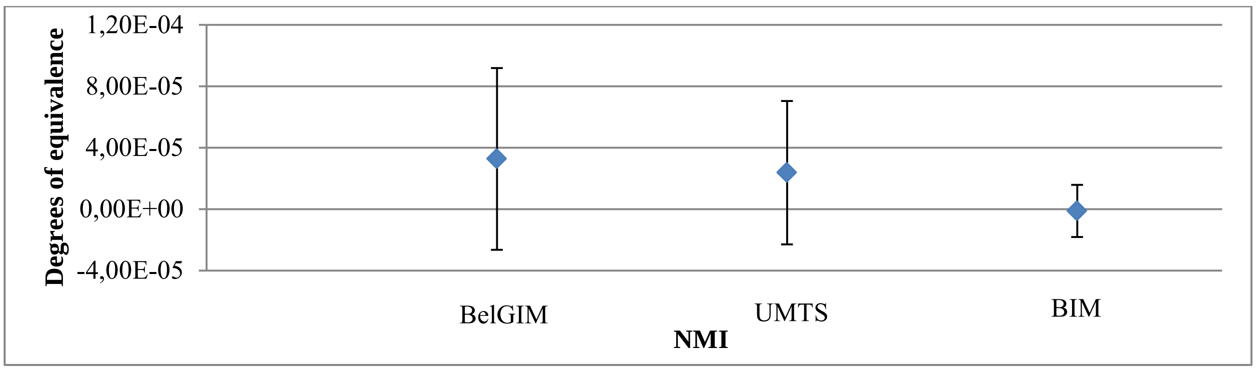


Figure 21 Degrees of equivalence for PF=0.5 Lag and *f*=53 Hz

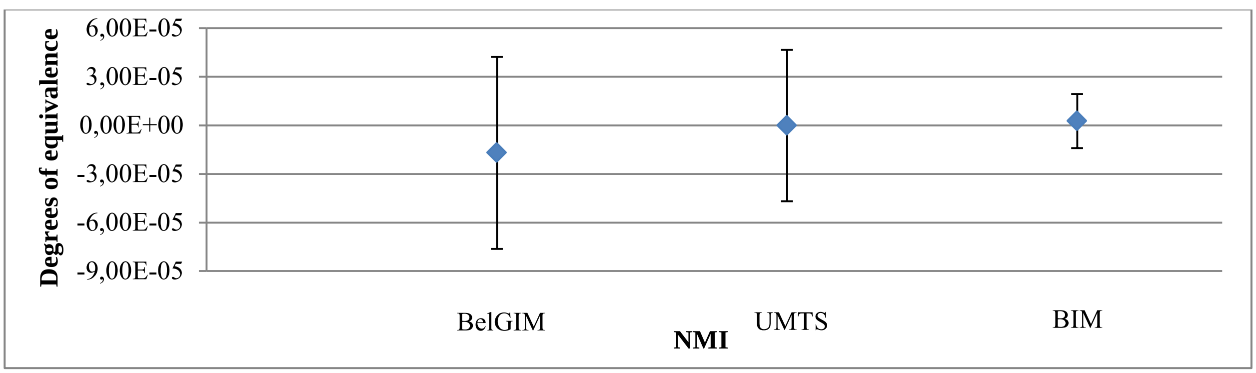


Figure 22 Degrees of equivalence for PF=0.5 Lead and *f*=50 Hz

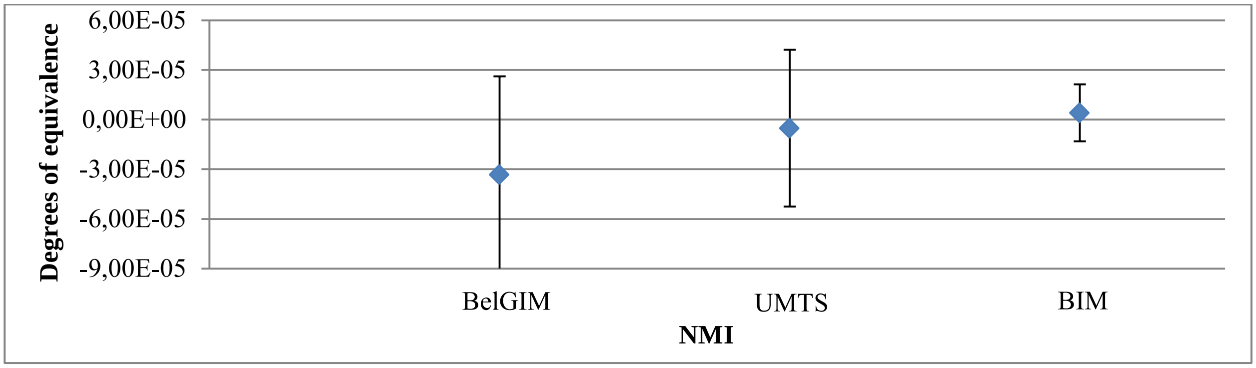


Figure 23 Degrees of equivalence for PF=0.5 Lead and, *f*=53 Hz

6.4 Pair degrees of equivalence

Pair degree of equivalence of *i*-th NMI and *j*-th NMI participants D_{ij} with combined standard uncertainty $u_c(D_{ij})$ are estimated by:

$$D_{ij} = D_i - D_j, \quad (12)$$

$$u_c^2(D_{ij}) = u_c^2(D_i) + u_c^2(D_j). \quad (13)$$

The expanded uncertainties $U(D_{ij})$ is estimated by:

$$U(D_{ij}) = 2u_c(D_{ij}) = 2\sqrt{u_c^2(D_i) + u_c^2(D_j)}\,. \quad (14)$$

Pair degrees of equivalence of *i*-th NMI and *j*-th NMI participants D_{ij} and its expanded uncertainties $U(D_{ij})$ $(k = 2)$ with respect to the RV are shown in Tables 8-13.

Table 8 Degrees of equivalence (D_i) and expanded uncertainties $U(D_{ij})$ for PF=1.0 and *f*=50 Hz

NMI	**NMI**					
	BelGIM		UMTS		BIM	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM			–25.4	40.5	–36.9	37.9
UMTS	25.4	40.5			–11.5	20.0
BIM	36.9	37.9	11.5	20.0		

Table 9 Degrees of equivalence (D_i) and expanded uncertainties $U(D_{ij})$ for PF=1.0 and *f*=53 Hz

NMI	**NMI**					
	BelGIM		UMTS		BIM	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM			–17.6	33.5	–18.3	30.4
UMTS	17.6	33.5			–0.7	19.8
BIM	18.3	30.4	0.7	19.8		

Table 10 Degrees of equivalence (D_i) and expanded uncertainties $U(D_{ij})$ for PF=0.5 Lag and *f*=50 Hz

NMI	**NMI**					
	BelGIM		UMTS		BIM	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM			–31.1	74.8	–63.1	61.5
UMTS	31.1	74.8			–32.0	48.6
BIM	63.1	61.5	32.0	48.6		

Table 11 Degrees of equivalence (D_i) and expanded uncertainties $U(D_{ij})$ (PF=0.5 Lag, *f*=53 Hz)

NMI	**NMI**					
	BelGIM		UMTS		BIM	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM			–9.0	75.4	–34.0	61.7
UMTS	9.0	75.4			–25.0	49.6
BIM	34.0	61.7	61.7	25.0		

Table 12 Degrees of equivalence (D_i) and expanded uncertainties $U(D_{ij})$ for PF=0.5 Lead and *f*=50 Hz

NMI	**NMI**					
	BelGIM		UMTS		BIM	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM			16.8	75.5	19.7	61.6
UMTS	–16.8	75.5			2.9	49.6
BIM	–19.7	61.6	–2.9	49.6		

Table 13 Degrees of equivalence (D_i) and expanded uncertainties $U(D_{ij})$ for PF=0.5 Lead and *f*=53 Hz

NMI	**NMI**					
	BelGIM		UMTS		BIM	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM			28.0	76.0	37.3	61.8
UMTS	–28.0	76.0			9.3	50.4
BIM	–37.3	61.8	–9.3	50.4		

Conclusion

The comparison was organized to measure the active power at a nominal values of 120 V, 5 A, 50 Hz and 53 Hz at 1.0, 0.5 Lag, 0.5 Lead power factors. This comparison is identified as the COOMET.EM-S2 and was carried out as the COOMET project no 344/UA/05. The results from all out of three participants are in agreement with the Reference Values.
In this comparison, the participants report three different methods to realize the traceability of the unit of active power. The results from these different methods are in good agreement within the reported uncertainties.
During analyzing the data on the results of the supplementary comparison at 50 Hz and 53 Hz is determined that the data on the frequency of 53 Hz rather better than of 50 Hz, this is related to pickups external stress fields that lead to variations in the load current with a frequency beat frequency equal to the difference between the current source and voltage supply.

References

[1] EURAMET.EM-K5.1 Key Comparison of 50/60 Hz Power Final Report Hüseyin Çaycı March 2011 TÜB_TAK Ulusal Metroloji Enstitüsü.
[2] Recommendation COOMET R/GM/11: 2010 Regulations on comparisons national standards NMI COOMET.
[3] JCGM 100:2008 Evaluation of measurement data- Guide to the expression of uncertainty in measurement.
[4] JCGM 101:2008 Evaluation of measurement data -Supplement 1 to the“Guide to the expression of uncertainty in measurement”-Propagation of distributions using a Monte Carlo method.
[5] Recommendation COOMET R/GM/19: 2008 Guidelines for evaluating data Additional comparisons COOMET.

Appendix A1. Methods of measurement

UMTS

The base of State Standard of electrical power is precision comparator of electrical power COM 303 that is used for storage, measurements and transfer of the electrical power unit to other devices. The correction factors of comparator COM 303 are determined during electrical power unit reproduction procedure. The structural scheme of State Standard in the regime of electrical power unit reproduction procedure is presented on the Figure A1.

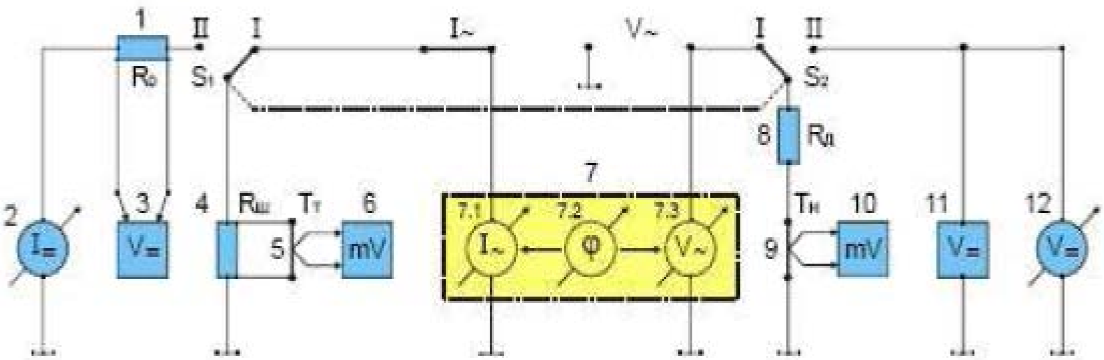


Figure A1 The structural scheme of State Standard in the regime of electrical power unit.

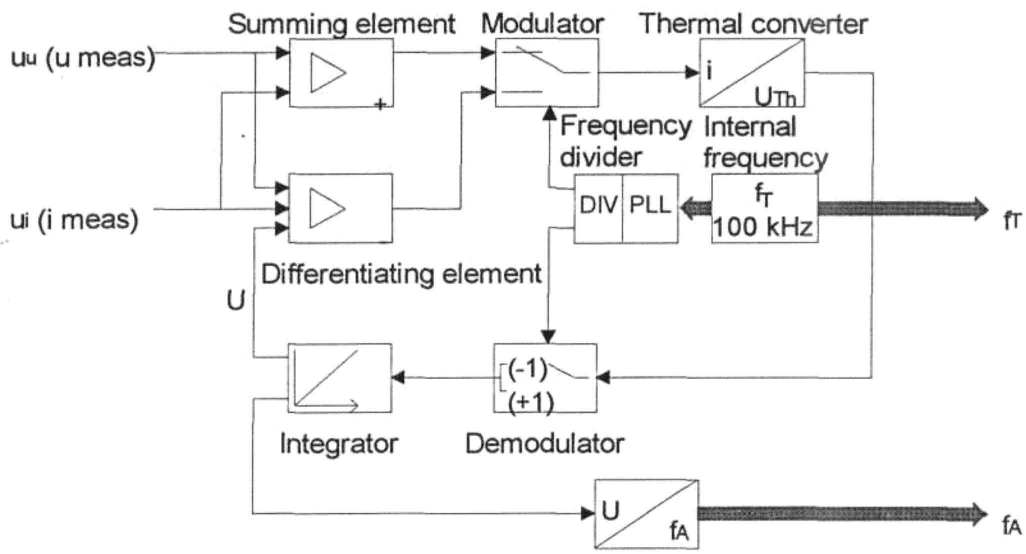
On the scheme above:
1 – precision shunt;
2 – highly stable generator of direct current;
3, 11 – precision digital voltmeters of direct voltage “AGILENT 3458A”;
4 – precision current shunt;
5, 9 – precision thermo-electric converters;
6, 10 – precision digital nano-voltmeters “AGILENT 34420A”;
7 – highly stable generator of alternate voltage and current;
8 – precision resistor voltage divider;
12 – highly stable generator of direct voltage.

The reproduction procedure is conducted as follows:
– the switches S1 and S2 are switched to position I;
– with assistance of highly stable generator of alternate voltage and current (7) the desired voltage V~, current I~ and phase shift angle are formed;
– the values of voltage V~, current I~ and phase shift angle measured by precision comparator COM 303 are recorded;
– the measurement results of precision digital nanovoltmeters VI (6) and VV (10) are recorded;
– the switches S1 and S2 are switched to position II;
– with assistance of highly stable generator of direct current adjust the current threw precision current shunt (4) until on precision digital nanovoltmeters (6) settles the same voltage VI;
– the value of voltage VDC, measured by precision digital voltmeter of direct voltage (3) is recorded;
– with assistance of highly stable generator of direct voltage adjust the voltage on precision resistor voltage divider (8) until on precision digital nanovoltmeters (9) settles the same voltage VV;
– the value of voltage VDC, measured by precision digital voltmeter of direct voltage (11) is recorded.

BelGIM

Description of the measuring scheme

The calibration scheme is presented on the Figure A2.



Measuring period T

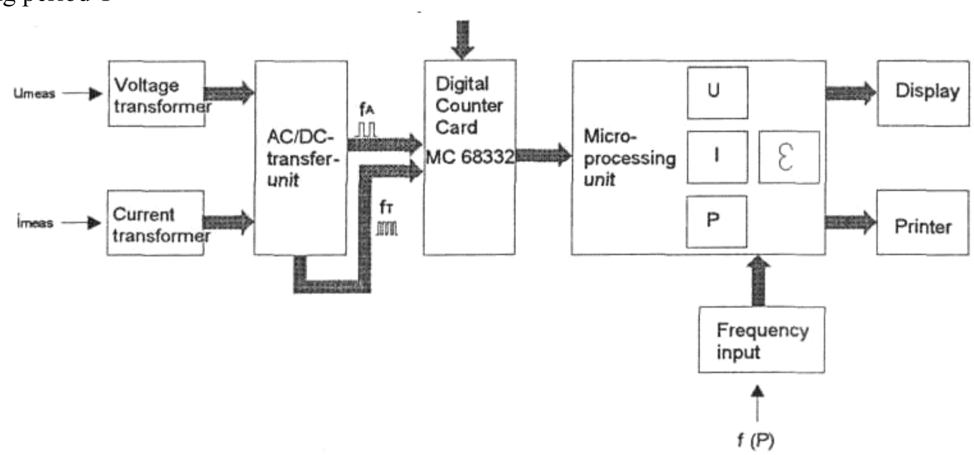


Figure A2 Calibration scheme

Temperature and humidity in the laboratory during the measurements:

– Temperature: 23°C ± 1°C;
– Relative humidity: from 30,0 % to 36,0 %;
– Period of measurement: 100 seconds.

BIM

The RM 15-04 was measured using the power standard of BIM. Reference values for the calculation of the relative error were in each case the apparent power calculated from voltage and current applied. The operating principle is based on synthesized ac voltages, the use of only a single sampling voltmeter, and on computerized evaluation by means of the discrete Fourier transform (DFT). The traceability to the SI units "dc voltage" and "dc resistance" is ensured by the rms voltmeter and the ac shunt with small and well-known frequency characteristics, both calibrated against national standards.

Description of the measuring scheme

Calibration is carried out according to the Figure A3.

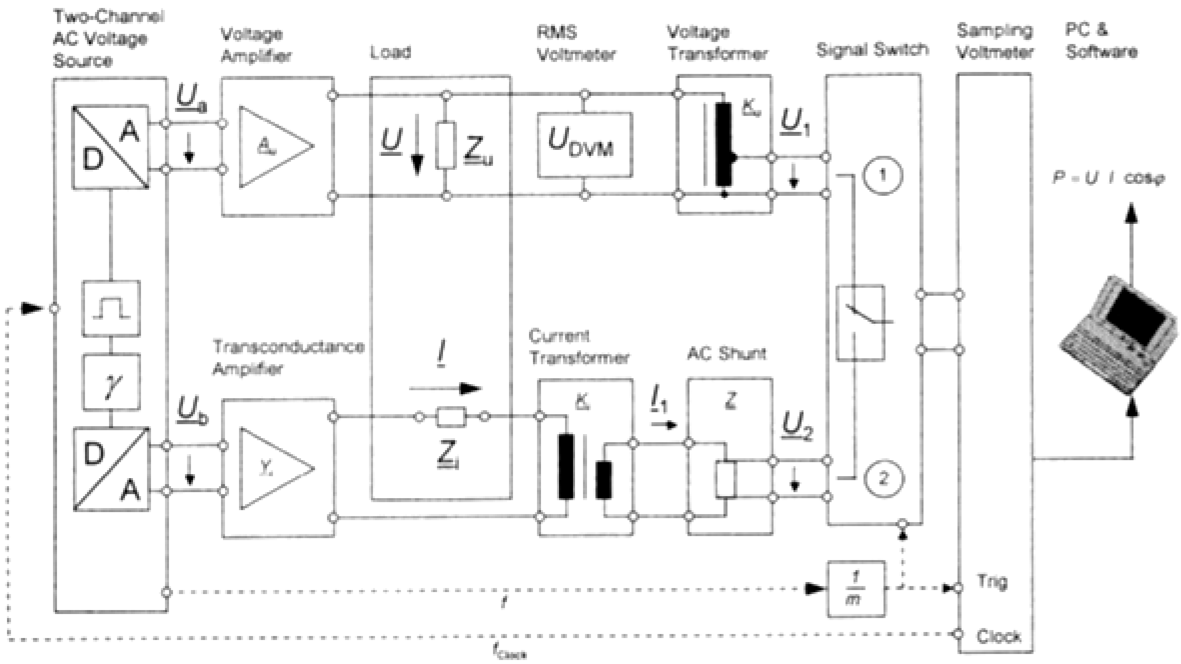


Figure A3 Calibration scheme

Confirmation of the traceability of measurements performed (if participating laboratories does not have realization system of the unit of electrical power, must provide proof of traceability from another laboratory):

– Two-Stage Standard Current transformer type SCT 100 (calibration mark 4218 PTB 08);
– Standard Inductive Voltage Divider type 480-120 (calibration mark 4250 PTB 08);
– High Precision Resistor type HPR 10 (calibration mark № 012-EMM/30.03.2011, NCM);
– Digital multimeter type 3458A (traceable to national standard for DC voltage).

Temperature and humidity in the laboratory during the measurements:

– Temperature: 23 °C ± 1 °C;
– Relative humidity: from 41,8 % to 60,0 %
– Period of measurement: 03.05.2011–17.06.2011.

Appendix A2. Uncertainty budgets

UMTS

Uncertainty Budget cosφ = 1.0, f = 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	normal	2.1	8.4	113	1	8.4
2	Error of DETU 08-08-02 – from converter, resistor and multimeter (μW/VA)	normal	0.6	13.7	∞	1	13.7
y	Std uncertainty of measurement	normal	2.7	16.1	∞		
		Conf. level = 95 %				k = 2.0000	
		Expanded uncertainty = 32					

Uncertainty Budget cosφ = 1.0, f = 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	normal	1.8	8.0	126	1	8.0
2	Error of DETU 08-08-02 – from converter, resistor and multimeter (μW/VA)	normal	0.6	13.7	∞	1	13.7
y	Std uncertainty of measurement	normal	2.4	15.9	∞		
		Conf. level = 95 %				k = 2.0000	
		Expanded uncertainty = 32					

Uncertainty Budget cosφ = 0.5 Lag, f = 50 Hz.

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	normal	–35.2	43.6	22	1	43.6
2	Error of DETU 08-08-02 – from converter, resistor and multimeter (μW/VA)	normal	–3.0	6.9	∞	1	6.9
y	Std uncertainty of measurement	normal	–38.2	44.1	23		
		Conf. level = 95 %				k = 2.1195	
		Expanded uncertainty = 94					

Uncertainty Budget cosφ = 0.5 Lag, *f* = 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	normal	–37.1	44.5	21	1	44.5
2	Error of DETU 08-08-02 – from converter, resistor and multimeter (μW/VA)	normal	–3.0	6.9	∞	1	6.9
y	Std uncertainty of measurement	normal	–40.1	45.0	22		
		Conf. level = 95 %				k = 2.1255	
		Expanded uncertainty = 96					

Uncertainty Budget cosφ = 0.5 Lead, *f* = 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	normal	45.0	44.6	18	1	44.6
2	Error of DETU 08-08-02 – from converter, resistor and multimeter (μW/VA)	normal	3.0	6.9	∞	1	6.9
y	Std uncertainty of measurement	normal	48.0	45.1	18		
		Conf. level = 95 %				k = 2.1471	
		Expanded uncertainty = 97					

Uncertainty Budget cosφ = 0.5 Lead, *f* = 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	normal	44.0	45.1	19	1	45.1
2	Error of DETU 08-08-02 – from converter, resistor and multimeter (μW/VA)	normal	3.0	6.9	∞	1	6.9
y	Std uncertainty of measurement	normal	47.0	45.6	19		
		Conf. level = 95 %				k = 2.1393	
		Expanded uncertainty = 98					

BelGIM

Uncertainty Budget cosφ = 1.0, f = 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	normal	28.1	0.4	99	1	0.4
2	Error of Comparator K2005 correction due to the quantization process (μW/VA)	rectangular	0	15.1	∞	1	15.1
3	Error of Comparator K2005 (from specification) (μW/VA)	rectangular	0	32.7	∞	1	32.7
y	Std uncertainty of measurement	normal	28.1	36.0	∞		
		Conf. level = 95 %				k = 2	
		Expanded uncertainty = 72					

Uncertainty Budget cosφ = 1.0, f = 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	normal	20.0	1.3	99	1	1.3
2	Error of Comparator K2005 correction due to the quantization process (μW/VA)	rectangular	0	14.7	∞	1	14.7
3	Error of Comparator K2005 (from specification) (μW/VA)	rectangular	0	23.8	∞	1	23.8
y	Std uncertainty of measurement	normal	20.0	28.0	∞		
		Conf. level = 95 %				k = 2	
		Expanded uncertainty = 56					

Uncertainty Budget cosφ = 0.5 Lag, f = 50 Hz.

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	Normal	–7.1	1.5	99	1	1.5
2	Error of Comparator K2005 correction due to the quantization process (μW/VA)	rectangular	0	22.1	∞	1	22.1
3	Error of Comparator K2005 (from specification) (μW/VA)	rectangular	0	53.6	∞	1	53.6
y	Std uncertainty of measurement	normal	–7.1	58.0	∞		
		Conf. level = 95 %				k = 2	
		Expanded uncertainty = 116					

Uncertainty Budget cosφ = 0.5 Lag, f = 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (µW/VA)	normal	–31.1	1.7	99	1	1.7
2	Error of Comparator K2005 correction due to the quantization process (µW/VA)	rectangular	0	22.6	∞	1	22.6
3	Error of Comparator K2005 (from specification) (µW/VA)	rectangular	0	53.4	∞	1	53.4
y	Std uncertainty of measurement	normal	–31.1	58.0	∞		
		Conf. level = 95 %				k = 2	
		Expanded uncertainty = 116					

Uncertainty Budget cosφ = 0.5 Lead, f = 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (µW/VA)	Normal	31.2	1.3	99	1	1.3
2	Error of Comparator K2005 correction due to the quantization process (µW/VA)	rectangular	0	21.6	∞	1	21.6
3	Error of Comparator K2005 (from specification) (µW/VA)	rectangular	0	53.8	∞	1	53.8
y	Std uncertainty of measurement	normal	31.2	58.0	∞		
		Conf. level = 95 %				k = 2	
		Expanded uncertainty = 116					

Uncertainty Budget cosφ = 0.5 Lead, f = 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (µW/VA)	normal	19.0	1.4	99	1	1.4
2	Error of Comparator K2005 correction due to the quantization process (µW/VA)	rectangular	0	21.9	∞	1	21.9
3	Error of Comparator K2005 (from specification) (µW/VA)	rectangular	0	53.7	∞	1	53.7
y	Std uncertainty of measurement	normal	19.0	58.0	∞		
		Conf. level = 95 %				k = 2	
		Expanded uncertainty = 116					

BIM

Uncertainty Budget cosφ = 1.0, f = 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (µW/VA)	Normal	–4.675	3.6376	17	1	3.6376
2	Error of PPCS – from transformers, resistor and multimeter (µW/VA)	Normal	–4.1329	6.37951	50	1	6.37951
y	Std uncertainty of measurement	Normal	–8.8079	7.343724	66.97519039		
		Conf. level = 95.45 %				k = 2.0380	
		Expanded uncertainty = 15					

Uncertainty Budget cosφ = 1.0, f = 52.63 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (µW/VA)	Normal	0.47722	3.668709	17	1	3.668709
2	Error of PPCS – from transformers, resistor and multimeter (µW/VA)	Normal	1.20596	6.4167852	50	1	6.4167852
y	Std uncertainty of measurement	Normal	1.68318	7.3915194	66.98074625		
		Conf. level = 95.45 %				k = 2.0380	
		Expanded uncertainty = 15					

Uncertainty Budget cosφ = 0.5 Lag, f = 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (µW/VA)	Normal	–34.459	11.01673	17	1	11.01673
2	Error of PPCS – from transformers, resistor and multimeter (µW/VA)	Normal	–35.6943	3.4396556	50	1	3.4396556
y	Std uncertainty of measurement	Normal	–70.1533	11.541212	20.40999201		
		Conf. level = 95.45 %				k = 2.1303	
		Expanded uncertainty = 24					

Uncertainty Budget cosφ = 0.5 Lag, *f* = 52.63 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	Normal	–31.002	11.272	17	1	11.272
2	Error of PPCS – from transformers, resistor and multimeter (μW/VA)	Normal	–34.033	3.356945	50	1	3.356945
y	Std uncertainty of measurement	Normal	–65.035	11.761253	20.0955234		
		Conf. level = 95.45 %				k = 2.1324	
		Expanded uncertainty = 25					

Uncertainty Budget cosφ = 0.5 Lead, *f* = 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	Normal	21.52944	8.153015	17	1	8.153015
2	Error of PPCS – from transformers, resistor and multimeter (μW/VA)	Normal	29.40128	7.8982927	50	1	7.8982927
y	Std uncertainty of measurement	Normal	50.93072	11.351418	49.16017672		
		Conf. level = 95.45 %				k = 2.0522	
		Expanded uncertainty = 23					

Uncertainty Budget cosφ = 0.5 Lead, *f* = 52.63 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Error from RM 15-04 (μW/VA)	Normal	23.61444	8.3710459	17	1	8.3710459
2	Error of PPCS – from transformers, resistor and multimeter (μW/VA)	Normal	32.70106	7.8966462	50	1	7.8966462
y	Std uncertainty of measurement	Normal	56.3155	11.507886	47.83770016		
		Conf. level = 95.45 %				k = 2.0536	
		Expanded uncertainty = 23					