State Enterprise “All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer” (SE “Ukrmetrteststandard”)

Approved by the chairman of TC 1.3 COOMET
Chairman of TC 1.3 COOMET

__________________ T. Kolomiets

Final Report on
COOMET Key Comparison of Power
(COOMET.EM-K5)

Oleh Velychko, Stanislav Karpenko

Pilot laboratory: SE “Ukrmetrteststandard”
4, Metrologichna Str., 03143, Kyiv, Ukraine
E-mail: velychko@ukrcsm.kiev.ua

Coordinator of comparison:

_________________ O. Velychko

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1 Introduction

Key of acronyms used:
NMIs is national metrology institutes;
KC is Key Comparison;
CRV is key comparison reference values for COOMET comparison;
KCRV is key comparison reference values for CCEM comparison.

The COOMET Key Comparison (KC) of Power (comparison identifier – COOMET.EM-K5) was conducted in the framework of COOMET 695/UA/16 project from 2016 to 2018.

This project for comparing of national standards of electric power for electrical standards of low-frequency 50/60 Hz power was conducted between counties which are member laboratories of five regional metrology organizations: COOMET; EURAMET; APMP; GULFMET, and AFRIMET. In this comparison take part 13 national metrology institutes (NMI): SE "Ukrmetrteststandard" (UMTS, Ukraine); BelGIM (Belarus); VNIIM (Russia); GEOSTM (Georgia); CSM (Kyrgyzstan); UME (Turkey); SMU (Slovakia); LEM-FEIT (R. Macedonia); NIM (China); MASM (Mongolia); QCC EMI (United Arab Emirates); SASO-NMCC (Saudi Arabia), and NIS (Egypt). MASM (Mongolia); CSM (Kyrgyzstan); LEM-FEIT (Republic of Macedonia); QCC EMI (United Arab Emirates); SASO-NMCC (Saudi Arabia), and NIS (Egypt) joined to comparison in 2017. KazInMetr (Kazakhstan) was excluded in 2018 from the list of participants of comparison for technical reasons.

The State Enterprise "All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer" (SE "Ukrmetrteststandard"), Ukraine was selected as the pilot laboratory. Dr. Oleh Velychko was the comparison coordinator. The pilot laboratory is responsible for providing the travelling standard, coordinating the schedule, collecting and analyzing the comparison data, preparing the draft report, etc.

Proposed to link the results from COOMET.EM-K5 to the CCEM-K5 [1] carried out between 1996 and 2000. NIM (China) and VNIIM (Russia) are linking NMIs as far as they participated in CCEM-K5. Relevance of the comparison results are expected at the level of better than 0.005%.

2 Participants

List of participating NMIs, countries and regional organizations is show in Tables 1 and 2.

Table 1 List of participating NMIs, countries and regional organizations

NMI	Country	Regional organization
UMTS – State Enterprise "All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer" (SE "Ukrmetrteststandard") – **pilot**	Ukraine	COOMET
BelGIM – Belarusian State Institute of Metrology	Belarus	COOMET
VNIIM – D. I. Mendeleyev Institute for Metrology	Russia	COOMET/APMP
GEOSTM – Georgian National Agency for Standards and Metrology	Georgia	COOMET

NMI	Country	Regional organization
CSM – Center for Standardization and Metrology under the Ministry of Economy of the Kyrgyz Republic	Kyrgyzstan	COOMET
UME – TÜBITAK Ulusal Metroloji Enstitüsü	Turkey	EURAMET/COOMET
SMU – Slovensky Metrologicky Ustav	Slovakia	EURAMET/COOMET
LEM-FEIT – Laboratory for Electrical Measurements, Faculty of Electrical Engineering and Information Technologies of Ss. Cyril and Methdoius University in Skopje	Republic of Macedonia	EURAMET
NIM – National Institute of Metrology	China	APMP/COOMET
MASM – Mongolian Agency For Standardization and Metrology	Mongolia	APMP
QCC EMI – Abu Dhabi Quality and Conformity Council, Emirates Metrology Institute	United Arab Emirates	GULFMET
SASO-NMCC – Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi – National Measurements and Calibration Center	Saudi Arabia	GULFMET
NIS – National Institute for Standards	Egypt	AFRIMET

Table 2 List of participants of the comparison

№	NMI	Abbrevia-tion of NMI	Address	Contact person	e-mail, phone, fax
1	State Enterprise “All-Ukrainian state research and production center of standardiza-tion, metrology, certify-cation consumers’ right protection” (SE “Ukrmetrteststandard”)	**UMTS**	4, Metrolo-gichna Str., 03143, Kyiv, Ukraine	O. Velychko	velychko@ukrcsm.kiev.ua Tel./Fax: +38 044 526 0335
2	Belarussian State Institute of Metrology	**BelGIM**	93, Starovilen-sky Ave, 220053, Minsk, Belarus	E. Kazakova	yarmolovich@belgim.by Tel.: +375 17 223-15-10

№	NMI	Abbrevia-tion of NMI	Address	Contact person	e-mail, phone, fax
3	D.I. Mendeleyev institute for Metrology	**VNIIM**	Moskovsky pr., 19, St. Petersburg, 190005, Russia	G. Gubler	g.b.gubler@vniim.ru Tel.:+7 812 251 7444
4	Georgian National Agency for Standards and Metrology	**GEOSTM**	67 Chargali Str., 0178, Tbilisi, Georgia	M. Gelo-vani	elmetrology@gmail.com Tel.: +995 322 60 66 53
5	Center for Standardization and Metrology under the Ministry of Economy of the Kyrgyz Republic	**CSM**	197 Panfilov Str., 720040 Bishkek, Kyrgyz Republic	E. Abas-bekova	elmiraqwer@gmail.com Tel: +996-312625809 Fax: +996-312661367
6	TÜBITAK Ulusal Metroloji Enstitüsü	**UME**	TÜBİTAK Gebze Yerleskesi Baris Mah., Dr. Zeki Acar Cad. No. 1 41470, Gebze Kocaeli, Turkey	H. Çayci	huseyin.cayci@tubitak.gov.tr Tel.: +90 262 679 5000
7	Slovensky Metrologicky Ustav	**SMU**	63, Karloveská Str., 84104 Bratislava, Slovakia	J. Slučiak	sluciak@smu.gov.sk Tel.: +602 94235
8	Laboratory for Electrical Measure-ments, Faculty of Electrical Engineering and Information Technologies of Ss. Cyril and Methdoius University in Skopje	**LEM-FEIT**	ul. Ruger Boskovic, br. 18, POBox 574, 1000 Skopje, Republic of Macedonia	M. Cundeva-Blajer	mcundeva@feit.ukim.edu.mk Tel: +389 75 603222 Fax: +389 2 3064262

№	NMI	Abbrevia-tion of NMI	Address	Contact person	e-mail, phone, fax
9	National Institute of Metrology	**NIM**	No. 18, Bei San Huan Dong Rd., 100013, Beijing, China	W. Lei	wl@nim.ac.cn Tel.: +86 10 6452 4531 Fax: +86 10 6421 8629
10	Mongolian Agency for Standard and Metrology	**MASM**	P.O.Box-48, Peace street-46A, Ulaanbaa-tar 13343, Mongolia	J. Ariun-tungalag	ariuntungalag@masm.gov.mn Tel.: +976 51 263647 Fax: +976 11 458032
11	Abu Dhabi Quality and Conformity Council, Emirates Metrology Institute	**QCC EMI**	CERT Sultan Bin Zayed the First Street, Abu Dha-bi, United Arab Emirates	J. Bartho-lomew	Jon.Bartholomew@qcc.abudhabi.ae Tel: +971 503862676 Fax: +971 24066677
12	Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi – National Measurements and Calibration Center	**SASO-NMCC**	Front king Saud Univer-sity Riyadh 11471, P.O. Box 3437, Saudi Arabia	A. M. Alrobaish	a.robaish@saso.gov.sa Tel: +966 11 2529730
13	National Institute for Standards	**NIS**	Al-haram, Tersa Street, 12211, P.O: 136, Giza, Egypt	M. Halawa	mamdouh_halawa@yahoo.com Tel.: +20 100 540 2742 Fax: +20 23 386 2224

3 Travelling standard and measurement instructions

3.1 Description of travelling standard

Selected travelling standard is Radian Research type RD-33-332 (serial number 301308). The RD-33-332 has a guaranteed accuracy of 0.01 %.

Appearance of RD-33-332 is shown on Figure 1.

Figure 1 Travelling standard RD-33-332

Terminal block of the travelling standard RD-33-332 is shown on Figure 2.

Figure 2 Terminal block of travelling standard RD-33-332

Travelling standard RD-33-332 is three-phase electric power meter, works on principles of digital processing of electrical current and voltage signals.

Main characteristics of travelling standard RD-33-332:

input voltage: 30…525 V (RMS);

input current: 0,2…120 A (RMS);

frequency of the input voltage and current signals: 45…65 Hz;

constant of the frequency output: 125 000 000 pulse/kWh;

supply voltage: 60…525 V (RMS);

working range of the temperature: –20 °C…40 °C;

keeping range of the temperature: –25 °C...80 °C;

working range of the humidity: 0...95%;

dimensions: 444.5×172×131 mm;

weight: 6.21 kg.

3.2 Measurement

Before the measurements of active power in the RD-33-332 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 hours 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 in Table 3.

Table 3 The measurement points and condition of measurements

Unit	Value of the unit
Voltage	120 V ± 0.2 %
Current	5 A ± 0.2 %
Power factor	1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, 0.0 Lead deviation from the nominal value not exceeding ± 0.1 %
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 Uncertainty of measurement

Uncertainty of the measurements should be calculated according to the GUM – Guide to the expression of uncertainty in measurement JCGM 100:2008 [2] (GUM 1995 with minor corrections) and JCGM 101:2008 [3]. 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.

5 Traceability to the SI

The traceability to the SI of standards was provided to pilot NMI. All of the participating NMIs made measurements of 50/53 Hz Power.

UMTS, BelGIM, GeoSTM, SMU, NIS, and LEM FEIT measurements of power are traceable to PTB. PTB participated in CCEM-K5 and EURAMET.EM-K5.1, and also was a pilot laboratory for EUROMET.EM-K5.

CSM, SASO NMCC and NIS measurements of power are traceable to UME. UME was a pilot laboratory for EURAMET.EM-K5.1.

MASM measurements of power are traceable to NIM and KRISS. QCC EMI measurements of power are traceable to NMIA.

The traceability route for each NMIs national standard of power unit is given in Table 4.

Table 4 Traceability route for each participating NMI

NMI	Country	Traceability Route
VNIIM	Russia	VNIIM
NIM	China	NIM
UMTS	Ukraine	PTB
UME	Turkey	UME
BelGIM	Belarus	PTB
GeoSTM	Georgia	PTB
CSM	Kyrgyzstan	UME
SMU	Slovakia	PTB
LEM-FEIT	Republic of Macedonia	PTB
MASM	Mongolia	NIM, KRISS
QCC EMI	United Arab Emirates	NMIA
SASO-NMCC	Saudi Arabia	UME
NIS	Egypt	PTB, UME

6 Behaviour of the travelling standard

The UMTS as pilot laboratory has performed repeated measurements on the travelling standard RD-33-332 (serial number 301308) during the course of this comparison. Travelling standard RD-33-332 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 RD-33-332 is well-suited for test applications that require multiple measurements with high accuracy and stability.

The first day of starting comparison was 1 August 2016. Comparison finished 26 October 2018. UMTS has performed repeated measurements on travelling standard for 26 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 [4–7] and can be seen in Figures 1–10 for frequencies 50 Hz and 53 Hz and PF = 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead.

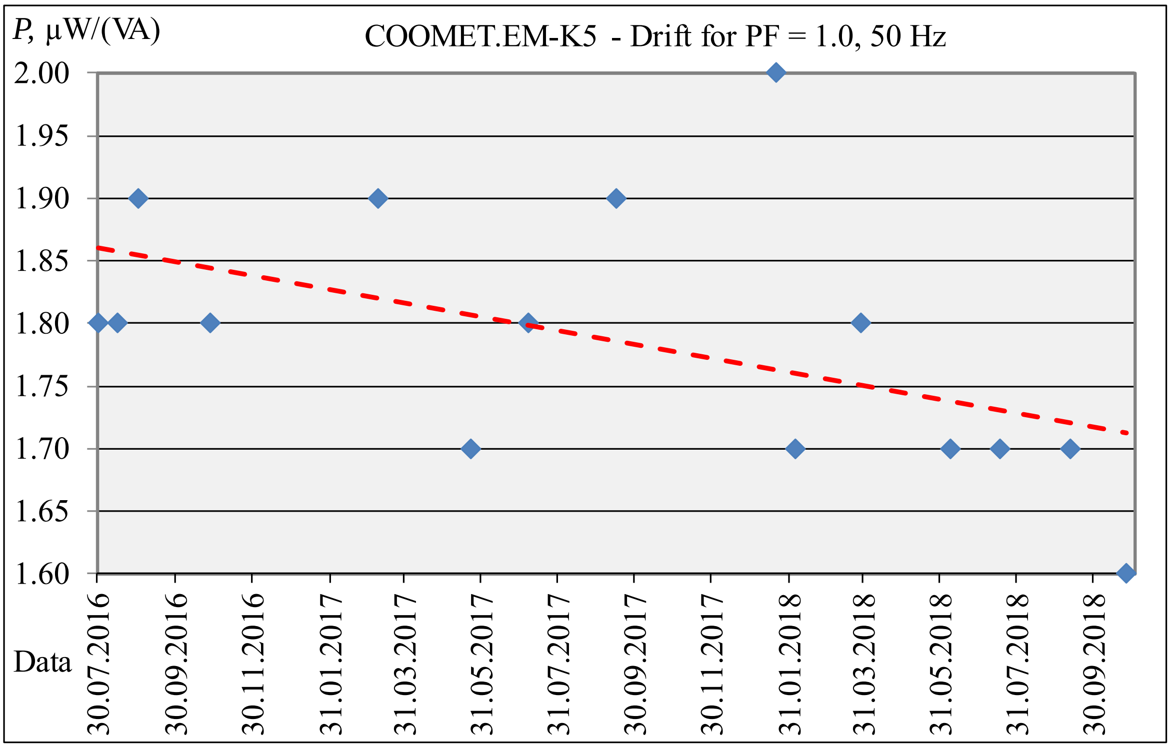

Figure 1 Behaviour of the travelling standard for PF = 1.0, 50 Hz

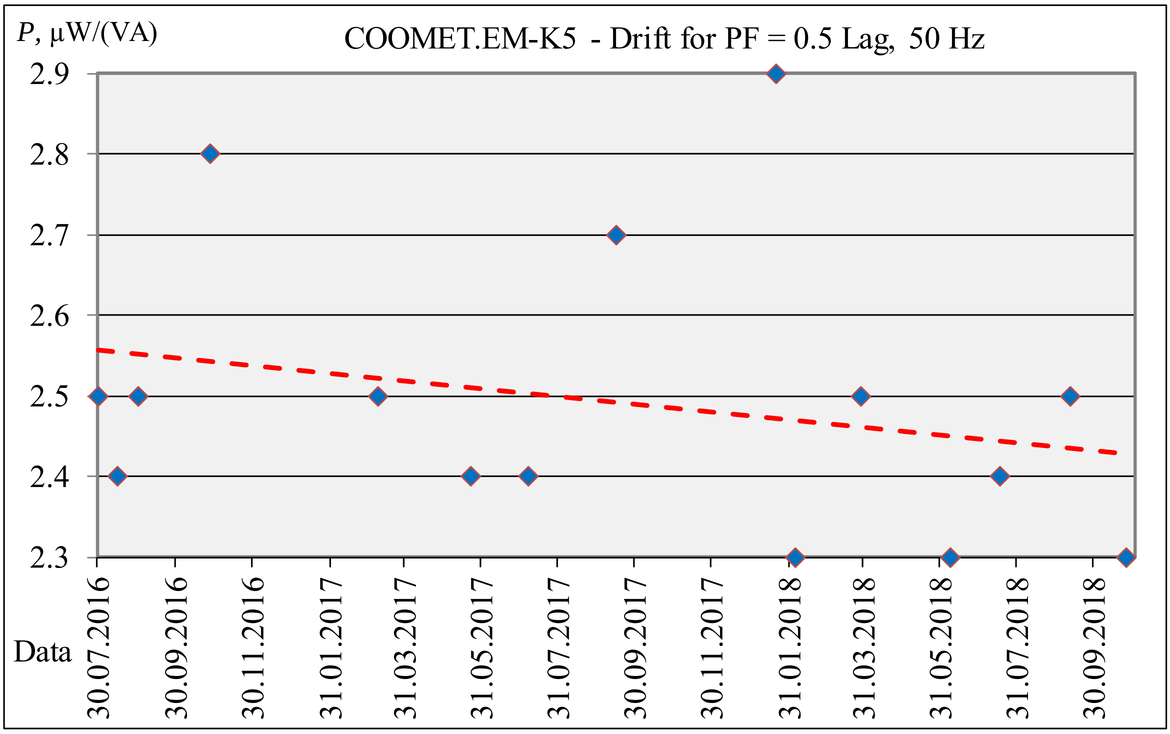

Figure 2 Behaviour of the travelling standard for PF = 0.5 Lag, 50 Hz

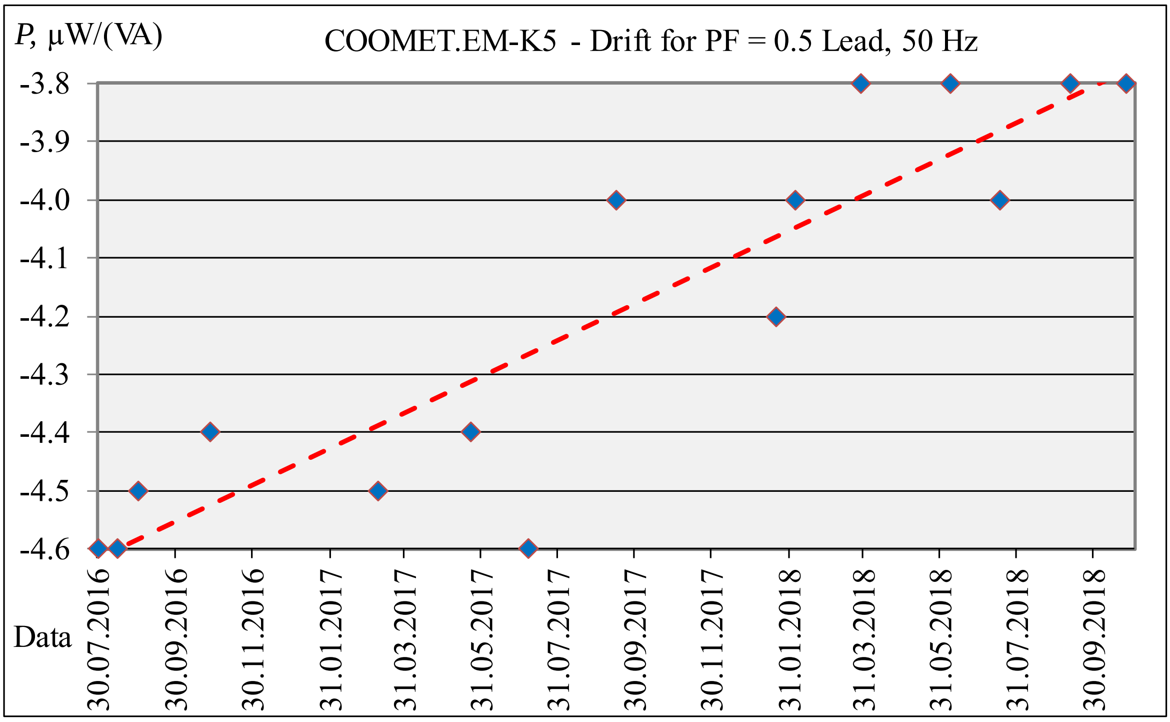

Figure 3 Behaviour of the travelling standard for PF = 0.5 Lead, 50 Hz

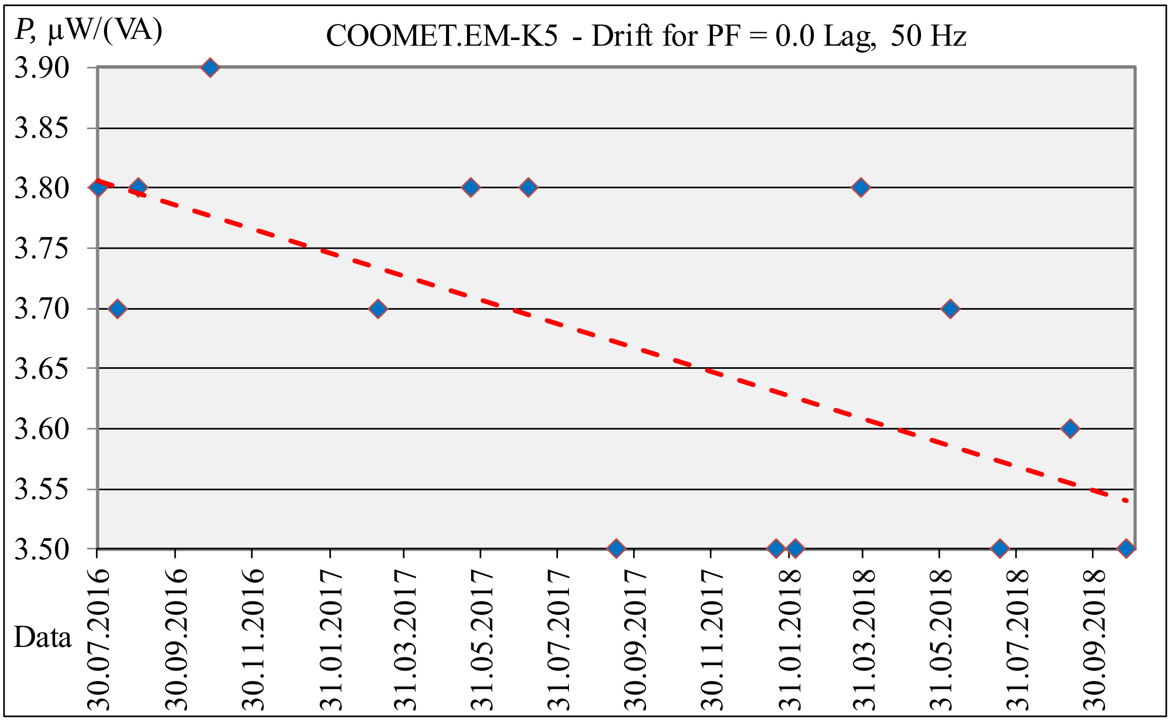

Figure 4 Behaviour of the travelling standard for PF = 0.0 Lag, 50 Hz

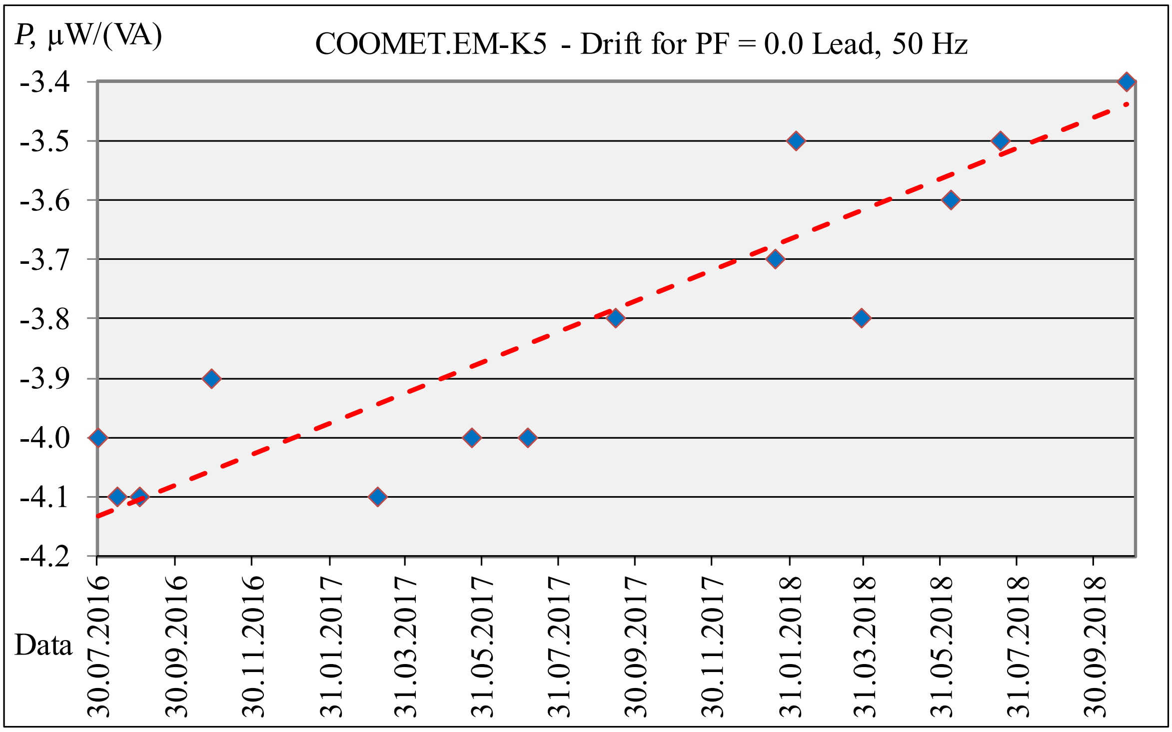

Figure 5 Behaviour of the travelling standard for PF = 0.0 Lead, 50 Hz

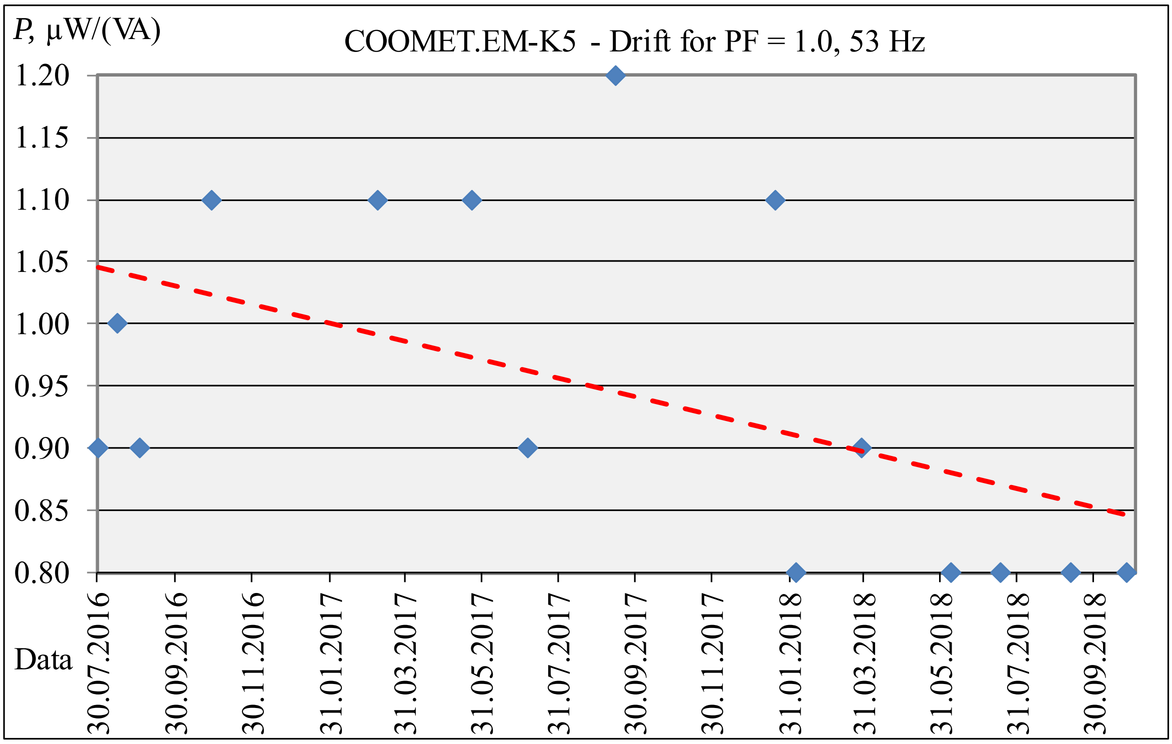

Figure 6 Behaviour of the travelling standard for PF = 1.0, 53 Hz

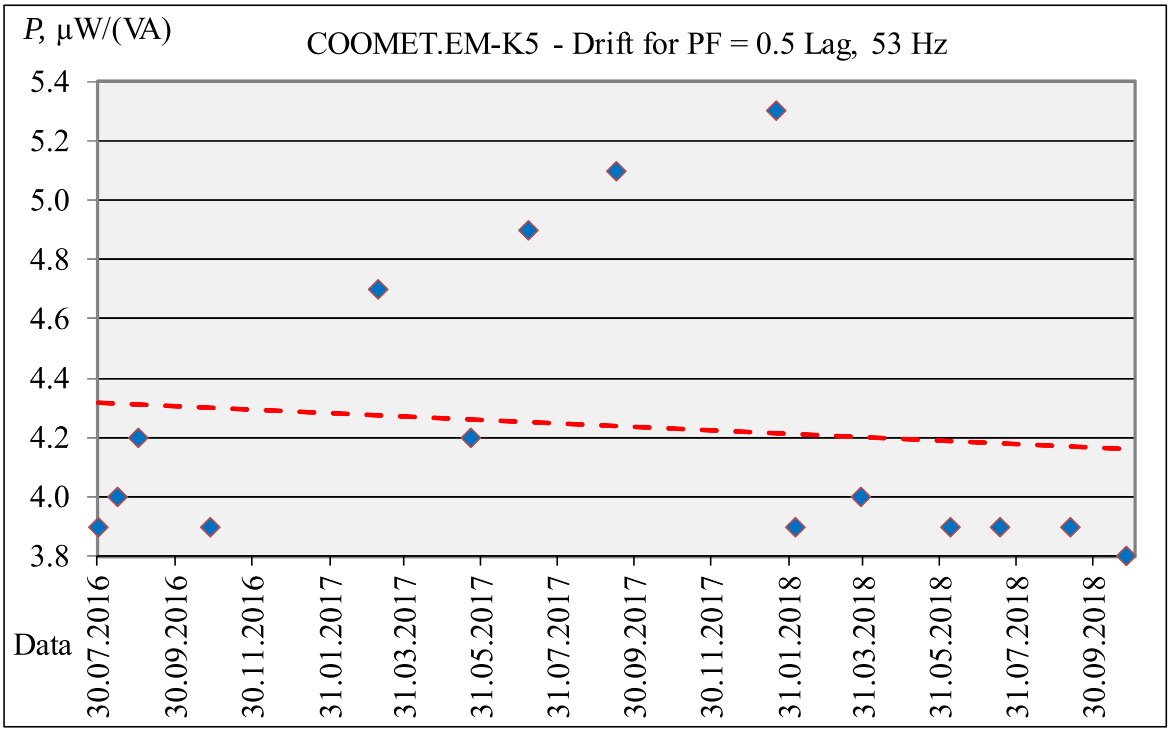

Figure 7 Behaviour of the travelling standard for PF = 0.5 Lag, 53 Hz

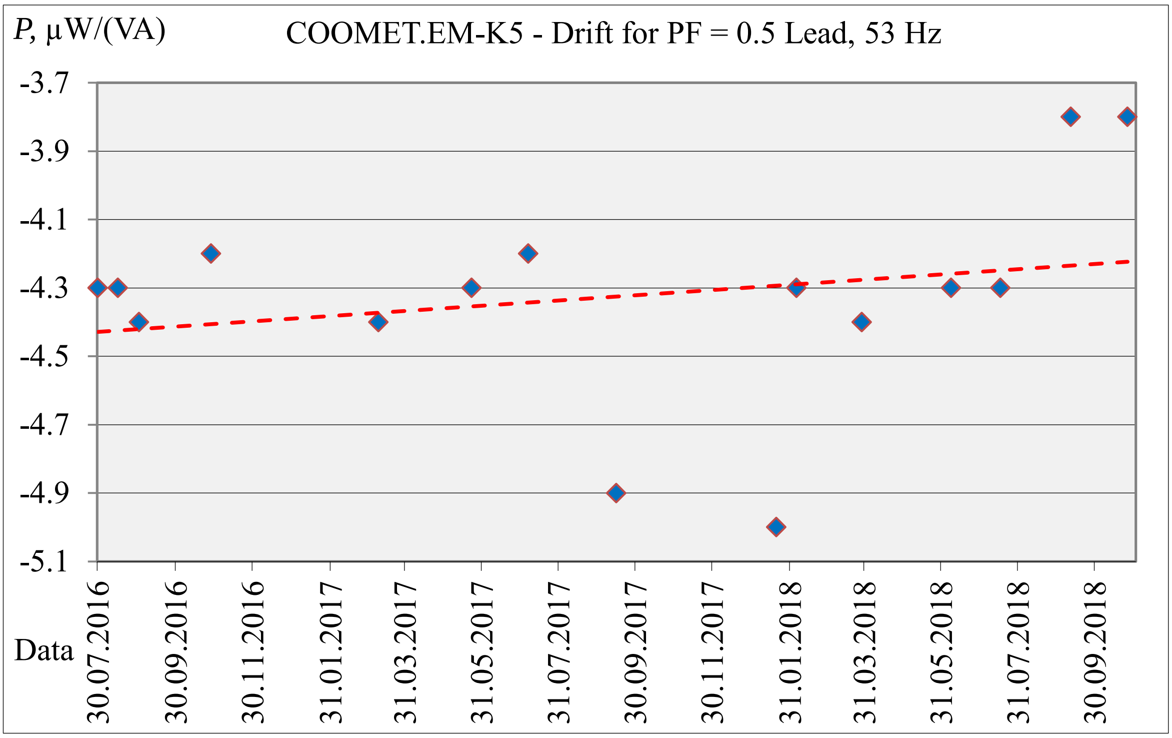

Figure 8 Behaviour of the travelling standard for PF = 0.5 Lead, 53 Hz

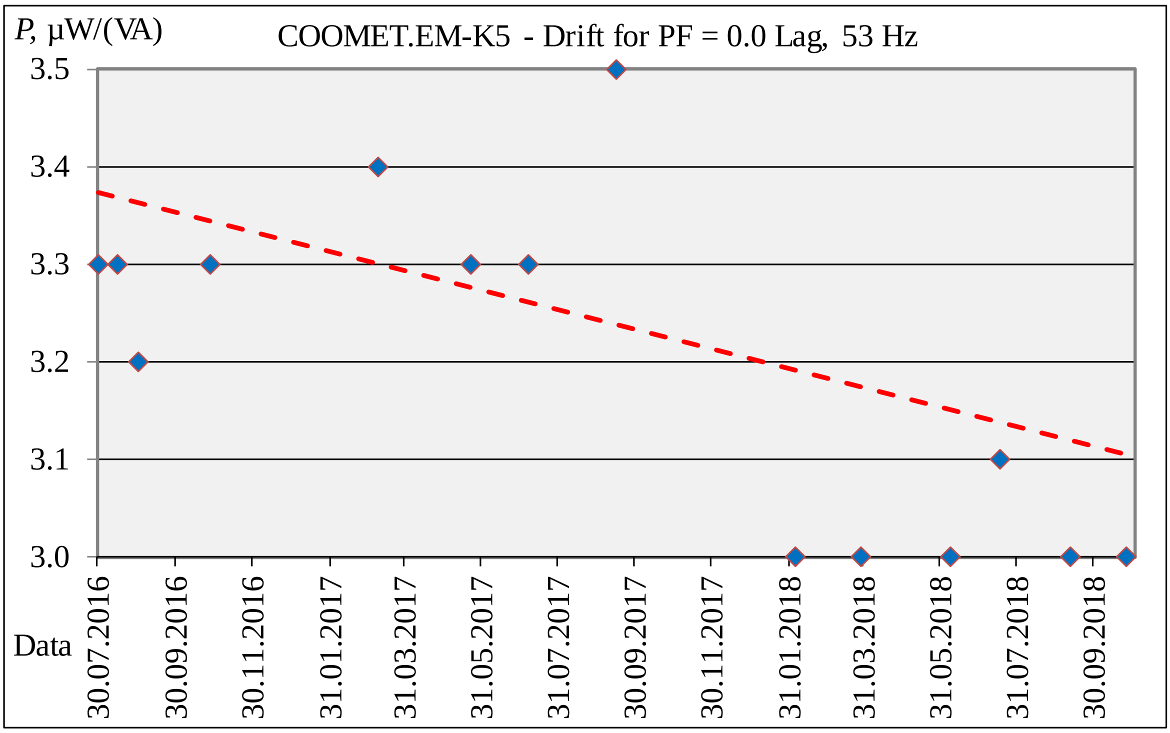

Figure 9 Behaviour of the travelling standard for PF = 0.0 Lag, 53 Hz

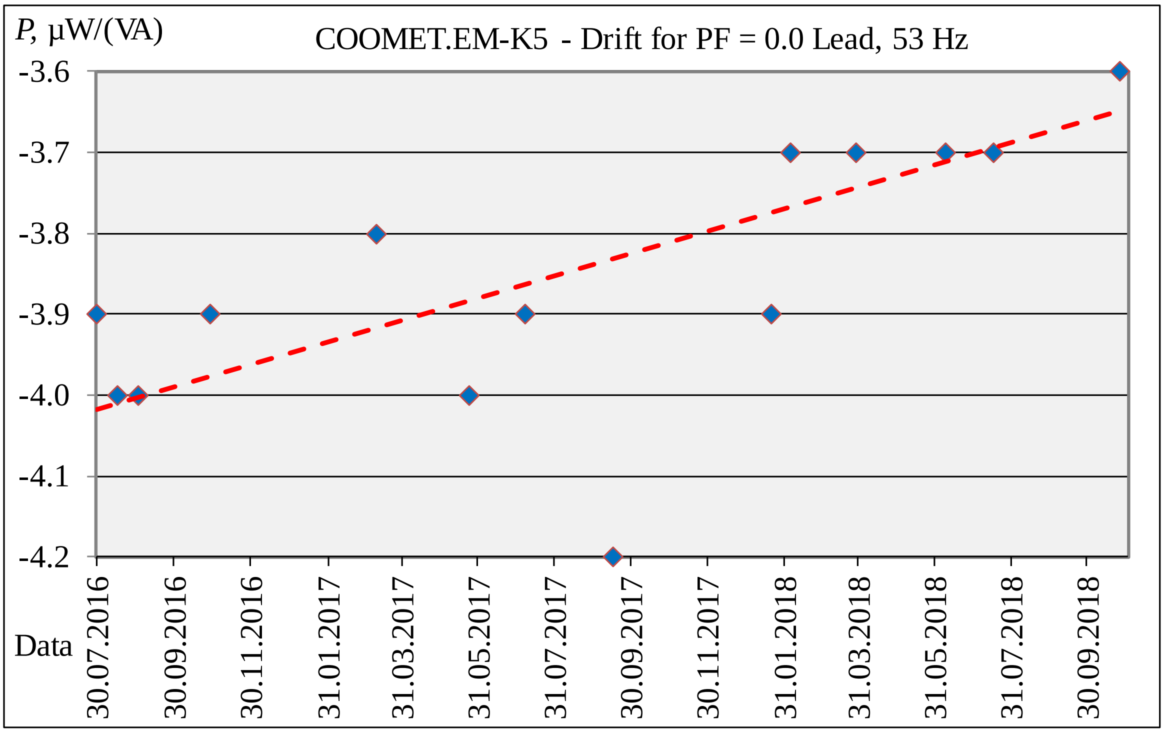

Figure 10 Behaviour of the travelling standard for PF = 0.0 Lead, 53 Hz

The drift values δP_{drift} (the difference between the initial and final values of the linear approximation) given in Table 5 for frequencies 50 Hz and 53 Hz and PF = 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead. The drifts were small for all measurement points, so they can be neglected.

Table 5 The drift values δP_{drift}, μW/(VA)

Frequency	Power factor	δP_{drift}
50 Hz	1.0	-0.14
	0.5 Lag	-0.14
	0.5 Lead	0.80
	0.0 Lag	-0.26
	0.0 Lead	0.72
53 Hz	1.0	-0.21
	0.5 Lag	-0.14
	0.5 Lead	0.22
	0.0 Lag	-0.28
	0.0 Lead	0.37

7 Reported results

7.1 General information and data

A full measurement report containing all relevant data and uncertainty estimates was forwarded to the coordinator within six weeks of completing measurement of the travelling standard. The report included a description of the measurements method, the traceability to the SI, and the results, associated uncertainty and number of degrees of freedom.

List of measurement dates of the NMI participants is show in Table 6.

Table 6 List of measurement dates of the NMI participants

NMI	Measurement dates	Frequency	
		50 Hz	53 Hz
UMTS1, Ukraine	30.07.2016	yes	yes
UMTS2, Ukraine	15.08.2016	yes	yes
UMTS3, Ukraine	01.09.2016	yes	yes
BelGIM, Belarus	15–22.09.2016	yes	yes
UMTS4, Ukraine	28.10.2016	yes	yes
UME, Turkey	15-28.02.2017	yes	yes
UMTS5, Ukraine	10.03.2017	yes	yes

NMI	Measurement dates	Frequency	
GeoSTM, Georgia	19–28.04.2017	yes	yes
UMTS6, Ukraine	23.05.2017	yes	yes
VNIIM, Russia	05–15.06.2017	yes	yes
UMTS7, Ukraine	07.07.2017	yes	yes
MASM, Mongolia	17–28.07.2017	yes	yes
UMTS8, Ukraine	15.09.2017	yes	yes
SMU, Slovakia	09–20.10.2017	yes	yes
NIM, China	14-28.12.2017	yes	yes
UMTS9, Ukraine	20.01.2018	yes	yes
UMTS10, Ukraine	05.02.2018	yes	yes
QCC EMI, United Arab Emirates	25.02–05.03.2018	yes	yes
UMTS11, Ukraine	29.03.2018	yes	yes
NIS, Egypt	22.04–08.05.2018	yes	yes
UMTS12, Ukraine	08.06.2018	yes	yes
CSM, Kyrgyzstan	20–29.06.2018	yes	yes
UMTS13, Ukraine	17.07.2018	yes	yes
SASO-NMCC, Saudi Arabia	05–11.08.2018	yes	yes
UMTS14, Ukraine	11.09.2018	yes	yes
LEM-FEIT, R. Macedonia	24.09–10.10.2018	yes	yes
UMTS15, Ukraine	22-26.10.2018	yes	yes

Additional parameters for measurement of the NMI participants (Appendix 1) are show in Table 7.

Table 7 Additional parameters for measurement of the NMI participants

Parameter	Value	Absolute expanded uncertainty (k = 2)
BelGIM, Belarus		
Frequency, Hz	50 and 53	0.0005
Voltage, V	120.0	0.019

Parameter	Value	Absolute expanded uncertainty (*k* = 2)
Current, A	5.0	0.0008
Temperature, °C	22.0…24.0	0.06
Relative humidity, %	56…57	0.6
UME, Turkey		
Frequency, Hz	50 and 53	0.05
Voltage, V	120.0	0.36
Current, A	5.0	0.02
Temperature, °C	22.0…24.0	0.3
Relative humidity, %	35…55	3.5
GEOSTM, Georgia		
Frequency, Hz	50 and 53	0.01
Voltage, V	120.0	0.024
Current, A	5.0	0.001
Temperature, °C	23.0	0.3
Relative humidity, %	35…45	0.9
VNIIM, Russia		
Frequency, Hz	50 and 53	0.05
Voltage, V	120.0	0.1
Current, A	5.0	0.005
Temperature, °C	23.0	0.5
Relative humidity, %	38…40	3.0
MASM, Mongolia		
Frequency, Hz	50 and 53	0.005
Voltage, V	120.0	0.01
Current, A	5.0	0.0003
Temperature, °C	23.4	0.02

Parameter	Value	Absolute expanded uncertainty (*k* = 2)
Relative humidity, %	43.1	0.11
SMU, Slovakia		
Frequency, Hz	50 and 53	0.05
Voltage, V	120.0	0.06
Current, A	5.0	0.01
Temperature, °C	22.0…24.0	1.0
Relative humidity, %	20…70	5.0
NIM, China		
Frequency, Hz	50 and 53	0.0025
Voltage, V	120.0	0.024
Current, A	5.0	0.001
Temperature, °C	20.0	1.0
Relative humidity, %	45	5
QCC EMI, United Arab Emirates		
Frequency, Hz	50 and 53	0.005
Voltage, V	120.0	0.1
Current, A	5.0	0.02
Temperature, °C	22.0…24.0	1.0
Relative humidity, %	40…70	2.5
NIS, Egypt		
Frequency, Hz	50 and 53	0.1
Voltage, V	120.0	0.04
Current, A	5.0	0.01
Temperature, °C	22.0…24.0	1.0
Relative humidity, %	50	10

Parameter	Value	Absolute expanded uncertainty (*k* = 2)
CSM, Kyrgyzstan		
Frequency, Hz	50 and 53	0.1
Voltage, V	120.0	0.01
Current, A	5.0	0.01
Temperature, °C	22.0…24.0	0.1
Relative humidity, %	46…52	2.5
SASO-NMCC, Saudi Arabia		
Frequency, Hz	50 and 53	0.05
Voltage, V	120.0	0.36
Current, A	5.0	0.02
Temperature, °C	22.0…24.0	0.5
Relative humidity, %	25…55	5.0
LEM-FEIT, R. Macedonia		
Frequency, Hz	50 and 53	0.005
Voltage, V	120.0	0.0036
Current, A	5.0	0.00025
Temperature, °C	22.0…24.0	1.0
Relative humidity, %	55	0.77
UMTS, Ukraine		
Frequency, Hz	50 and 53	0.05
Voltage, V	120.0	0.06
Current, A	5.0	0.01
Temperature, °C	22.0…24.0	0.3
Relative humidity, %	25…55	2.2

The active power values x_i and their standard uncertainties $u(x_i)$ reported by the participants are given in Table 8 for frequencies 50 Hz and 53 Hz and PF = 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead.

Table 8 Relative deviations from nominal values and standard uncertainties (k = 1)

NMI	**50 Hz**		**53 Hz**	
	x_i, μW/(VA)	$u(x_i)$, μW/(VA)	x_i, μW/(VA)	$u(x_i)$, μW/(VA)
PF = 1.0				
BelGIM	-1.9	21.0	-0.9	20.5
UME	-5.0	10.5	-9.0	10.5
GEOSTM	17.3	44.7	14.6	44.7
VNIIM	1.4	5.8	-0.4	4.5
MASM	-3.0	43.6	1.0	37.4
SMU	-52.6	37.3	-53.0	28.5
NIM	1.0	6.0	1.9	6.0
QCC EMI	-6.4	10.7	-10.3	10.7
NIS	-7.8	17.9	-7.6	17.9
CSM	-18.0	79.1	-7.0	79.1
SASO-NMCC	-9.0	19.5	-18.0	19.5
LEM-FEIT	45.6	57.8	39.9	57.8
UMTS	1.8	9.2	1.0	9.0
PF = 0.5 Lag				
BelGIM	2.9	21.2	-1.8	20.6
UME	-1.0	10.9	-4.0	10.9
GEOSTM	14.9	67.9	16.8	67.9
VNIIM	9.4	5.1	11.3	3.7
MASM	34.0	61.0	32.0	57.2
SMU	8.3	42.3	6.6	34.7
NIM	4.7	6.0	5.0	6.0

NMI	50 Hz		53 Hz	
	x_i, µW/(VA)	$u(x_i)$, µW/(VA)	x_i, µW/(VA)	$u(x_i)$, µW/(VA)
QCC EMI	2.2	12.4	2.3	12.4
NIS	15.8	23.1	30.1	18.1
CSM	-10.0	79.0	-13.0	79.0
SASO-NMCC	-7.0	20.0	-13.0	20.0
LEM-FEIT	5.8	57.8	11.2	57.8
UMTS	2.5	13.2	4.3	13.2
PF = 0.5 Lead				
BelGIM	-5.2	21.5	-5.8	20.6
UME	-5.0	10.9	-6.0	10.9
GEOSTM	-1.4	67.9	-7.5	67.9
VNIIM	-8.1	5.1	-13.3	3.7
MASM	-30.0	53.3	-36.0	38.4
SMU	-19.7	43.3	-21.5	34.7
NIM	-4.4	6.0	-4.3	6.0
QCC EMI	-10.4	12.1	-12.5	12.1
NIS	21.2	20.2	12.4	18.6
CSM	-22.0	79.1	-11.0	79.0
SASO-NMCC	-3.0	20.0	-4.0	20.0
LEM-FEIT	80.9	57.8	66.7	57.8
UMTS	-4.3	13.3	-4.4	13.2
PF = 0.0 Lag				
BelGIM	4.8	20.9	-3.8	20.6
UME	4.0	11.0	-9.0	11.0
GEOSTM	5.8	101.5	11.0	101.5
VNIIM	6.9	4.6	12.2	3.7

NMI	50 Hz		53 Hz	
	x_i, µW/(VA)	$u(x_i)$, µW/(VA)	x_i, µW/(VA)	$u(x_i)$, µW/(VA)
MASM	23.0	42.0	27.0	42.1
SMU	31.8	45.6	27.0	38.7
NIM	2.1	5.0	2.0	5.0
QCC EMI	6.7	10.0	7.3	10.0
NIS	-25,8	19.6	-24,7	20.2
CSM	-64.0	80.1	-87.0	81.5
SASO-NMCC	-2.0	20.5	-6.0	20.5
LEM-FEIT	42.6	57.8	38.4	57.8
UMTS	3.7	12.0	3.3	11.9
PF = 0.0 Lead				
BelGIM	4.5	22.4	-1.8	20.6
UME	-6.0	11.0	-5.0	11.0
GEOSTM	-12.9	101.5	-17.8	101.5
VNIIM	-9.1	4.6	-14.1	3.7
MASM	27.0	42.0	-33.0	42.1
SMU	44.7	45.6	45.6	38.8
NIM	-6.6	5.0	-6.8	5.0
QCC EMI	-6.5	10.1	-8.3	10.1
NIS	-25.5	18.6	-30,7	19.1
CSM	-51.0	80.8	-7.0	79.1
SASO-NMCC	-1.0	20.5	4.0	20.5
LEM-FEIT	47.9	57.8	37.7	57.8
UMTS	-3.9	12.2	-3.9	12.1

Note: The value for UMTS is measurement result calculated as simple mean value.

Detailed uncertainty budgets from all participants are given in Appendix 2.

7.2 Calculation of the key comparison reference values and their uncertainties

The correlations in traceability between the NMI participants have been neglected for calculating the Key Comparison Reference Values (RV). Because three NMIs (NIM – linking NMI, VNIIM – linking NMI, and UME – pilot laboratory of EURAMET.EM-K5.1 comparison) with the lowest standard uncertainties specified in the Table 8 that thus essentially determine the KCRV have a different traceability source. Thus, in our partial case even if correlations in traceability would be correctly taken into account in calculating the KCRV, this would not significantly change the KCRV value. In this way the KCRV x_{ref} are calculated as the mean of participant results with COOMET.EM-K5 data and are given by:

$$x_{ref} = \sum_{i=1}^{N} \frac{x_i}{u_c^2(x_i)} \Bigg/ \sum_{i=1}^{N} \frac{1}{u_c^2(x_i)} \tag{1}$$

with combine standard uncertainties

$$u_c^2(x_{ref}) = 1 \Bigg/ \sum_{i=1}^{N} \frac{1}{u_c^2(x_i)} \,. \tag{2}$$

Reference values and expanded uncertainties for 50 and 53 Hz are given in Table 9.

Table 9 Reference values and expanded uncertainties ($k = 2$) for frequencies 50 and 53 Hz

Frequency	Power factor	x_{ref}, µW/(VA)	U_{ref}, µW/(VA)
50 Hz	1.0	-0.8	6.4
	0.5 Lag	5.8	6.5
	0.5 Lead	-5.6	6.4
	0.0 Lag	4.2	5.7
	0.0 Lead	-7.1	5.7
53 Hz	1.0	-2.1	5.8
	0.5 Lag	8.0	5.5
	0.5 Lead	-9.7	5.5
	0.0 Lag	6.4	5.2
	0.0 Lead	-10.2	5.2

7.3 Degrees of equivalence of NMI participants

The principal results of this comparison are the pair-wise degrees of equivalence and the degrees of equivalence with respect to the KCRV of CCEM-K5. Only one value is reported for NMI participants. Degrees of equivalence of the NMI participants are reported with respect to the measurement at 50 Hz and 53 Hz.

The degrees of equivalence of i-th NMI and its combined standard uncertainties with respect to the KCRV (j is number marking for frequencies 50 Hz and 53 Hz and PF = 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead, $j = 10$) are estimated as

$$D_i = x_i - x_{ref\ j} \,, \tag{3}$$

$$u_c^2(D_i) = u_c^2(x_i) + u_c^2(x_{ref\ j}) \,. \tag{4}$$

Additionally, the performance indicator E_n is calculated as:

$$E_n = \frac{|D_i|}{2u_c(D_i)} \tag{5}$$

All degrees of equivalence and the E_n values are given in Table 10, and the graphs on Figures 11–20. The indicator E_n for all NMI participants satisfies the condition of performance ($E_n \le 1.0$).

Table 10 Degrees of equivalence with expanded uncertainties (k=2) and the E_n values for NMIs

NMI	50 Hz			53 Hz		
	D_i, μW/(VA)	$U(D_i)$, μW/(VA)	E_n	D_i, μW/(VA)	$U(D_i)$, μW/(VA)	E_n
PF = 1.0						
BelGIM	-1.1	42.5	0.02	1.2	41.5	0.03
UME	-4.2	21.9	0.19	-6.9	21.7	0.32
GEOSTM	18.1	89.6	0.20	16.7	89.6	0.19
VNIIM	2.2	13.2	0.17	1.7	10.6	0.16
MASM	-2.2	87.3	0.02	3.1	75.1	0.04
SMU	-51.8	74.9	0.69	-50.9	57.2	0.89
NIM	1.8	13.6	0.14	4.0	13.3	0.30
QCC EMI	-5.6	22.3	0.25	-8.2	22.2	0.37
NIS	-7.0	36.4	0.19	-5.5	36.3	0.15
CSM	-17.2	158.2	0.11	-4.9	158.1	0.03
SASO-NMCC	-8.2	39.5	0.21	-15.9	39.4	0.40
LEM-FEIT	46.4	115.7	0.40	42.0	115.6	0.36
UMTS	2.6	19.6	0.14	3.0	19.0	0.16
PF = 0.5 Lag						
BelGIM	-2.9	42.9	0.07	-9.8	41.6	0.24
UME	-6.8	22.6	0.30	-12.0	22.4	0.54
GEOSTM	9.1	136.0	0.07	8.8	135.9	0.06
VNIIM	3.6	12.1	0.30	3.3	9.1	0.36
MASM	28.2	122.2	0.23	24.0	114.6	0.21

NMI	50 Hz			53 Hz		
	D_i, µW/(VA)	$U(D_i)$, µW/(VA)	E_n	D_i, µW/(VA)	$U(D_i)$, µW/(VA)	E_n
SMU	2.5	84.7	0.03	-1.4	69.5	0.02
NIM	-1.1	13.6	0.08	-3.0	13.2	0.23
QCC EMI	-3.6	25.6	0.14	-5.7	25.4	0.22
NIS	10.0	46.7	0.22	22.1	36.5	0.60
CSM	-15.8	158.1	0.10	-21.0	158.1	0.13
SASO-NMCC	-12.8	40.5	0.31	-21.0	40.4	0.52
LEM-FEIT	0.0	115.7	0.00	3.2	115.6	0.03
UMTS	-3.3	27.2	0.12	-3.8	26.9	0.14
PF = 0.5 Lead						
BelGIM	0.4	43.6	0.01	3.9	41.7	0.09
UME	0.6	22.6	0.03	3.7	22.4	0.16
GEOSTM	4.2	136.0	0.03	2.2	135.9	0.02
VNIIM	-2.5	12.1	0.21	-3.6	9.1	0.40
MASM	-24.4	106.7	0.23	-26.3	76.9	0.34
SMU	-14.1	84.7	0.17	-11.8	69.5	0.17
NIM	1.2	13.6	0.09	5.4	13.2	0.41
QCC EMI	-4.8	25.0	0.19	-2.8	24.8	0.11
NIS	26.8	40.9	0.66	22.1	37.5	0.59
CSM	-16.4	158.2	0.10	-1.3	158.1	0.01
SASO-NMCC	2.6	40.5	0.06	5.7	40.4	0.14
LEM-FEIT	86.5	115.7	0.75	76.4	115.6	0.66
UMTS	1.4	27.3	0.05	5.4	27.0	0.20
PF = 0.0 Lag						
BelGIM	0.6	42.2	0.01	-10.2	41.4	0.25
UME	-0.2	22.6	0.01	-15.4	22.5	0.68

NMI	50 Hz			53 Hz		
	D_i, µW/(VA)	$U(D_i)$, µW/(VA)	E_n	D_i, µW/(VA)	$U(D_i)$, µW/(VA)	E_n
GEOSTM	1.6	203.1	0.01	4.6	203.1	0.02
VNIIM	2.7	10.8	0.25	5.8	9.0	0.64
MASM	18.8	84.2	0.22	20.6	84.3	0.24
SMU	27.6	91.4	0.30	20.6	77.5	0.27
NIM	-2.1	11.5	0.18	-4.4	11.3	0.39
QCC EMI	2.5	20.8	0.12	0.9	20.7	0.04
NIS	-30.0	39.6	0.76	-31.1	40.7	0.76
CSM	-68.2	160.3	0.43	-93.4	163.1	0.57
SASO-NMCC	-6.2	41.4	0.15	-12.4	41.3	0.30
LEM-FEIT	38.4	115.6	0.33	32.0	115.6	0.28
UMTS	-0.5	24.6	0.02	-3.2	24.4	0.13
PF = 0.0 Lead						
BelGIM	11.6	45.2	0.26	8.4	41.4	0.20
UME	1.1	22.6	0.05	5.2	22.5	0.23
GEOSTM	-5.8	203.1	0.03	-7.6	203.1	0.04
VNIIM	-2.0	10.8	0.18	-3.9	9.0	0.43
MASM	34.1	84.2	0.40	-22.8	84.4	0.27
SMU	51.8	91.4	0.57	55.8	77.5	0.72
NIM	0.5	11.5	0.04	3.4	11.3	0.31
QCC EMI	0.6	20.9	0.03	1.9	20.8	0.09
NIS	-18.4	37.6	0.49	-20.5	38.6	0.53
CSM	-43.9	161.7	0.27	3.2	158.3	0.02
SASO-NMCC	6.1	41.4	0.15	14.2	41.3	0.34
LEM-FEIT	55.0	115.6	0.48	47.9	115.6	0.41
UMTS	3.3	25.2	0.13	6.4	24.8	0.26

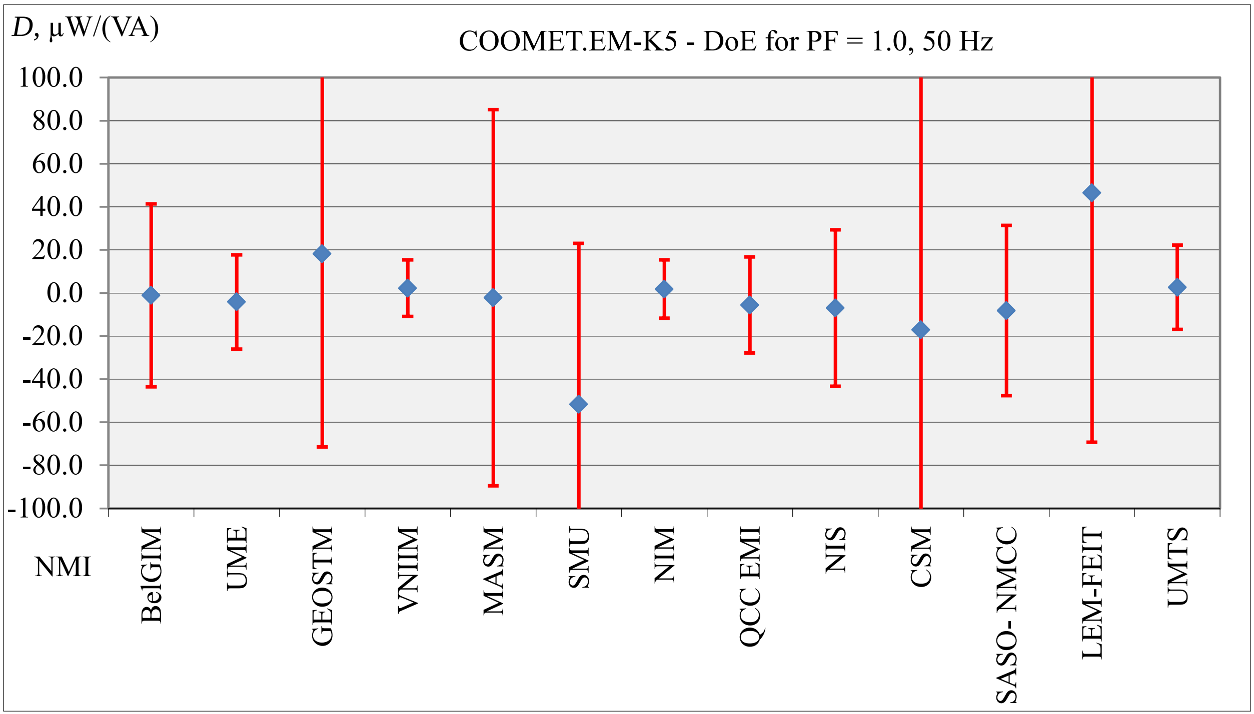

Figure 11 Degree of equivalence for NMI participants for PF = 1.0, 50 Hz

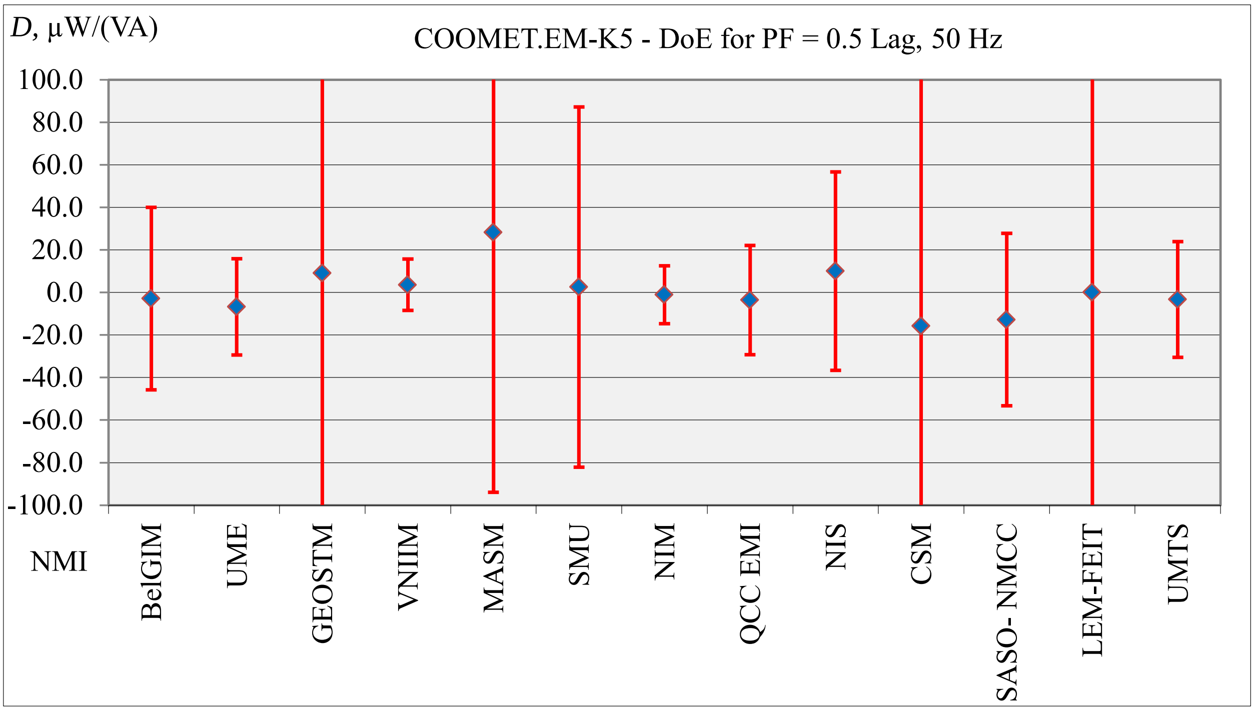

Figure 12 Degree of equivalence for NMI participants for PF = 0.5 Lag, 50 Hz

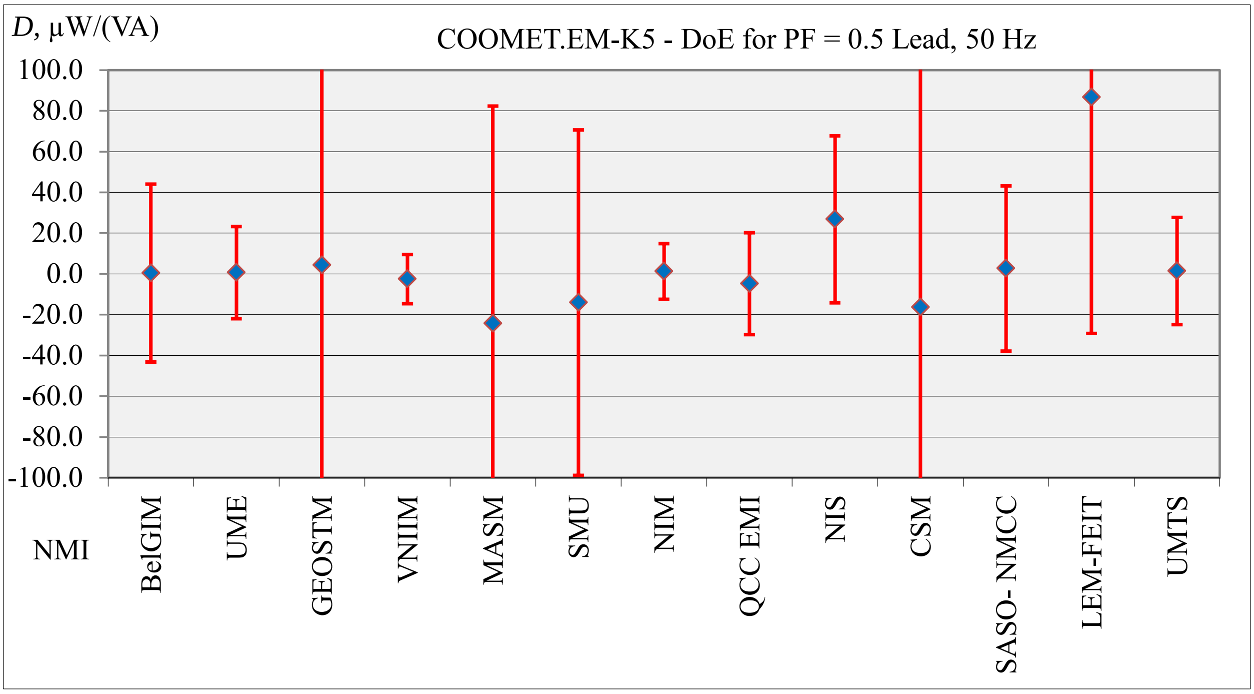

Figure 13 Degree of equivalence for NMI participants for PF = 0.5 Lead, 50 Hz

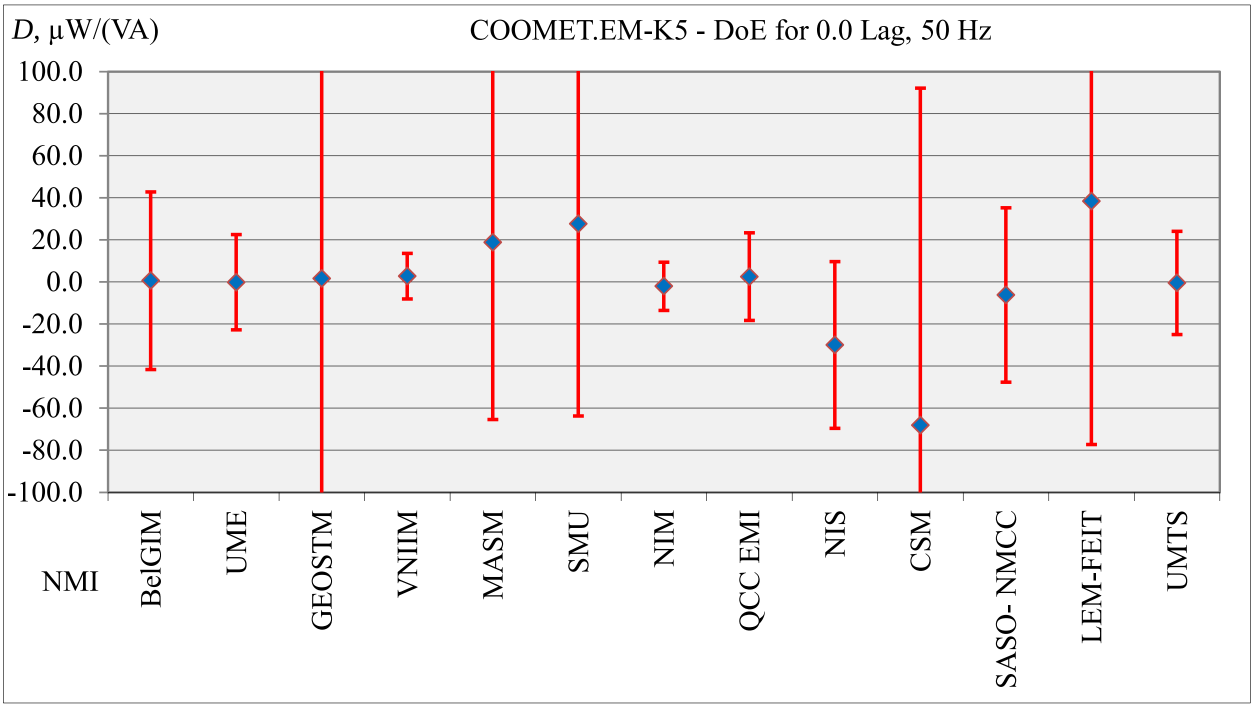

Figure 14 Degree of equivalence for NMI participants for PF = 0.0 Lag, 50 Hz

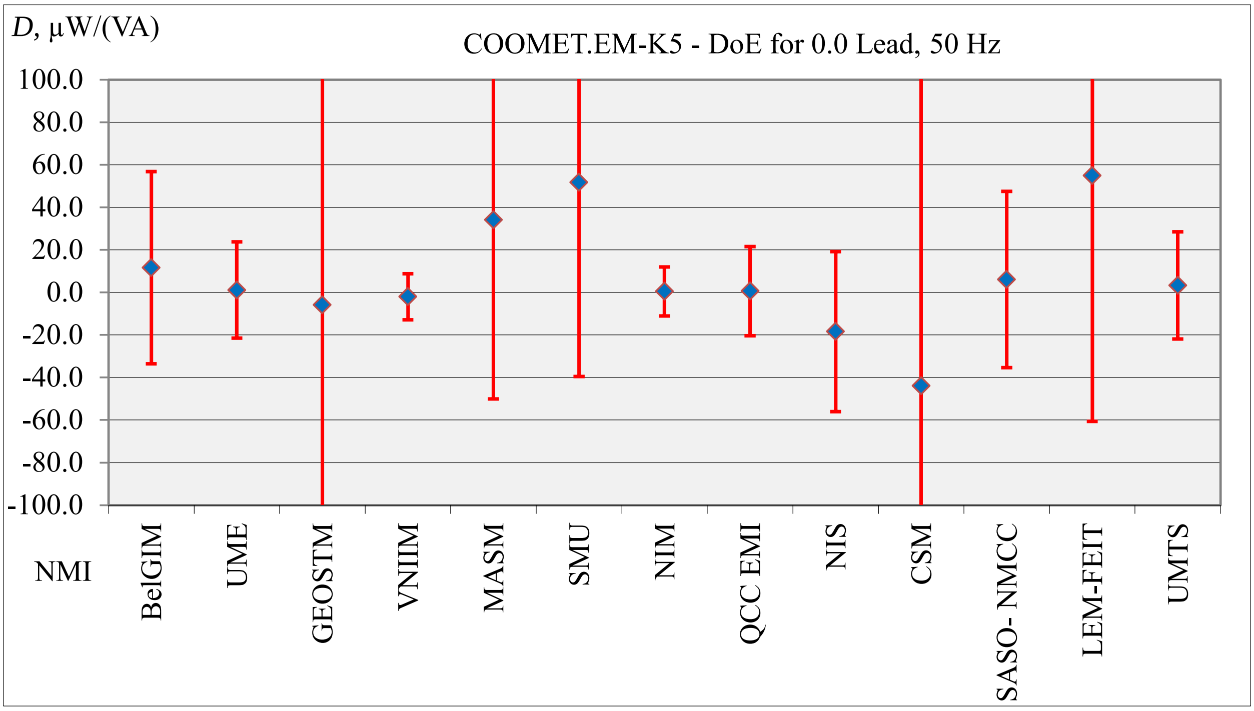

Figure 15 Degree of equivalence for NMI participants for PF = 0.0 Lead, 50 Hz

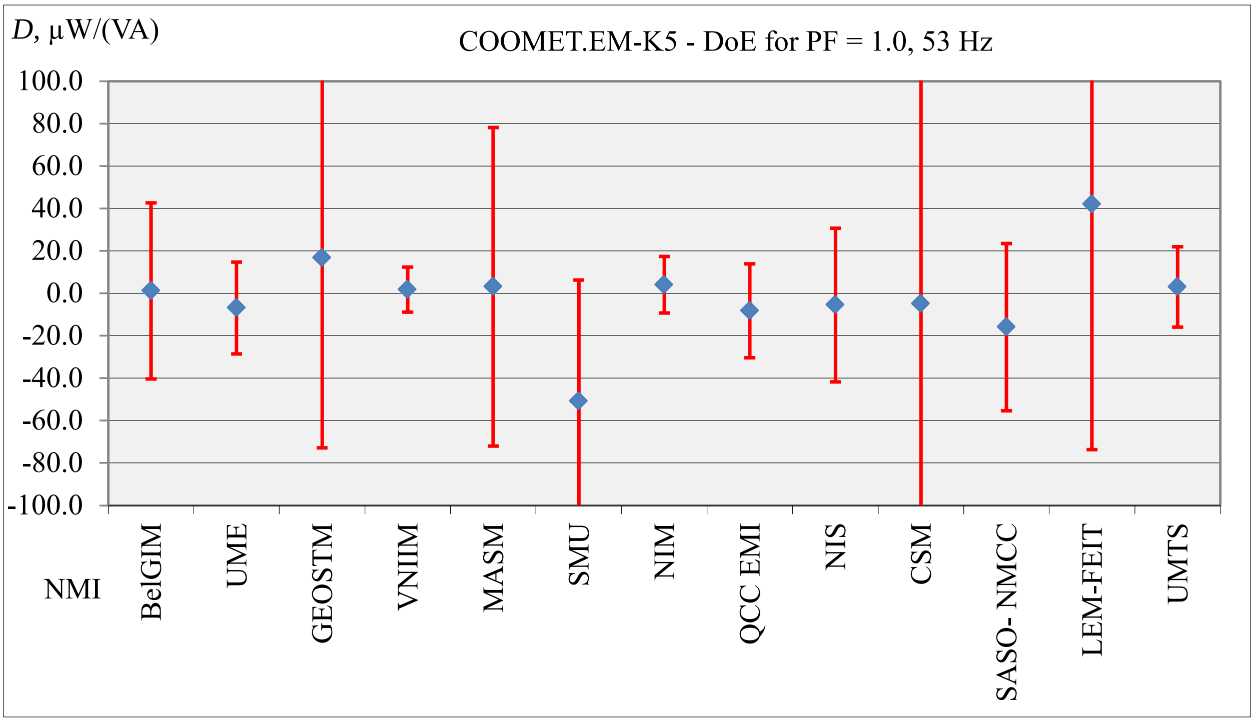

Figure 16 Degree of equivalence for NMI participants for PF = 1.0, 53 Hz

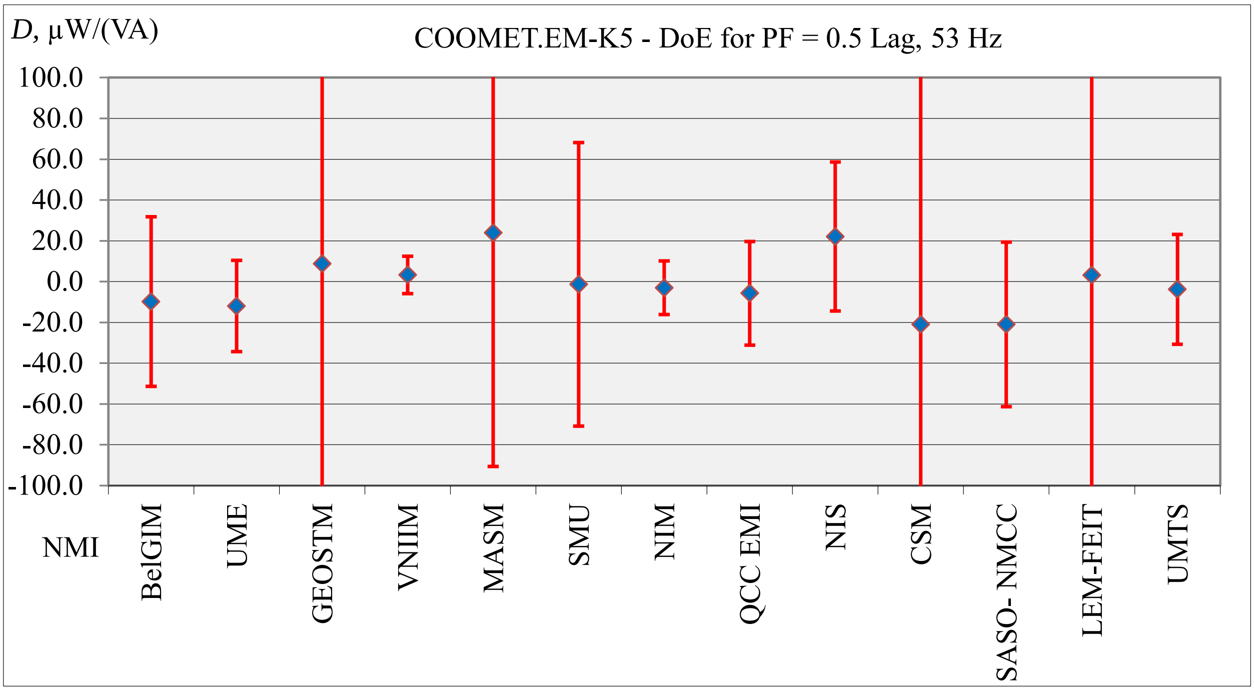

Figure 17 Degree of equivalence for NMI participants for PF = 0.5 Lag, 53 Hz

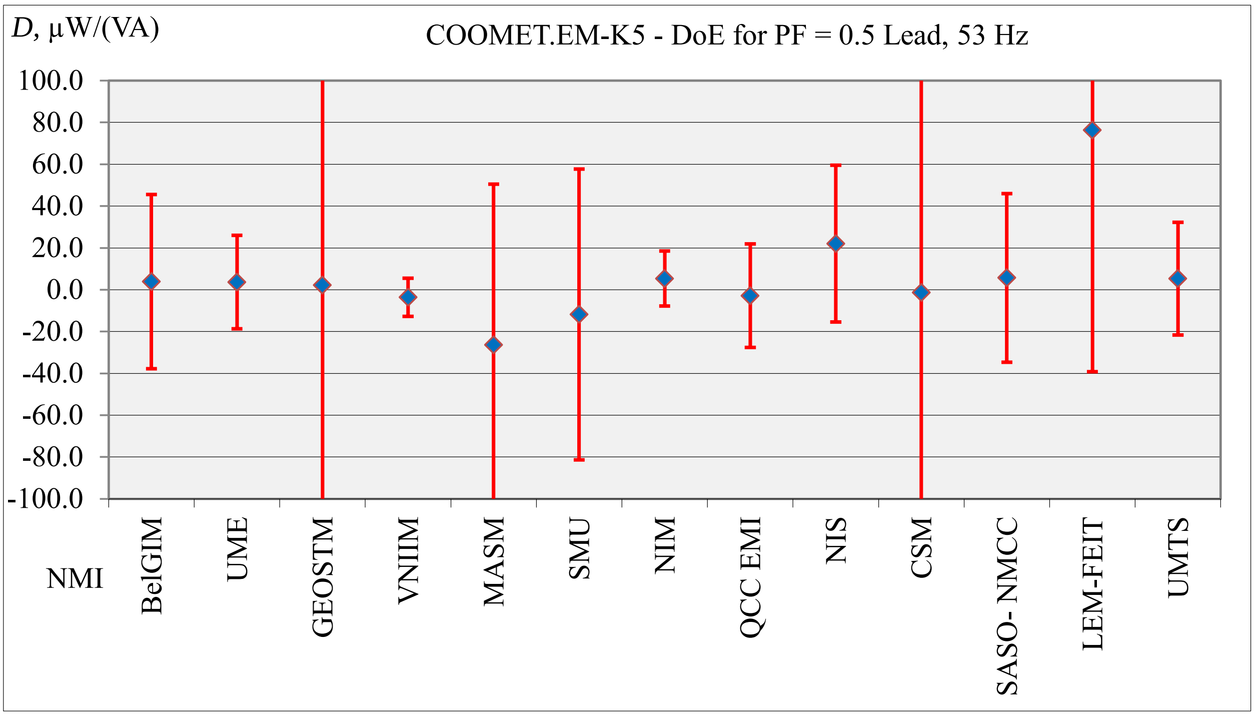

Figure 18 Degree of equivalence for NMI participants for PF = 0.5 Lead, 53 Hz

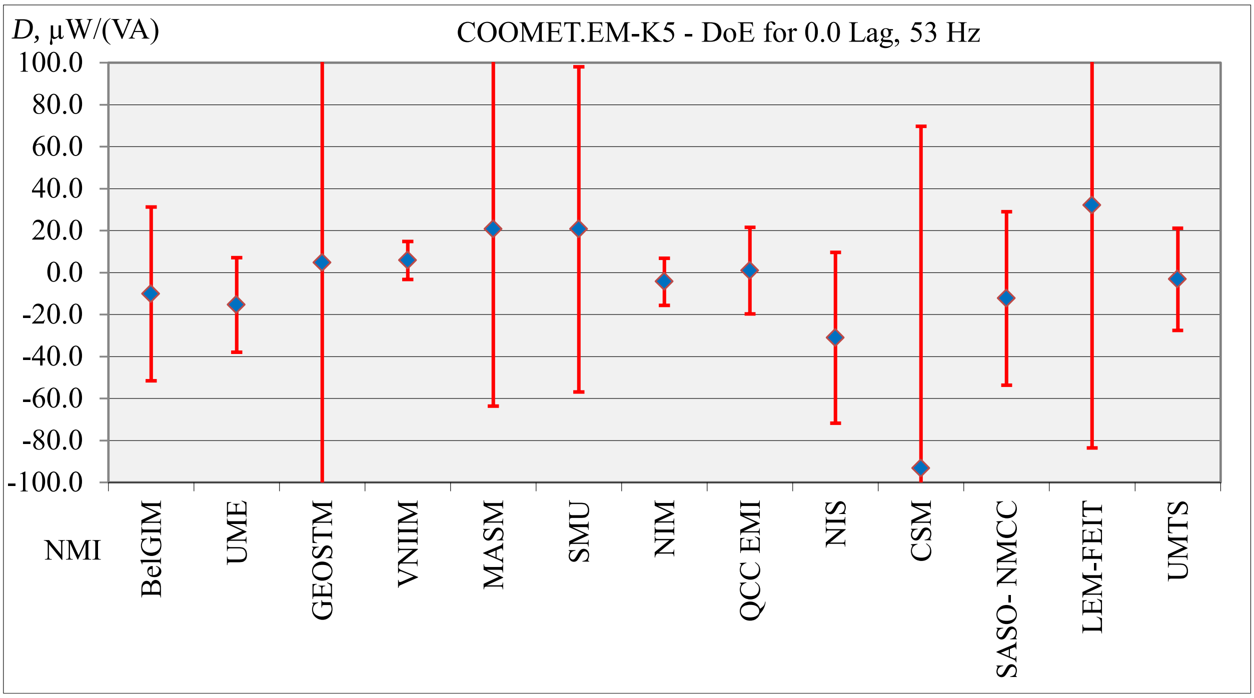

Figure 19 Degree of equivalence for NMI participants for PF = 0.0 Lag, 53 Hz

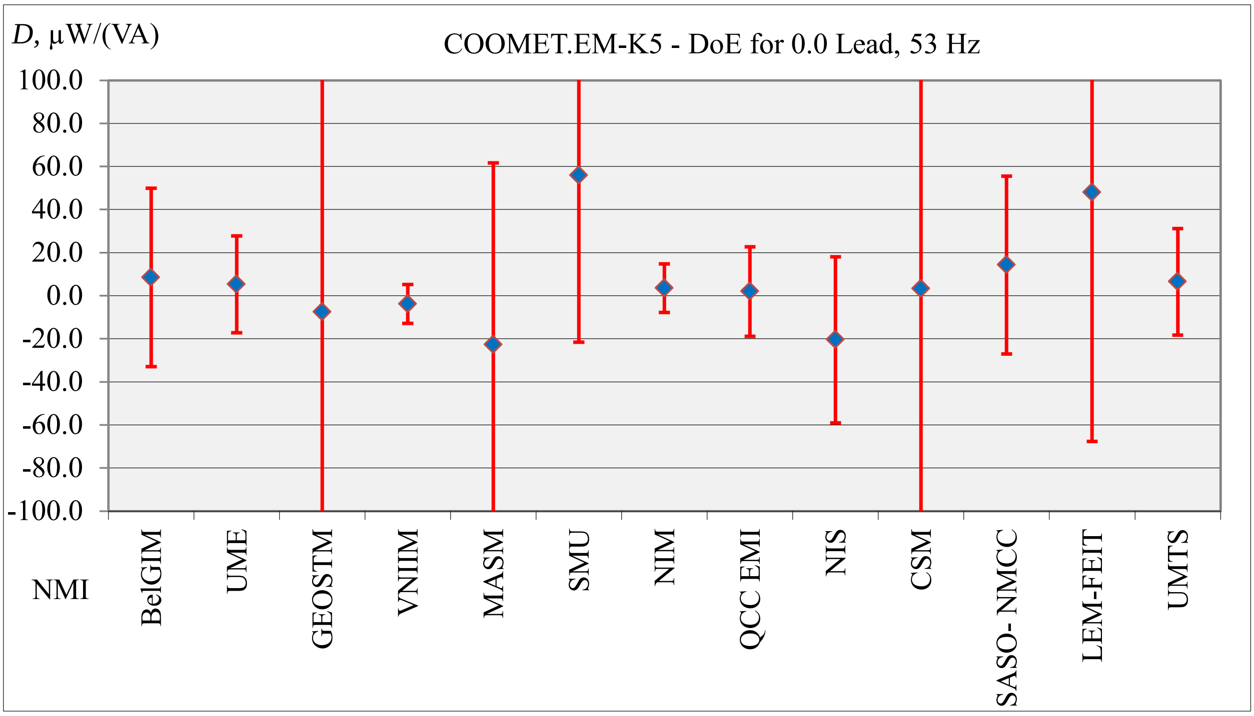

Figure 20 Degree of equivalence for NMI participants for PF = 0.0 Lead, 53 Hz

The 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 CRV at 50 Hz and 53 Hz are shown in Tables 11–20.

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

$$D_{ij} = x_i - x_j, \tag{6}$$

$$u_c^2(D_{ij}) = u_c^2(x_i) + u_c^2(x_j). \tag{7}$$

8 Summary

A key comparison of 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, 0.0 Lag, and 0.0 Lead power factors has been conducted between participating COOMET member NMIs and NMIs from other regional metrological organizations (EURAMET, APMP, GULFMET, and AFRIMET). In general there is good agreement between NMI participants for this quantity. It is expected that this comparison will be able to provide support for participants' entries in Appendix C of the Mutual Recognition Arrangement. Proposal for linking to CCEM-K5 key comparison and degrees of equivalence of NMI participants was made. In this comparison, the participants report about all NMIs for realization the traceability of the unit of active power.

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Table 11 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 1.0, 50 Hz, µW/(VA)

NMI			**BelGIM**		**UME**		**GEOSTM**		**VNIIM**		**MASM**		**SMU**	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	-1.1	42.5	0.0	0.0	-3.1	47.8	19.2	99.2	3.3	44.5	-1.1	97.1	-50.7	86.1
UME	-4.2	21.9	3.1	47.8	0.0	0.0	22.3	92.2	6.4	25.6	2.0	90.0	-47.6	78.0
GEOSTM	18.1	89.6	-19.2	99.2	-22.3	92.2	0.0	0.0	-15.9	90.6	-20.3	125.1	-69.9	116.8
VNIIM	2.2	13.2	-3.3	44.5	-6.4	25.6	15.9	90.6	0.0	0.0	-4.4	88.3	-54.0	76.1
MASM	-2.2	87.3	1.1	97.1	-2.0	90.0	20.3	125.1	4.4	88.3	0.0	0.0	-49.6	115.0
SMU	-51.8	74.9	50.7	86.1	47.6	78.0	69.9	116.8	54.0	76.1	49.6	115.0	0.0	0.0
NIM	1.8	13.6	-2.9	44.6	-6.0	25.8	16.3	90.6	0.4	19.0	-4.0	88.4	-53.6	76.1
QCC EMI	-5.6	22.3	4.5	48.0	1.4	31.3	23.7	92.3	7.8	25.9	3.4	90.1	-46.2	78.1
NIS	-7.0	36.4	5.9	56.0	2.8	42.5	25.1	96.7	9.2	38.7	4.8	94.6	-44.8	83.3
CSM	-17.2	158.2	16.1	163.8	13.0	159.7	35.3	181.8	19.4	158.7	15.0	180.7	-34.6	175.0
SASO-NMCC	-8.2	39.5	7.1	58.0	4.0	45.2	26.3	97.9	10.4	41.6	6.0	95.8	-43.6	84.7
LEM-FEIT	46.4	115.7	-47.5	123.3	-50.6	117.8	-28.3	146.3	-44.2	116.5	-48.6	144.9	-98.2	137.8
UMTS	2.6	19.6	-3.7	46.8	-6.8	29.4	15.5	91.7	-0.4	23.6	-4.8	89.5	-54.4	77.4

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	2.9	44.6	-4.5	48.0	-5.9	56.0	-16.1	163.8	-7.1	58.0	47.5	123.3	3.7	46.8
UME	6.0	25.8	-1.4	31.3	-2.8	42.5	-13.0	159.7	-4.0	45.2	50.6	117.8	6.8	29.4
GEOSTM	-16.3	90.6	-23.7	92.3	-25.1	96.7	-35.3	181.8	-26.3	97.9	28.3	146.3	-15.5	91.7
VNIIM	-0.4	19.0	-7.8	25.9	-9.2	38.7	-19.4	158.7	-10.4	41.6	44.2	116.5	0.4	23.6
MASM	4.0	88.4	-3.4	90.1	-4.8	94.6	-15.0	180.7	-6.0	95.8	48.6	144.9	4.8	89.5
SMU	53.6	76.1	46.2	78.1	44.8	83.3	34.6	175.0	43.6	84.7	98.2	137.8	54.4	77.4
NIM	0.0	0.0	-7.4	26.1	-8.8	38.9	-19.0	158.8	-10.0	41.8	44.6	116.5	0.8	23.9
QCC EMI	7.4	26.1	0.0	0.0	-1.4	42.7	-11.6	159.8	-2.6	45.4	52.0	117.8	8.2	29.7
NIS	8.8	38.9	1.4	42.7	0.0	0.0	-10.2	162.3	-1.2	53.7	53.4	121.3	9.6	41.3
CSM	19.0	158.8	11.6	159.8	10.2	162.3	0.0	0.0	9.0	163.1	63.6	196.0	19.8	159.4
SASO-NMCC	10.0	41.8	2.6	45.4	1.2	53.7	-9.0	163.1	0.0	0.0	54.6	122.3	10.8	44.1
LEM-FEIT	-44.6	116.5	-52.0	117.8	-53.4	121.3	-63.6	196.0	-54.6	122.3	0.0	0.0	-43.8	117.3
UMTS	-0.8	23.9	-8.2	29.7	-9.6	41.3	-19.8	159.4	-10.8	44.1	43.8	117.3	0.0	0.0

Table 12 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 0.5 Lag, 50 Hz, µW/(VA)

NMI			BelGIM		UME		GEOSTM		VNIIM		MASM		SMU	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	-2.9	42.9	0.0	0.0	-3.9	48.5	12.0	142.6	6.5	44.6	31.1	129.5	5.4	94.9
UME	-6.8	22.6	3.9	48.5	0.0	0.0	15.9	137.9	10.4	25.6	35.0	124.3	9.3	87.7
GEOSTM	9.1	136.0	-12.0	142.6	-15.9	137.9	0.0	0.0	-5.5	136.5	19.1	182.8	-6.6	160.2
VNIIM	3.6	12.1	-6.5	44.6	-10.4	25.6	5.5	136.5	0.0	0.0	24.6	122.8	-1.1	85.6
MASM	28.2	122.2	-31.1	129.5	-35.0	124.3	-19.1	182.8	-24.6	122.8	0.0	0.0	-25.7	148.7
SMU	2.5	84.7	-5.4	94.9	-9.3	87.7	6.6	160.2	1.1	85.6	25.7	148.7	0.0	0.0
NIM	-1.1	13.6	-1.8	45.0	-5.7	26.4	10.2	136.7	4.7	18.2	29.3	123.0	3.6	85.8
QCC EMI	-3.6	25.6	0.7	50.0	-3.2	34.1	12.7	138.4	7.2	28.3	31.8	124.9	6.1	88.5
NIS	10.0	46.7	-12.9	63.4	-16.8	51.9	-0.9	143.8	-6.4	48.2	18.2	130.8	-7.5	96.7
CSM	-15.8	158.1	12.9	163.8	9.0	159.7	24.9	208.5	19.4	158.6	44.0	199.8	18.3	179.4
SASO-NMCC	-12.8	40.5	9.9	59.0	6.0	46.4	21.9	141.9	16.4	42.3	41.0	128.7	15.3	93.9
LEM-FEIT	0.0	115.7	-2.9	123.4	-6.8	117.9	9.1	178.6	3.6	116.3	28.2	168.3	2.5	143.4
UMTS	-3.3	27.2	0.4	50.8	-3.5	35.4	12.4	138.7	6.9	29.8	31.5	125.2	5.8	89.0

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	1.8	45.0	-0.7	50.0	12.9	63.4	-12.9	163.8	-9.9	59.0	2.9	123.4	-0.4	50.8
UME	5.7	26.4	3.2	34.1	16.8	51.9	-9.0	159.7	-6.0	46.4	6.8	117.9	3.5	35.4
GEOSTM	-10.2	136.7	-12.7	138.4	0.9	143.8	-24.9	208.5	-21.9	141.9	-9.1	178.6	-12.4	138.7
VNIIM	-4.7	18.2	-7.2	28.3	6.4	48.2	-19.4	158.6	-16.4	42.3	-3.6	116.3	-6.9	29.8
MASM	-29.3	123.0	-31.8	124.9	-18.2	130.8	-44.0	199.8	-41.0	128.7	-28.2	168.3	-31.5	125.2
SMU	-3.6	85.8	-6.1	88.5	7.5	96.7	-18.3	179.4	-15.3	93.9	-2.5	143.4	-5.8	89.0
NIM	0.0	0.0	-2.5	29.0	11.1	48.6	-14.7	158.7	-11.7	42.7	1.1	116.5	-2.2	30.4
QCC EMI	2.5	29.0	0.0	0.0	13.6	53.3	-12.2	160.2	-9.2	47.9	3.6	118.5	0.3	37.4
NIS	-11.1	48.6	-13.6	53.3	0.0	0.0	-25.8	164.9	-22.8	61.8	-10.0	124.8	-13.3	54.0
CSM	14.7	158.7	12.2	160.2	25.8	164.9	0.0	0.0	3.0	163.2	15.8	195.9	12.5	160.4
SASO-NMCC	11.7	42.7	9.2	47.9	22.8	61.8	-3.0	163.2	0.0	0.0	12.8	122.6	9.5	48.8
LEM-FEIT	-1.1	116.5	-3.6	118.5	10.0	124.8	-15.8	195.9	-12.8	122.6	0.0	0.0	-3.3	118.9
UMTS	2.2	30.4	-0.3	37.4	13.3	54.0	-12.5	160.4	-9.5	48.8	3.3	118.9	0.0	0.0

Table 13 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 0.5 Lead, 50 Hz, µW/(VA)

NMI			BelGIM		UME		GEOSTM		VNIIM		MASM		SMU	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	0.4	43.6	0.0	0.0	0.2	49.1	3.8	142.8	-2.9	45.2	-24.8	115.3	-14.5	95.3
UME	0.6	22.6	-0.2	49.1	0.0	0.0	3.6	137.9	-3.1	25.6	-25.0	109.1	-14.7	87.7
GEOSTM	4.2	136.0	-3.8	142.8	-3.6	137.9	0.0	0.0	-6.7	136.5	-28.6	172.9	-18.3	160.2
VNIIM	-2.5	12.1	2.9	45.2	3.1	25.6	6.7	136.5	0.0	0.0	-21.9	107.4	-11.6	85.6
MASM	-24.4	106.7	24.8	115.3	25.0	109.1	28.6	172.9	21.9	107.4	0.0	0.0	10.3	136.2
SMU	-14.1	84.7	14.5	95.3	14.7	87.7	18.3	160.2	11.6	85.6	-10.3	136.2	0.0	0.0
NIM	1.2	13.6	-0.8	45.7	-0.6	26.4	3.0	136.7	-3.7	18.2	-25.6	107.6	-15.3	85.8
QCC EMI	-4.8	25.0	5.2	50.3	5.4	33.7	9.0	138.3	2.3	27.8	-19.6	109.6	-9.3	88.3
NIS	26.8	40.9	-26.4	59.8	-26.2	46.7	-22.6	142.0	-29.3	42.7	-51.2	114.3	-40.9	94.1
CSM	-16.4	158.2	16.8	164.1	17.0	159.8	20.6	208.6	13.9	158.7	-8.0	190.8	2.3	179.4
SASO-NMCC	2.6	40.5	-2.2	59.5	-2.0	46.4	1.6	141.9	-5.1	42.3	-27.0	114.1	-16.7	93.9
LEM-FEIT	86.5	115.7	-86.1	123.6	-85.9	117.9	-82.3	178.6	-89.0	116.3	-110.9	157.4	-100.6	143.4
UMTS	1.4	26.3	-1.0	50.9	-0.8	34.7	2.8	138.5	-3.9	28.9	-25.8	109.9	-15.5	88.7

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	0.8	45.7	-5.2	50.3	26.4	59.8	-16.8	164.1	2.2	59.5	86.1	123.6	1.0	50.9
UME	0.6	26.4	-5.4	33.7	26.2	46.7	-17.0	159.8	2.0	46.4	85.9	117.9	0.8	34.7
GEOSTM	-3.0	136.7	-9.0	138.3	22.6	142.0	-20.6	208.6	-1.6	141.9	82.3	178.6	-2.8	138.5
VNIIM	3.7	18.2	-2.3	27.8	29.3	42.7	-13.9	158.7	5.1	42.3	89.0	116.3	3.9	28.9
MASM	25.6	107.6	19.6	109.6	51.2	114.3	8.0	190.8	27.0	114.1	110.9	157.4	25.8	109.9
SMU	15.3	85.8	9.3	88.3	40.9	94.1	-2.3	179.4	16.7	93.9	100.6	143.4	15.5	88.7
NIM	0.0	0.0	-6.0	28.5	25.6	43.1	-17.6	158.8	1.4	42.7	85.3	116.5	0.2	29.6
QCC EMI	6.0	28.5	0.0	0.0	31.6	47.9	-11.6	160.2	7.4	47.6	91.3	118.4	6.2	36.3
NIS	-25.6	43.1	-31.6	47.9	0.0	0.0	-43.2	163.4	-24.2	57.6	59.7	122.7	-25.4	48.6
CSM	17.6	158.8	11.6	160.2	43.2	163.4	0.0	0.0	19.0	163.3	102.9	196.0	17.8	160.4
SASO-NMCC	-1.4	42.7	-7.4	47.6	24.2	57.6	-19.0	163.3	0.0	0.0	83.9	122.6	-1.2	48.3
LEM-FEIT	-85.3	116.5	-91.3	118.4	-59.7	122.7	-102.9	196.0	-83.9	122.6	0.0	0.0	-85.1	118.7
UMTS	-0.2	29.6	-6.2	36.3	25.4	48.6	-17.8	160.4	1.2	48.3	85.1	118.7	0.0	0.0

Table 14 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 0.0 Lag, 50 Hz, µW/(VA)

NMI			**BelGIM**		**UME**		**GEOSTM**		**VNIIM**		**MASM**		**SMU**	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	0.6	42.2	0.0	0.0	-0.8	47.9	1.0	207.4	2.1	43.6	18.2	94.2	27.0	100.7
UME	-0.2	22.6	0.8	47.9	0.0	0.0	1.8	204.4	2.9	25.0	19.0	87.2	27.8	94.2
GEOSTM	1.6	203.1	-1.0	207.4	-1.8	204.4	0.0	0.0	1.1	203.4	17.2	219.9	26.0	222.7
VNIIM	2.7	10.8	-2.1	43.6	-2.9	25.0	-1.1	203.4	0.0	0.0	16.1	84.9	24.9	92.0
MASM	18.8	84.2	-18.2	94.2	-19.0	87.2	-17.2	219.9	-16.1	84.9	0.0	0.0	8.8	124.3
SMU	27.6	91.4	-27.0	100.7	-27.8	94.2	-26.0	222.7	-24.9	92.0	-8.8	124.3	0.0	0.0
NIM	-2.1	11.5	2.7	43.7	1.9	25.4	3.7	203.4	4.8	15.8	20.9	85.0	29.7	92.1
QCC EMI	2.5	20.8	-1.9	47.0	-2.7	30.7	-0.9	204.2	0.2	23.4	16.3	86.7	25.1	93.7
NIS	-30.0	39.6	30.6	57.9	29.8	45.6	31.6	206.9	32.7	41.0	48.8	93.0	57.6	99.6
CSM	-68.2	160.3	68.8	165.8	68.0	161.9	69.8	258.7	70.9	160.7	87.0	181.1	95.8	184.5
SASO-NMCC	-6.2	41.4	6.8	59.1	6.0	47.2	7.8	207.3	8.9	42.8	25.0	93.8	33.8	100.3
LEM-FEIT	38.4	115.6	-37.8	123.1	-38.6	117.8	-36.8	233.7	-35.7	116.1	-19.6	143.0	-10.8	147.4
UMTS	-0.5	24.6	1.1	48.8	0.3	33.4	2.1	204.6	3.2	26.9	19.3	87.7	28.1	94.7

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	-2.7	43.7	1.9	47.0	-30.6	57.9	-68.8	165.8	-6.8	59.1	37.8	123.1	-1.1	48.8
UME	-1.9	25.4	2.7	30.7	-29.8	45.6	-68.0	161.9	-6.0	47.2	38.6	117.8	-0.3	33.4
GEOSTM	-3.7	203.4	0.9	204.2	-31.6	206.9	-69.8	258.7	-7.8	207.3	36.8	233.7	-2.1	204.6
VNIIM	-4.8	15.8	-0.2	23.4	-32.7	41.0	-70.9	160.7	-8.9	42.8	35.7	116.1	-3.2	26.9
MASM	-20.9	85.0	-16.3	86.7	-48.8	93.0	-87.0	181.1	-25.0	93.8	19.6	143.0	-19.3	87.7
SMU	-29.7	92.1	-25.1	93.7	-57.6	99.6	-95.8	184.5	-33.8	100.3	10.8	147.4	-28.1	94.7
NIM	0.0	0.0	4.6	23.8	-27.9	41.2	-66.1	160.7	-4.1	43.0	40.5	116.2	1.6	27.2
QCC EMI	-4.6	23.8	0.0	0.0	-32.5	44.7	-70.7	161.6	-8.7	46.3	35.9	117.5	-3.0	32.2
NIS	27.9	41.2	32.5	44.7	0.0	0.0	-38.2	165.1	23.8	57.3	68.4	122.2	29.5	46.6
CSM	66.1	160.7	70.7	161.6	38.2	165.1	0.0	0.0	62.0	165.6	106.6	197.6	67.7	162.2
SASO-NMCC	4.1	43.0	8.7	46.3	-23.8	57.3	-62.0	165.6	0.0	0.0	44.6	122.8	5.7	48.2
LEM-FEIT	-40.5	116.2	-35.9	117.5	-68.4	122.2	-106.6	197.6	-44.6	122.8	0.0	0.0	-38.9	118.2
UMTS	-1.6	27.2	3.0	32.2	-29.5	46.6	-67.7	162.2	-5.7	48.2	38.9	118.2	0.0	0.0

Table 15 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 0.0 Lead, 50 Hz, µW/(VA)

NMI			BelGIM		UME		GEOSTM		VNIIM		MASM		SMU	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	11.6	45.2	0.0	0.0	-10.5	50.5	-17.4	208.1	-13.6	46.5	22.5	95.6	40.2	102.0
UME	1.1	22.6	10.5	50.5	0.0	0.0	-6.9	204.4	-3.1	25.0	33.0	87.2	50.7	94.2
GEOSTM	-5.8	203.1	17.4	208.1	6.9	204.4	0.0	0.0	3.8	203.4	39.9	219.9	57.6	222.7
VNIIM	-2.0	10.8	13.6	46.5	3.1	25.0	-3.8	203.4	0.0	0.0	36.1	84.9	53.8	92.0
MASM	34.1	84.2	-22.5	95.6	-33.0	87.2	-39.9	219.9	-36.1	84.9	0.0	0.0	17.7	124.3
SMU	51.8	91.4	-40.2	102.0	-50.7	94.2	-57.6	222.7	-53.8	92.0	-17.7	124.3	0.0	0.0
NIM	0.5	11.5	11.1	46.6	0.6	25.4	-6.3	203.4	-2.5	15.8	33.6	85.0	51.3	92.1
QCC EMI	0.6	20.9	11.0	49.8	0.5	30.8	-6.4	204.2	-2.6	23.5	33.5	86.8	51.2	93.8
NIS	-18.4	37.6	30.0	58.8	19.5	43.9	12.6	206.6	16.4	39.1	52.5	92.2	70.2	98.8
CSM	-43.9	161.7	55.5	167.9	45.0	163.3	38.1	259.6	41.9	162.1	78.0	182.3	95.7	185.7
SASO-NMCC	6.1	41.4	5.5	61.3	-5.0	47.2	-11.9	207.3	-8.1	42.8	28.0	93.8	45.7	100.3
LEM-FEIT	55.0	115.6	-43.4	124.1	-53.9	117.8	-60.8	233.7	-57.0	116.1	-20.9	143.0	-3.2	147.4
UMTS	3.3	25.2	8.3	51.8	-2.2	33.8	-9.1	204.7	-5.3	27.4	30.8	87.9	48.5	94.8

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	-11.1	46.6	-11.0	49.8	-30.0	58.8	-55.5	167.9	-5.5	61.3	43.4	124.1	-8.3	51.8
UME	-0.6	25.4	-0.5	30.8	-19.5	43.9	-45.0	163.3	5.0	47.2	53.9	117.8	2.2	33.8
GEOSTM	6.3	203.4	6.4	204.2	-12.6	206.6	-38.1	259.6	11.9	207.3	60.8	233.7	9.1	204.7
VNIIM	2.5	15.8	2.6	23.5	-16.4	39.1	-41.9	162.1	8.1	42.8	57.0	116.1	5.3	27.4
MASM	-33.6	85.0	-33.5	86.8	-52.5	92.2	-78.0	182.3	-28.0	93.8	20.9	143.0	-30.8	87.9
SMU	-51.3	92.1	-51.2	93.8	-70.2	98.8	-95.7	185.7	-45.7	100.3	3.2	147.4	-48.5	94.8
NIM	0.0	0.0	0.1	23.9	-18.9	39.3	-44.4	162.1	5.6	43.0	54.5	116.2	2.8	27.7
QCC EMI	-0.1	23.9	0.0	0.0	-19.0	43.0	-44.5	163.0	5.5	46.4	54.4	117.5	2.7	32.7
NIS	18.9	39.3	19.0	43.0	0.0	0.0	-25.5	166.0	24.5	55.9	73.4	121.6	21.7	45.3
CSM	44.4	162.1	44.5	163.0	25.5	166.0	0.0	0.0	50.0	166.9	98.9	198.8	47.2	163.7
SASO-NMCC	-5.6	43.0	-5.5	46.4	-24.5	55.9	-50.0	166.9	0.0	0.0	48.9	122.8	-2.8	48.5
LEM-FEIT	-54.5	116.2	-54.4	117.5	-73.4	121.6	-98.9	198.8	-48.9	122.8	0.0	0.0	-51.7	118.3
UMTS	-2.8	27.7	-2.7	32.7	-21.7	45.3	-47.2	163.7	2.8	48.5	51.7	118.3	0.0	0.0

Table 16 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 1.0, 53 Hz, µW/(VA)

NMI			BelGIM		UME		GEOSTM		VNIIM		MASM		SMU	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	1.2	41.5	0.0	0.0	-8.1	46.8	15.5	98.7	0.5	42.8	1.9	85.8	-52.1	70.7
UME	-6.9	21.7	8.1	46.8	0.0	0.0	23.6	92.2	8.6	24.2	10.0	78.2	-44.0	61.2
GEOSTM	16.7	89.6	-15.5	98.7	-23.6	92.2	0.0	0.0	-15.0	90.2	-13.6	116.9	-67.6	106.3
VNIIM	1.7	10.6	-0.5	42.8	-8.6	24.2	15.0	90.2	0.0	0.0	1.4	75.8	-52.6	58.2
MASM	3.1	75.1	-1.9	85.8	-10.0	78.2	13.6	116.9	-1.4	75.8	0.0	0.0	-54.0	94.4
SMU	-50.9	57.2	52.1	70.7	44.0	61.2	67.6	106.3	52.6	58.2	54.0	94.4	0.0	0.0
NIM	4.0	13.3	-2.8	43.6	-10.9	25.5	12.7	90.6	-2.3	17.0	-0.9	76.3	-54.9	58.7
QCC EMI	-8.2	22.2	9.4	47.1	1.3	31.0	24.9	92.3	9.9	24.6	11.3	78.3	-42.7	61.4
NIS	-5.5	36.3	6.7	55.1	-1.4	42.3	22.2	96.7	7.2	37.8	8.6	83.4	-45.4	67.7
CSM	-4.9	158.1	6.1	163.5	-2.0	159.6	21.6	181.7	6.6	158.5	8.0	175.0	-46.0	168.1
SASO-NMCC	-15.9	39.4	17.1	57.2	9.0	45.0	32.6	97.9	17.6	40.8	19.0	84.8	-35.0	69.5
LEM-FEIT	42.0	115.6	-40.8	122.8	-48.9	117.6	-25.3	146.3	-40.3	116.1	-38.9	137.9	-92.9	129.0
UMTS	3.0	19.0	-1.8	45.6	-9.9	28.8	13.7	91.6	-1.3	21.8	0.1	77.5	-53.9	60.3

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	2.8	43.7	-9.4	47.2	-6.7	55.2	-6.1	163.5	-17.1	57.4	40.8	123.0	1.8	45.8
UME	10.9	25.6	-1.3	31.2	1.4	42.3	2.0	159.6	-9.0	45.1	48.9	117.7	9.9	29.0
GEOSTM	-12.7	90.6	-24.9	92.3	-22.2	96.7	-21.6	181.7	-32.6	97.9	25.3	146.3	-13.7	91.6
VNIIM	2.3	17.3	-9.9	24.8	-7.2	37.9	-6.6	158.5	-17.6	40.9	40.3	116.2	1.3	21.9
MASM	0.9	76.4	-11.3	78.4	-8.6	83.5	-8.0	175.1	-19.0	84.9	38.9	138.0	-0.1	77.6
SMU	54.9	58.8	42.7	61.4	45.4	67.7	46.0	168.1	35.0	69.5	92.9	129.1	53.9	60.3
NIM	0.0	0.0	-12.2	26.1	-9.5	38.7	-8.9	158.7	-19.9	41.7	38.0	116.5	-1.0	23.4
QCC EMI	12.2	26.1	0.0	0.0	2.7	42.6	3.3	159.7	-7.7	45.4	50.2	117.8	11.2	29.4
NIS	9.5	38.7	-2.7	42.6	0.0	0.0	0.6	162.2	-10.4	53.6	47.5	121.3	8.5	41.0
CSM	8.9	158.7	-3.3	159.7	-0.6	162.2	0.0	0.0	-11.0	163.0	46.9	195.9	7.9	159.2
SASO-NMCC	19.9	41.7	7.7	45.4	10.4	53.6	11.0	163.0	0.0	0.0	57.9	122.3	18.9	43.9
LEM-FEIT	-38.0	116.5	-50.2	117.8	-47.5	121.3	-46.9	195.9	-57.9	122.3	0.0	0.0	-39.0	117.3
UMTS	1.0	23.4	-11.2	29.4	-8.5	41.0	-7.9	159.2	-18.9	43.9	39.0	117.3	0.0	0.0

Table 17 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 0.5 Lag, 53 Hz, µW/(VA)

NMI			BelGIM		UME		GEOSTM		VNIIM		MASM		SMU	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	-9.8	41.6	0.0	0.0	-2.2	47.2	18.6	142.1	13.1	42.6	33.8	121.9	8.4	81.0
UME	-12.0	22.4	2.2	47.2	0.0	0.0	20.8	137.7	15.3	24.2	36.0	116.8	10.6	73.0
GEOSTM	8.8	135.9	-18.6	142.1	-20.8	137.7	0.0	0.0	-5.5	136.2	15.2	177.8	-10.2	152.6
VNIIM	3.3	9.1	-13.1	42.6	-15.3	24.2	5.5	136.2	0.0	0.0	20.7	115.0	-4.7	70.1
MASM	24.0	114.6	-33.8	121.9	-36.0	116.8	-15.2	177.8	-20.7	115.0	0.0	0.0	-25.4	134.0
SMU	-1.4	69.5	-8.4	81.0	-10.6	73.0	10.2	152.6	4.7	70.1	25.4	134.0	0.0	0.0
NIM	-3.0	13.2	-6.8	43.6	-9.0	26.0	11.8	136.5	6.3	16.0	27.0	115.4	1.6	70.7
QCC EMI	-5.7	25.4	-4.1	48.7	-6.3	33.9	14.5	138.3	9.0	27.0	29.7	117.4	4.3	74.0
NIS	22.1	36.5	-31.9	55.3	-34.1	42.8	-13.3	140.7	-18.8	37.6	1.9	120.3	-23.5	78.5
CSM	-21.0	158.1	11.2	163.5	9.0	159.7	29.8	208.5	24.3	158.4	45.0	195.3	19.6	172.7
SASO-NMCC	-21.0	40.4	11.2	58.0	9.0	46.2	29.8	141.8	24.3	41.4	45.0	121.5	19.6	80.4
LEM-FEIT	3.2	115.6	-13.0	122.9	-15.2	117.8	5.6	178.4	0.1	116.0	20.8	162.8	-4.6	134.9
UMTS	-3.8	26.9	-6.0	49.5	-8.2	35.0	12.6	138.5	7.1	28.4	27.8	117.7	2.4	74.5

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	6.8	43.6	4.1	48.7	31.9	55.3	-11.2	163.5	-11.2	58.0	13.0	122.9	6.0	49.5
UME	9.0	26.0	6.3	33.9	34.1	42.8	-9.0	159.7	-9.0	46.2	15.2	117.8	8.2	35.0
GEOSTM	-11.8	136.5	-14.5	138.3	13.3	140.7	-29.8	208.5	-29.8	141.8	-5.6	178.4	-12.6	138.5
VNIIM	-6.3	16.0	-9.0	27.0	18.8	37.6	-24.3	158.4	-24.3	41.4	-0.1	116.0	-7.1	28.4
MASM	-27.0	115.4	-29.7	117.4	-1.9	120.3	-45.0	195.3	-45.0	121.5	-20.8	162.8	-27.8	117.7
SMU	-1.6	70.7	-4.3	74.0	23.5	78.5	-19.6	172.7	-19.6	80.4	4.6	134.9	-2.4	74.5
NIM	0.0	0.0	-2.7	28.6	25.1	38.8	-18.0	158.7	-18.0	42.5	6.2	116.4	-0.8	30.0
QCC EMI	2.7	28.6	0.0	0.0	27.8	44.5	-15.3	160.1	-15.3	47.7	8.9	118.4	1.9	37.0
NIS	-25.1	38.8	-27.8	44.5	0.0	0.0	-43.1	162.3	-43.1	54.4	-18.9	121.2	-25.9	45.3
CSM	18.0	158.7	15.3	160.1	43.1	162.3	0.0	0.0	0.0	163.2	24.2	195.9	17.2	160.4
SASO-NMCC	18.0	42.5	15.3	47.7	43.1	54.4	0.0	163.2	0.0	0.0	24.2	122.5	17.2	48.5
LEM-FEIT	-6.2	116.4	-8.9	118.4	18.9	121.2	-24.2	195.9	-24.2	122.5	0.0	0.0	-7.0	118.7
UMTS	0.8	30.0	-1.9	37.0	25.9	45.3	-17.2	160.4	-17.2	48.5	7.0	118.7	0.0	0.0

Table 18 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 0.5 Lead, 53 Hz, µW/(VA)

NMI			BelGIM		UME		GEOSTM		VNIIM		MASM		SMU	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	3.9	41.7	0.0	0.0	-0.2	47.3	-1.7	142.2	-7.5	42.7	-30.2	87.5	-15.7	81.1
UME	3.7	22.4	0.2	47.3	0.0	0.0	-1.5	137.7	-7.3	24.2	-30.0	80.1	-15.5	73.0
GEOSTM	2.2	135.9	1.7	142.2	1.5	137.7	0.0	0.0	-5.8	136.2	-28.5	156.1	-14.0	152.6
VNIIM	-3.6	9.1	7.5	42.7	7.3	24.2	5.8	136.2	0.0	0.0	-22.7	77.4	-8.2	70.1
MASM	-26.3	76.9	30.2	87.5	30.0	80.1	28.5	156.1	22.7	77.4	0.0	0.0	14.5	103.7
SMU	-11.8	69.5	15.7	81.1	15.5	73.0	14.0	152.6	8.2	70.1	-14.5	103.7	0.0	0.0
NIM	5.4	13.2	-1.5	43.7	-1.7	26.0	-3.2	136.5	-9.0	16.0	-31.7	78.0	-17.2	70.7
QCC EMI	-2.8	24.8	6.7	48.5	6.5	33.4	5.0	138.1	-0.8	26.4	-23.5	80.8	-9.0	73.8
NIS	22.1	37.5	-18.2	56.1	-18.4	43.7	-19.9	141.0	-25.7	38.6	-48.4	85.6	-33.9	79.0
CSM	-1.3	158.1	5.2	163.5	5.0	159.7	3.5	208.5	-2.3	158.4	-25.0	175.8	-10.5	172.7
SASO-NMCC	5.7	40.4	-1.8	58.1	-2.0	46.2	-3.5	141.8	-9.3	41.4	-32.0	86.9	-17.5	80.4
LEM-FEIT	76.4	115.6	-72.5	122.9	-72.7	117.8	-74.2	178.4	-80.0	116.0	-102.7	138.8	-88.2	134.9
UMTS	5.4	27.0	-1.5	49.7	-1.7	35.1	-3.2	138.6	-9.0	28.5	-31.7	81.5	-17.2	74.6

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	1.5	43.7	-6.7	48.5	18.2	56.1	-5.2	163.5	1.8	58.1	72.5	122.9	1.5	49.7
UME	1.7	26.0	-6.5	33.4	18.4	43.7	-5.0	159.7	2.0	46.2	72.7	117.8	1.7	35.1
GEOSTM	3.2	136.5	-5.0	138.1	19.9	141.0	-3.5	208.5	3.5	141.8	74.2	178.4	3.2	138.6
VNIIM	9.0	16.0	0.8	26.4	25.7	38.6	2.3	158.4	9.3	41.4	80.0	116.0	9.0	28.5
MASM	31.7	78.0	23.5	80.8	48.4	85.6	25.0	175.8	32.0	86.9	102.7	138.8	31.7	81.5
SMU	17.2	70.7	9.0	73.8	33.9	79.0	10.5	172.7	17.5	80.4	88.2	134.9	17.2	74.6
NIM	0.0	0.0	-8.2	28.1	16.7	39.8	-6.7	158.7	0.3	42.5	71.0	116.4	0.0	30.1
QCC EMI	8.2	28.1	0.0	0.0	24.9	45.0	1.5	160.0	8.5	47.4	79.2	118.2	8.2	36.7
NIS	-16.7	39.8	-24.9	45.0	0.0	0.0	-23.4	162.5	-16.4	55.1	54.3	121.5	-16.7	46.2
CSM	6.7	158.7	-1.5	160.0	23.4	162.5	0.0	0.0	7.0	163.2	77.7	195.9	6.7	160.4
SASO-NMCC	-0.3	42.5	-8.5	47.4	16.4	55.1	-7.0	163.2	0.0	0.0	70.7	122.5	-0.3	48.6
LEM-FEIT	-71.0	116.4	-79.2	118.2	-54.3	121.5	-77.7	195.9	-70.7	122.5	0.0	0.0	-71.0	118.7
UMTS	0.0	30.1	-8.2	36.7	16.7	46.2	-6.7	160.4	0.3	48.6	71.0	118.7	0.0	0.0

Table 19 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 0.0 Lag, 53 Hz, µW/(VA)

NMI			BelGIM		UME		GEOSTM		VNIIM		MASM		SMU	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	-10.2	41.4	0.0	0.0	-5.2	47.1	14.8	207.3	16.0	42.4	30.8	93.9	30.8	87.9
UME	-15.4	22.5	5.2	47.1	0.0	0.0	20.0	204.3	21.2	24.2	36.0	87.3	36.0	80.7
GEOSTM	4.6	203.1	-14.8	207.3	-20.0	204.3	0.0	0.0	1.2	203.3	16.0	219.9	16.0	217.4
VNIIM	5.8	9.0	-16.0	42.4	-21.2	24.2	-1.2	203.3	0.0	0.0	14.8	84.8	14.8	78.0
MASM	20.6	84.3	-30.8	93.9	-36.0	87.3	-16.0	219.9	-14.8	84.8	0.0	0.0	0.0	114.5
SMU	20.6	77.5	-30.8	87.9	-36.0	80.7	-16.0	217.4	-14.8	78.0	0.0	114.5	0.0	0.0
NIM	-4.4	11.3	-5.8	42.9	-11.0	25.2	9.0	203.4	10.2	14.4	25.0	85.1	25.0	78.3
QCC EMI	0.9	20.7	-11.1	46.3	-16.3	30.6	3.7	204.2	4.9	22.6	19.7	86.8	19.7	80.2
NIS	-31.1	40.7	20.9	58.1	15.7	46.5	35.7	207.1	36.9	41.7	51.7	93.6	51.7	87.5
CSM	-93.4	163.1	83.2	168.3	78.0	164.6	98.0	260.5	99.2	163.3	114.0	183.6	114.0	180.6
SASO-NMCC	-12.4	41.3	2.2	58.5	-3.0	47.0	17.0	207.3	18.2	42.3	33.0	93.9	33.0	87.8
LEM-FEIT	32.0	115.6	-42.2	122.8	-47.4	117.8	-27.4	233.7	-26.2	115.9	-11.4	143.1	-11.4	139.2
UMTS	-3.2	24.4	-7.0	48.1	-12.2	33.2	7.8	204.6	9.0	26.0	23.8	87.8	23.8	81.3

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	5.8	42.9	11.1	46.3	-20.9	58.1	-83.2	168.3	-2.2	58.5	42.2	122.8	7.0	48.1
UME	11.0	25.2	16.3	30.6	-15.7	46.5	-78.0	164.6	3.0	47.0	47.4	117.8	12.2	33.2
GEOSTM	-9.0	203.4	-3.7	204.2	-35.7	207.1	-98.0	260.5	-17.0	207.3	27.4	233.7	-7.8	204.6
VNIIM	-10.2	14.4	-4.9	22.6	-36.9	41.7	-99.2	163.3	-18.2	42.3	26.2	115.9	-9.0	26.0
MASM	-25.0	85.1	-19.7	86.8	-51.7	93.6	-114.0	183.6	-33.0	93.9	11.4	143.1	-23.8	87.8
SMU	-25.0	78.3	-19.7	80.2	-51.7	87.5	-114.0	180.6	-33.0	87.8	11.4	139.2	-23.8	81.3
NIM	0.0	0.0	5.3	23.6	-26.7	42.2	-89.0	163.5	-8.0	42.8	36.4	116.2	1.2	26.9
QCC EMI	-5.3	23.6	0.0	0.0	-32.0	45.7	-94.3	164.4	-13.3	46.2	31.1	117.4	-4.1	32.0
NIS	26.7	42.2	32.0	45.7	0.0	0.0	-62.3	168.1	18.7	58.0	63.1	122.6	27.9	47.5
CSM	89.0	163.5	94.3	164.4	62.3	168.1	0.0	0.0	81.0	168.2	125.4	199.9	90.2	164.9
SASO-NMCC	8.0	42.8	13.3	46.2	-18.7	58.0	-81.0	168.2	0.0	0.0	44.4	122.8	9.2	48.0
LEM-FEIT	-36.4	116.2	-31.1	117.4	-63.1	122.6	-125.4	199.9	-44.4	122.8	0.0	0.0	-35.2	118.1
UMTS	-1.2	26.9	4.1	32.0	-27.9	47.5	-90.2	164.9	-9.2	48.0	35.2	118.1	0.0	0.0

Table 20 Pair degrees of equivalence of NMI participants and expanded uncertainties with respect to the KCRV for PF = 0.0 Lead, 53 Hz, µW/(VA)

NMI			BelGIM		UME		GEOSTM		VNIIM		MASM		SMU	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	8.4	41.4	0.0	0.0	-3.2	47.1	-16.0	207.3	-12.3	42.4	-31.2	94.0	47.4	87.9
UME	5.2	22.5	3.2	47.1	0.0	0.0	-12.8	204.3	-9.1	24.2	-28.0	87.3	50.6	80.7
GEOSTM	-7.6	203.1	16.0	207.3	12.8	204.3	0.0	0.0	3.7	203.3	-15.2	219.9	63.4	217.4
VNIIM	-3.9	9.0	12.3	42.4	9.1	24.2	-3.7	203.3	0.0	0.0	-18.9	84.9	59.7	78.0
MASM	-22.8	84.4	31.2	94.0	28.0	87.3	15.2	219.9	18.9	84.9	0.0	0.0	78.6	114.6
SMU	55.8	77.5	-47.4	87.9	-50.6	80.7	-63.4	217.4	-59.7	78.0	-78.6	114.6	0.0	0.0
NIM	3.4	11.3	5.0	42.9	1.8	25.2	-11.0	203.4	-7.3	14.4	-26.2	85.2	52.4	78.3
QCC EMI	1.9	20.8	6.5	46.3	3.3	30.6	-9.5	204.2	-5.8	22.7	-24.7	86.9	53.9	80.2
NIS	-20.5	38.6	28.9	56.6	25.7	44.7	12.9	206.7	16.6	39.6	-2.3	92.8	76.3	86.6
CSM	3.2	158.3	5.2	163.6	2.0	159.9	-10.8	257.5	-7.1	158.6	-26.0	179.4	52.6	176.3
SASO-NMCC	14.2	41.3	-5.8	58.5	-9.0	47.0	-21.8	207.3	-18.1	42.3	-37.0	94.0	41.6	87.8
LEM-FEIT	47.9	115.6	-39.5	122.8	-42.7	117.8	-55.5	233.7	-51.8	115.9	-70.7	143.1	7.9	139.2
UMTS	6.4	24.8	2.0	48.3	-1.2	33.5	-14.0	204.6	-10.3	26.4	-29.2	88.0	49.4	81.4

NMI	NIM		QCC EMI		NIS		CSM		SASO-NMCC		LEM-FEIT		UMTS	
	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
BelGIM	-5.0	42.9	-6.5	46.3	-28.9	56.6	-5.2	163.6	5.8	58.5	39.5	122.8	-2.0	48.3
UME	-1.8	25.2	-3.3	30.6	-25.7	44.7	-2.0	159.9	9.0	47.0	42.7	117.8	1.2	33.5
GEOSTM	11.0	203.4	9.5	204.2	-12.9	206.7	10.8	257.5	21.8	207.3	55.5	233.7	14.0	204.6
VNIIM	7.3	14.4	5.8	22.7	-16.6	39.6	7.1	158.6	18.1	42.3	51.8	115.9	10.3	26.4
MASM	26.2	85.2	24.7	86.9	2.3	92.8	26.0	179.4	37.0	94.0	70.7	143.1	29.2	88.0
SMU	-52.4	78.3	-53.9	80.2	-76.3	86.6	-52.6	176.3	-41.6	87.8	-7.9	139.2	-49.4	81.4
NIM	0.0	0.0	-1.5	23.7	-23.9	40.2	-0.2	158.7	10.8	42.8	44.5	116.2	3.0	27.3
QCC EMI	1.5	23.7	0.0	0.0	-22.4	43.8	1.3	159.7	12.3	46.2	46.0	117.5	4.5	32.4
NIS	23.9	40.2	22.4	43.8	0.0	0.0	23.7	162.9	34.7	56.5	68.4	121.9	26.9	45.9
CSM	0.2	158.7	-1.3	159.7	-23.7	162.9	0.0	0.0	11.0	163.6	44.7	196.0	3.2	160.2
SASO-NMCC	-10.8	42.8	-12.3	46.2	-34.7	56.5	-11.0	163.6	0.0	0.0	33.7	122.8	-7.8	48.2
LEM-FEIT	-44.5	116.2	-46.0	117.5	-68.4	121.9	-44.7	196.0	-33.7	122.8	0.0	0.0	-41.5	118.2
UMTS	-3.0	27.3	-4.5	32.4	-26.9	45.9	-3.2	160.2	7.8	48.2	41.5	118.2	0.0	0.0

Appendix 1

Reported measurement results for NMI participants

BelGIM (Belarus)

Frequency	Power factor	Relative error of active power measurement, μW/VA	Expanded uncertainty, μW/VA
50 Hz	1.0	-1.9	42.0
	0.5 Lag	2.9	42.4
	0.5 Lead	-5.2	43.1
	0.0 Lag	4.8	41.8
	0.0 Lead	4.5	44.8
53 Hz	1.0	-0.9	41.1
	0.5 Lag	-1.8	41.2
	0.5 Lead	-5.8	41.3
	0.0 Lag	-3.8	41.1
	0.0 Lead	-1.8	41.1

Standard used: power standard Fluke 6100A serial number 995658654 (further – Fluke 6100A); portable current and voltage source Calsourse 200 serial number 30079 (further – Calsourse 200); Radian Research three-phase electricity standard RD-33-211.

Fluke 6100A was used as a power source at the power factor equals 1 or 0.5, Calsourse 200 was used as a power source at the power factor equals 0 (but usually BelGIM does not calibrate at this power factor). Measurements were taken according to the scheme on Figure A1.1.

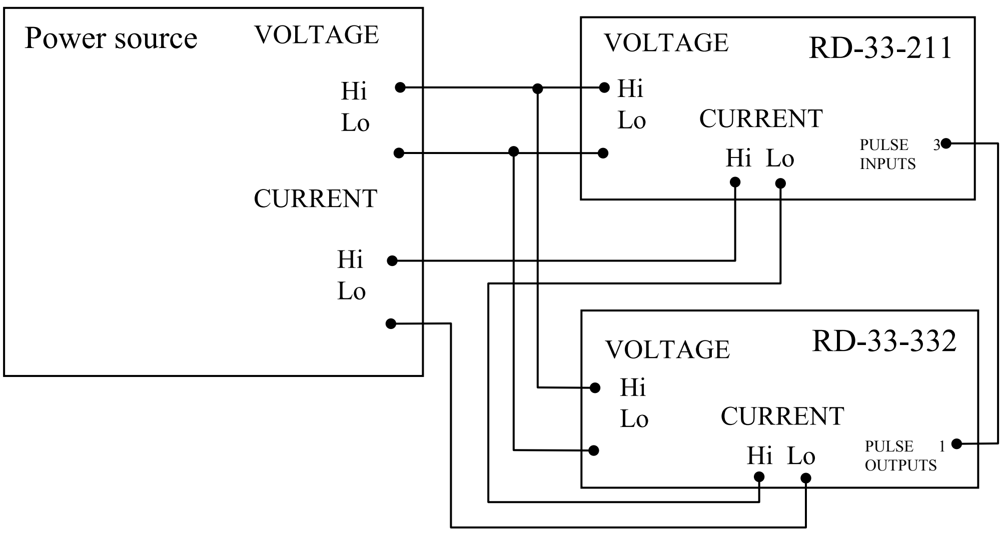

Figure A1.1 Block diagram of measurement setup

VNIIM (Russia)

Frequency	Power factor	Relative error of active power measurement, µW/VA	Expanded uncertainty, µW/VA
50 Hz	1.0	1.4	11.5
	0.5 Lag	9.4	10.2
	0.5 Lead	-8.1	10.2
	0.0 Lag	6.9	9.2
	0.0 Lead	-9.1	9.2
53 Hz	1.0	-0,4	8.9
	0.5 Lag	11,3	7.3
	0.5 Lead	-13,3	7.3
	0.0 Lag	12,2	7.4
	0.0 Lead	-14,1	7.4

National AC power standard includes: phantom power source with isolated voltage and current output circuits; inductive voltage divider; low-reactive “squirrel cage” type current shunt; two DVM Agilent 3458 A; DC voltage standard Fluke 732 B. The simplified diagram of AC Power Standard is pictured on the Figure A1.2.

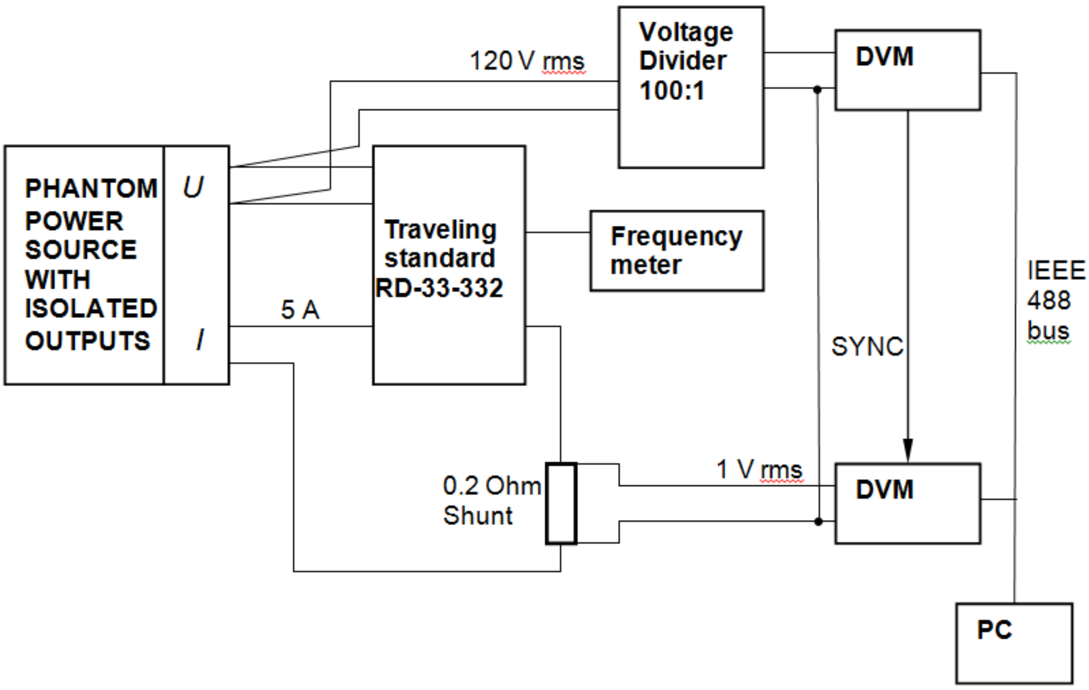

Figure A1.2 Simplified diagram of AC power standard

High-resolution phantom power source forms AC voltage and AC current signal of necessary level. Voltage signal is scaled by voltage divider to the level of 1 V or slightly more. Current signal is transformed by current shunt to voltage signal of the level near 1 V. These signals are sampled by two synchronized DVM. Thus active power value is obtained as a scalar product of sampled current and voltage curves.

GEOSTM (Georgia)

Frequency	Power factor	Relative error of active power measurement, µW/VA	Expanded uncertainty, µW/VA
50 Hz	1.0	17.3	89.4
	0.5 Lag	14.9	135.8
	0.5 Lead	-1.4	135.8
	0.0 Lag	5.8	203.0
	0.0 Lead	-12.9	203.0
53 Hz	1.0	14.6	89.4
	0.5 Lag	16.8	135.8
	0.5 Lead	-7.5	135.8
	0.0 Lag	11.0	203.0
	0.0 Lead	-17.8	203.0

The method used in comparison was the direct comparison of the travelling standard under the test with the reference standard of GEOSTM. The travelling standard under the test RD-33-332 and the reference standard COM3003 were supplied simultaneously with the same voltage and current by the three phases current and voltage source MT551 in single-phase mode. The output pulses of the travelling standard under the test were compared with the output pulses of the reference standard (Figure A1.3).

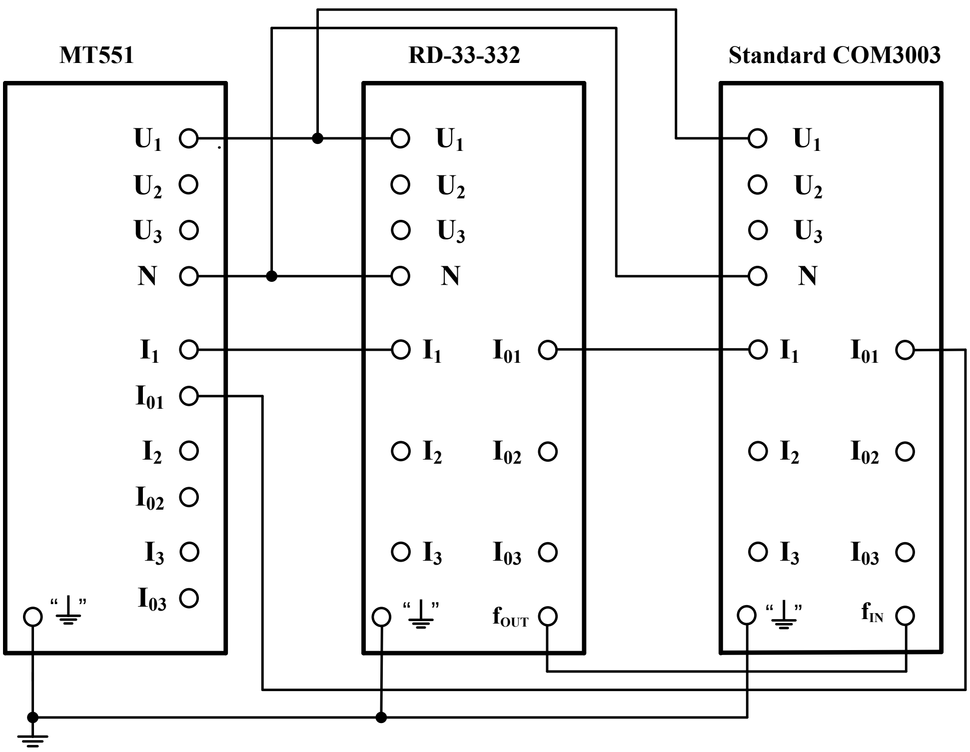

Figure A1.3 Block diagram of the measurement setup

CSM (Kyrgyzstan)

Frequency	Power factor	Relative error of active power measurement, μW/VA	Expanded uncertainty, μW/VA
50 Hz	1.0	-18.0	158.1
	0.5 Lag	-10.0	158.0
	0.5 Lead	-22.0	158.1
	0.0 Lag	-64.0	160.2
	0.0 Lead	-51.0	161.6
53 Hz	1.0	-7.0	158.0
	0.5 Lag	-13.0	158.0
	0.5 Lead	-11.0	158.0
	0.0 Lag	-87.0	163.0
	0.0 Lead	-7.0	158.2

During measurement of AC power was using a direct comparison method. The standard equipment MT3000 ZERA connected in 2 – wire circuit with travelling standard. The standard equipment MT3000 ZERA has own source the current block is MT3603 and the voltage block is MT 3604 (Figure A1.4).

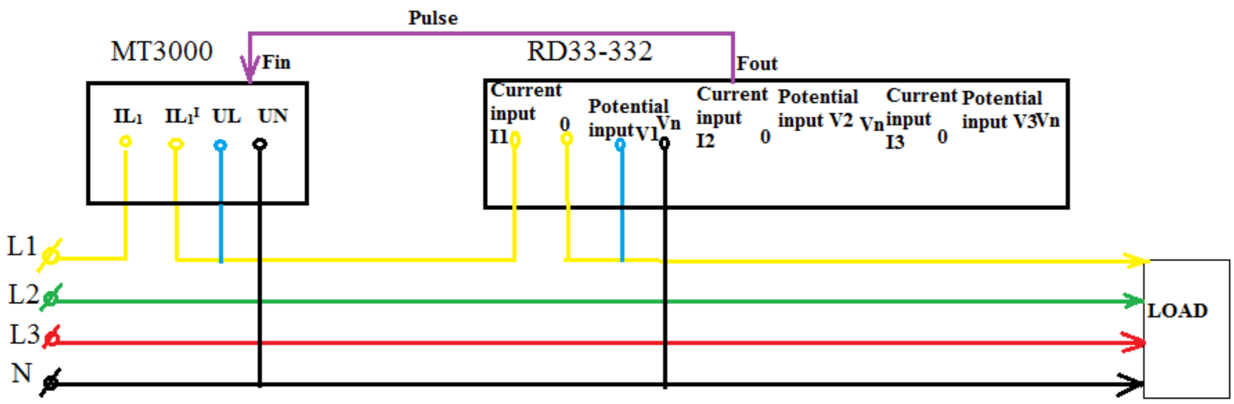

Figure A1.4 Block diagram of the measurement setup

UME (Turkey)

Frequency	Power factor	Relative error of active power measurement, μW/VA	Expanded uncertainty, μW/VA
50 Hz	1.0	-5.0	20.9
	0.5 Lag	-1.0	21.7
	0.5 Lead	-5.0	21.7
	0.0 Lag	4.0	21.9
	0.0 Lead	-6.0	21.9
53 Hz	1.0	-9.0	20.9
	0.5 Lag	-4.0	21.7
	0.5 Lead	-6.0	21.7
	0.0 Lag	-9.0	21.9
	0.0 Lead	-5.0	21.9

The operating principle of primary AC power measurement standard, known as Digital Sampling Wattmeter (DSWM), shown in the figure below, is based on the use of two sampling voltmeters and on computerized evaluation by means of discrete integration (DI) or discrete Fourier transform (DFT). It consists of two digital sampling voltmeters (DVMs), a precision voltage divider, a set of AC current shunts, a power source, a triggering unit and software.

The voltage and current signals from a phantom power source are applied to the relevant input terminals of the voltage divider and of the AC current shunts. A regulated voltage from secondary terminals of the voltage divider and a voltage obtained from the selected AC current shunt are then applied to the DVMs. With the help of software, DVMs are programmed with the calculated appropriate aperture times for the selected samples per period. Each programmed DVM then samples the applied voltage signals with the help of trigger signal which is synchronized to the power source.

The data from both DVMs are then transferred to the computer via IEEE488. The ratio and phase angle errors of the voltage divider and current shunts were corrected by the software. The amplitudes of both signals, the phase angles between them and the calculated results are displayed during the measurements.

Block diagram of DSWM show on Figure A1.5.

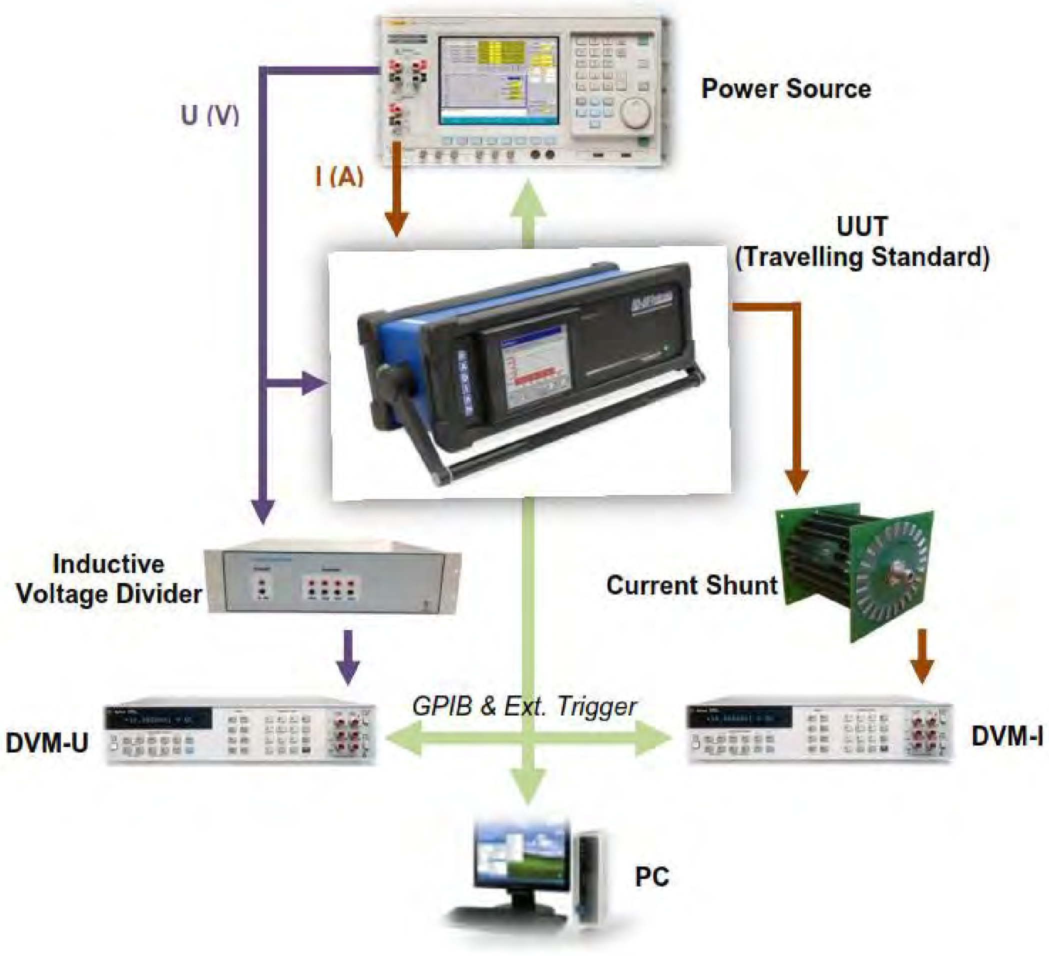

Figure A1.5 Block diagram of DSWM

SMU (Slovakia)

Frequency	Power factor	Relative error of active power measurement, μW/VA	Expanded uncertainty, μW/VA
50 Hz	1.0	-52.6	74.6
	0.5 Lag	8.3	84.5
	0.5 Lead	-19.7	84.5
	0.0 Lag	31.8	91.2
	0.0 Lead	44.7	91.2
53 Hz	1.0	-53.0	56.9
	0.5 Lag	6.6	69.3
	0.5 Lead	-21.5	69.3
	0.0 Lag	27.0	77.3
	0.0 Lead	45.6	77.3

The method used in comparison was the direct comparison of the traveling standard AC power under the test with the reference standard AC power. Reference standard RS2330S was connected throw frequency divider with the travelling standard RD-33 frequency output. Power source was connected with the travelling standard as was described in the setup for the direct connection. The block diagram is shown in Figure A1.6. As a control standard was used Reference standard RS2310S, S/N 1096050236.

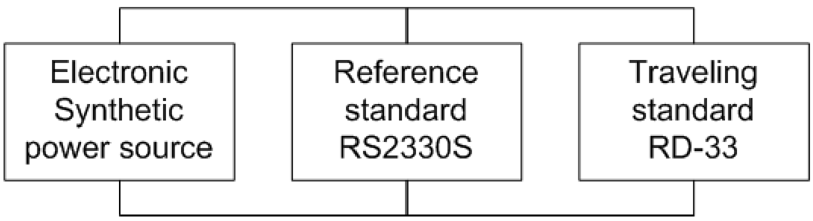

Figure A1.6 Block diagram of the measurement setup

LEM-FEIT (R. Macedonia)

Frequency	Power factor	Relative error of active power measurement, μW/VA	Expanded uncertainty, μW/VA
50 Hz	1.0	45.6	115.5
	0.5 Lag	5.8	115.5
	0.5 Lead	80.9	115.5
	0.0 Lag	42.6	115.5
	0.0 Lead	47.9	115.5
53 Hz	1.0	39.9	115.5
	0.5 Lag	11.2	115.5
	0.5 Lead	66.7	115.5
	0.0 Lag	38.4	115.5
	0.0 Lead	37.7	115.5

A three phase generator Calmet C300 is used as a source of voltage and current signals. The circuit for realization of the measurement procedure is illustrated in Figure A1.7. The generator is controlled via PC. The current circuit consists of the current source, and the first phase current inputs, of the two standards, connected in series. The voltage circuit consists of parallel connection of the voltage source and both ZERA COM 3003 and RD-33 voltage inputs. The frequency output of the UUT is connected with the frequency input of the reference standard via BNC connector. Error measurement is realized via the reference standard's RS 232 output connected with PC unit via RS 232/USB connector.

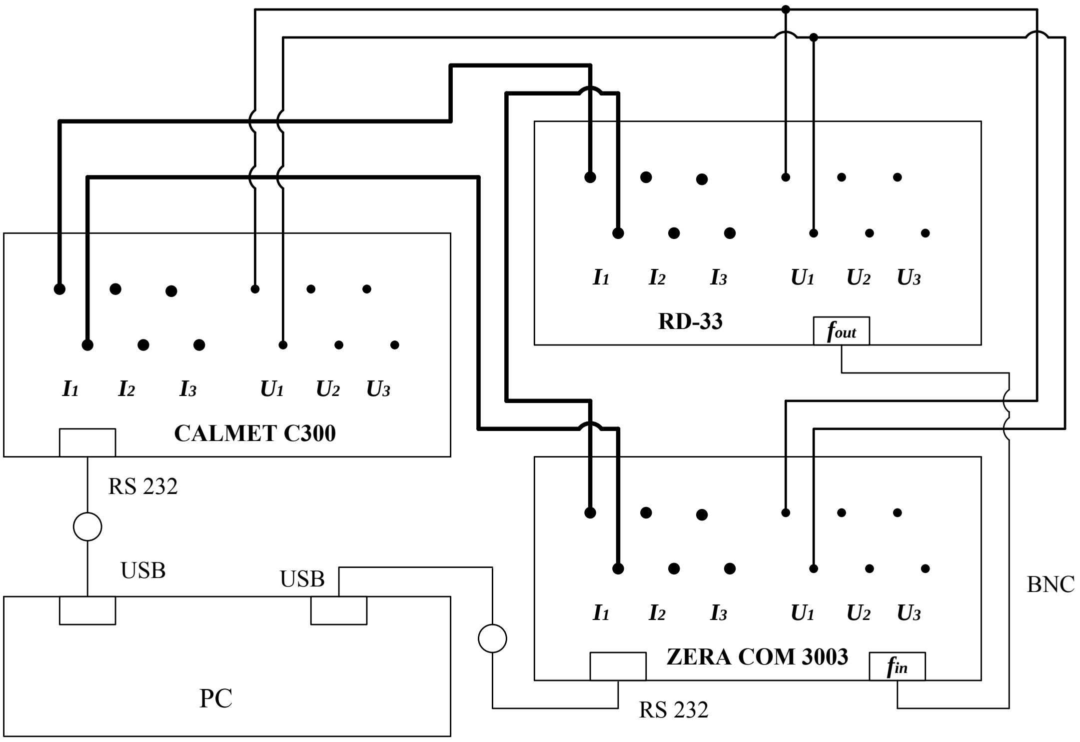

Figure A1.7 Block diagram of the measurement setup

NIM (China)

Frequency	Power factor	Relative error of active power measurement, µW/VA	Expanded uncertainty, µW/VA
50 Hz	1.0	1.9	12.0
	0.5 Lag	5.0	12.0
	0.5 Lead	-4.3	12.0
	0.0 Lag	2.0	10.0
	0.0 Lead	-6.8	10.0
53 Hz	1.0	1.0	12.0
	0.5 Lag	4.7	12.0
	0.5 Lead	-4.4	12.0
	0.0 Lag	2.1	10.0
	0.0 Lead	-6.6	10.0

The block diagram of the measurement setup is shown in Figure A1.8. The “double bridge power comparator” (DBPC) is adopted in the principle of the single phase energy primary standard. It compares the AC power to DC power directly by using two multijuction thermal converters.

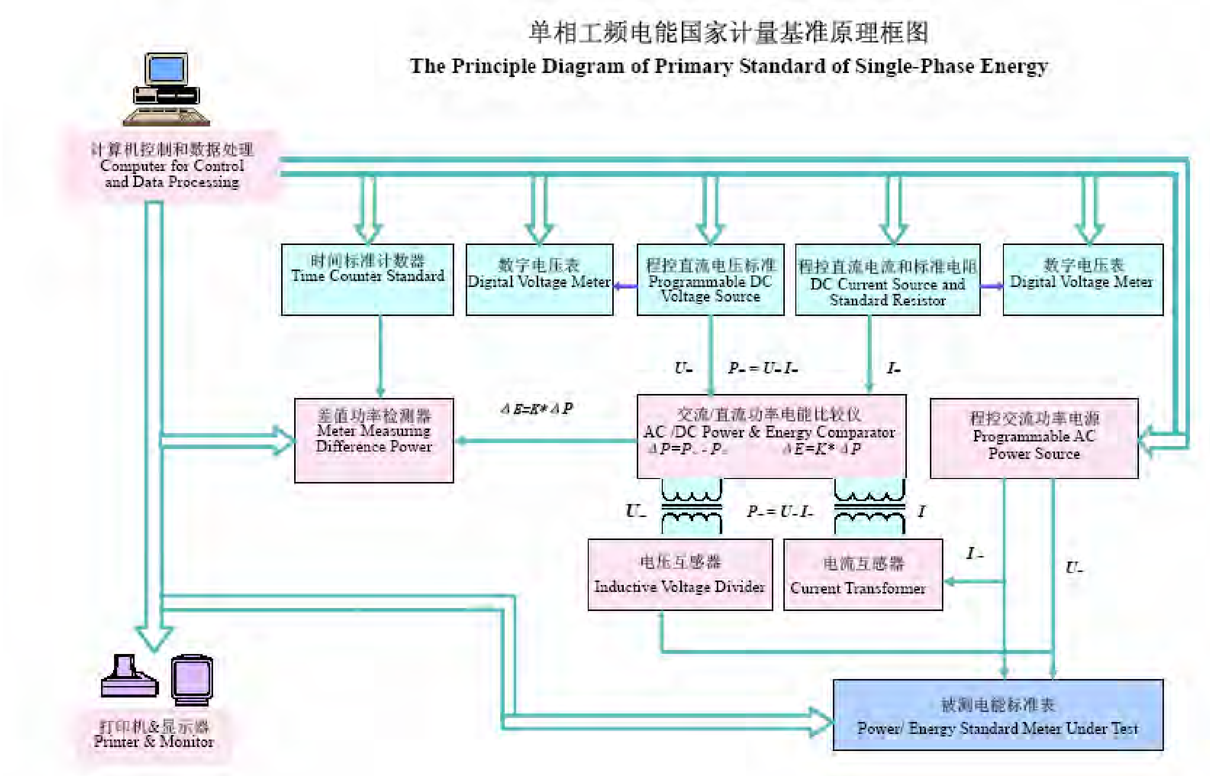

Figure A1.8 Block diagram of measurement setup

The ac current and voltage signals are generated using a power source. The ac signals are applied to the UUT and the DBPC, the DC signal is only applied to the DBPC. When the double bridge power comparator is balanced, the AC power is equal to the DC power and the DC power is calculated by the DC voltage and DC resistor. In the measurement the remainder unbalanced value is get from the Nano voltage meter and compensated by the computer.

MASM (Mongolia)

Frequency	Power factor	Relative error of active power measurement, µW/VA	Expanded uncertainty, µW/VA
50 Hz	1.0	3.0	87.1
	0.5 Lag	34.0	61.0
	0.5 Lead	-30.0	53.3
	0.0 Lag	23.0	42.0
	0.0 Lead	-27.0	42.0
53 Hz	1.0	1.0	37.4
	0.5 Lag	32.0	57.2
	0.5 Lead	-36.0	38.4
	0.0 Lag	27.0	42.1
	0.0 Lead	-33.0	42.1

The measurements were made using MASM's power and energy comparator COM3003 s/n 050023143 and source PTS3.3C s/n 53115. Testing signals from the PTS 3.3C standard were applied at the same time to COM3003 standard and the travelling standards for each set of measurements. The measured values of active power error percentage and standard deviation were recorded in a PC using the RS232 port. Block diagram of the measurement circuit shown on Figure A1.9.

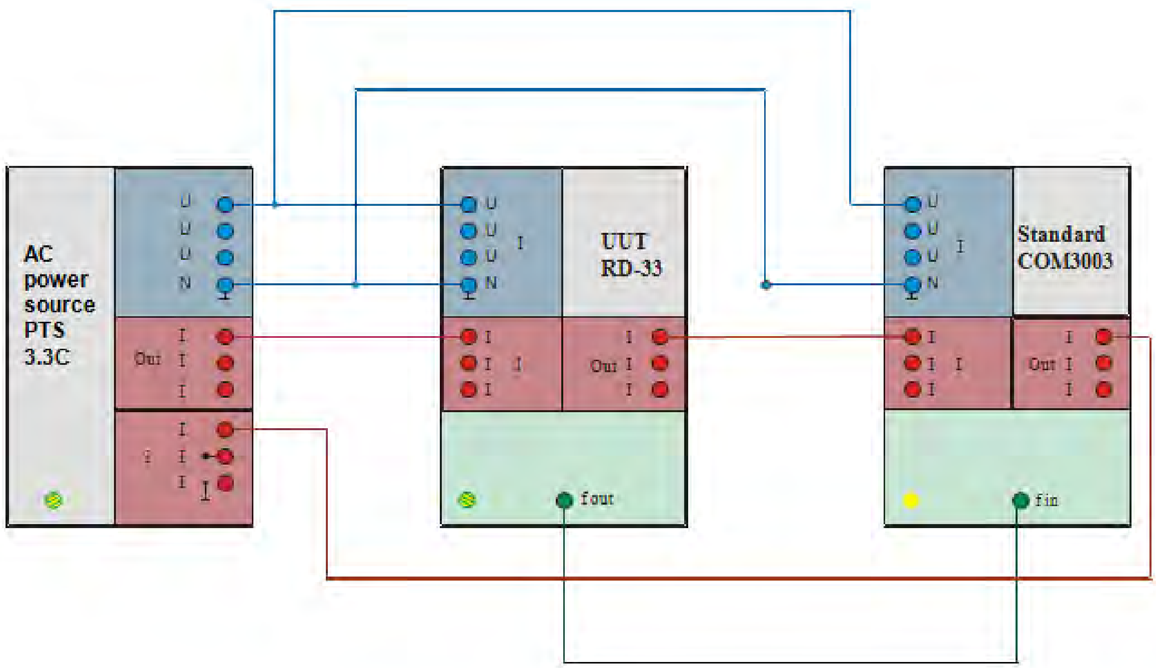

Figure A1.9 Block diagram of the measurement setup

QCC EMI (UAE)

Frequency	Power factor	Relative error of active power measurement, µW/VA	Expanded uncertainty, µW/VA
50 Hz	1.0	-6.4	21.4
	0.5 Lag	2.2	24.8
	0.5 Lead	-10.4	24.2
	0.0 Lag	6.7	20.0
	0.0 Lead	-6.5	20.1
53 Hz	1.0	-10.3	21.4
	0.5 Lag	2.3	24.8
	0.5 Lead	-12.5	24.2
	0.0 Lag	7.3	20.0
	0.0 Lead	-8.3	20.1

The measurement setup is shown schematically in Figure A1.10.

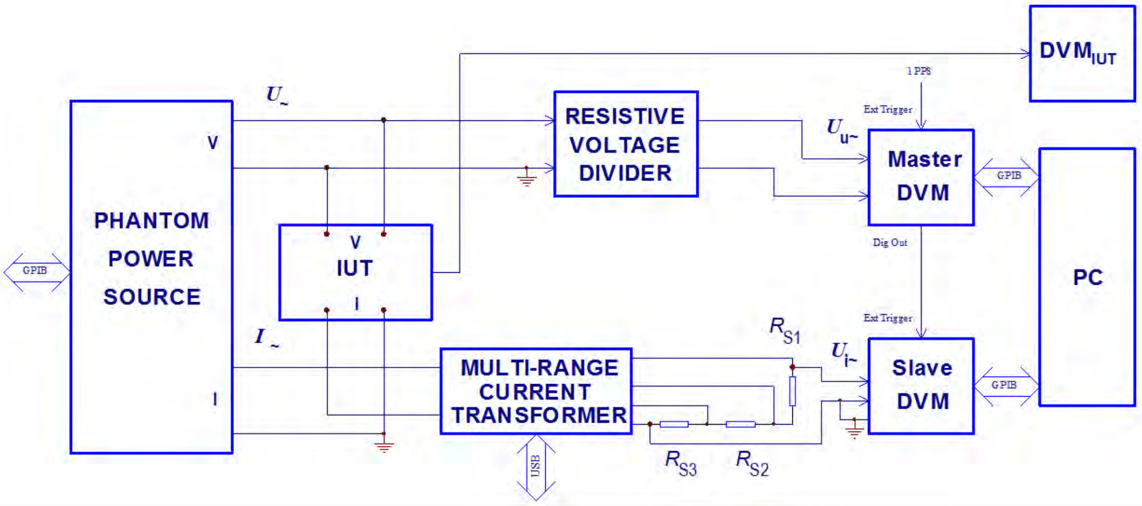

Figure A1.10 Simplified schematic diagram of the measurement setup

Alternating voltage and current from the phantom power source are applied to the Instrument Under Test (IUT) and the inputs of the Resistive Voltage Divider (RVD) and the Multi-range Current Transformer (MCT). The output voltages of the RVD and MCT measured by two digital voltmeters (DVMs), Master DVM and Slave DVM, that are controlled through the PC by “EnergoEtalon” sampling software. The output of the IUT is measured either using a counter, as in this ILC, or by a DVM. To enable the operation of the Master and Slave DVMs on dc, for calibration purposes, a 1 pulse per second TTL signal is applied to the trigger input of the Master DVM. The LO voltage and the current inputs of the IUT are earthed and so is the output of the MCT. To enable the series connection of the IUT and the MCT current inputs a special current tee is used. The voltage drop across the current circuit of the IUT forms a common mode signal on the MCT. However the MCT has been shown not to have any appreciable common mode dependence.

SASO NMCC (Saudi Arabia)

Frequency	Power factor	Relative error of active power measurement, μW/VA	Expanded uncertainty, μW/VA
50 Hz	1.0	-9.0	39.0
	0.5 Lag	-7.0	40.0
	0.5 Lead	-3.0	40.0
	0.0 Lag	-2.0	41.0
	0.0 Lead	-1.0	41.0
53 Hz	1.0	-18.0	39.0
	0.5 Lag	-13.0	40.0
	0.5 Lead	-4.0	40.0
	0.0 Lag	-6.0	41.0
	0.0 Lead	4.0	41.0

The operating principle of primary AC power measurement standard of SASO- NMCC, known as Digital Sampling Wattmeter (DSWM), shown in the figure below, is based on the use of two sampling voltmeters and on computerized evaluation by means of discrete integration (DI) or discrete Fourier transform (DFT). Similar to others, it consists of two digital sampling voltmeters (DVMs), a precision voltage divider, a set of AC current shunts, a power source, a triggering unit and software. The voltage and current signals from a phantom power source are applied to the relevant input terminals of the voltage divider and of the AC current shunts. A regulated voltage from secondary terminals of the voltage divider and a voltage obtained from the selected AC current shunt are then applied to the DVMs. With the help of software, DVMs are programmed with the calculated appropriate aperture times for the selected samples per period. Each programmed DVM then samples the applied voltage signals with the help of trigger signal which is synchronized to the power source.

The data from both DVMs are then transferred to the computer via IEEE488. The ratio and phase angle errors of the voltage divider and current shunts were corrected by the software. The amplitudes of both signals, the phase angles between them and the calculated results are displayed during the measurements.

The measurement setup is shown schematically in Figure A1.11.

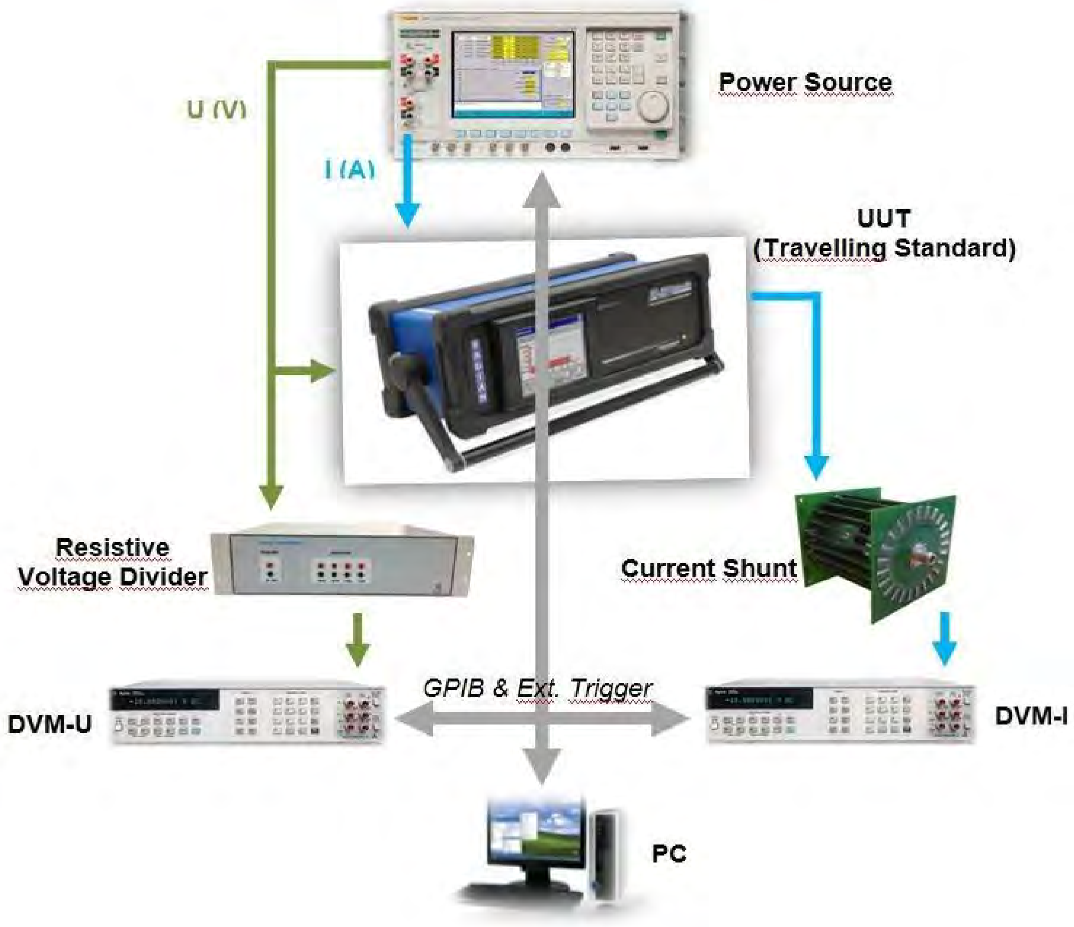

Figure A1.11 Block diagram of DSWM

NIS (Egypt)

Frequency	Power factor	Relative error of active power measurement, µW/VA	Expanded uncertainty, µW/VA
53 Hz	1.0	-7.6	35.8
	0.5 Lag	30.1	36.1
	0.5 Lead	12.4	37.1
	0.0 Lag	-24.7	40.4
	0.0 Lead	-30.7	38.2
50 Hz	1.0	-7.8	35.8
	0.5 Lag	15.8	46.2
	0.5 Lead	21.2	40.4
	0.0 Lag	-25.8	39.2
	0.0 Lead	-25.5	37.2

The operation principle of this measurement in NIS, Figures A1.12 and A1.13, are based upon the direct method of power calibration using the 3-phase comparator (s/n: 98-717-1), Type: (COM303), ZERA.

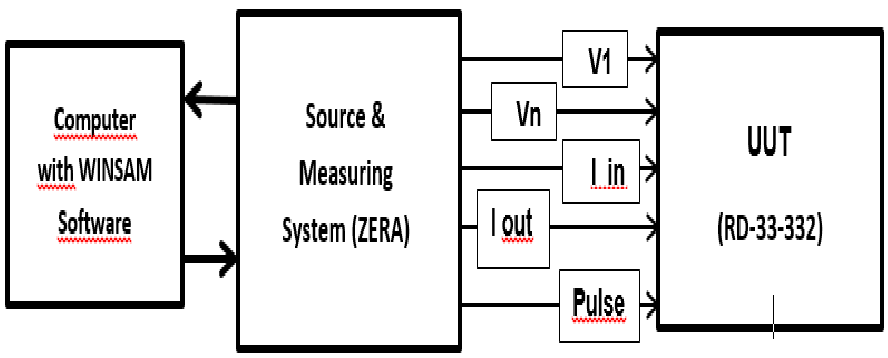

Figure A1.12 Block diagram of using ZERA system

The RD-33-332 measurement principle is based upon the fundamentals of a high-speed charge-balance integrating analogue to digital signal converter. To carry out measurements, NIS was used a single-phase switching circuit (phase A) in its calibration system. The reference of output signal was used frequency output to give the relevant pulses for phase A.

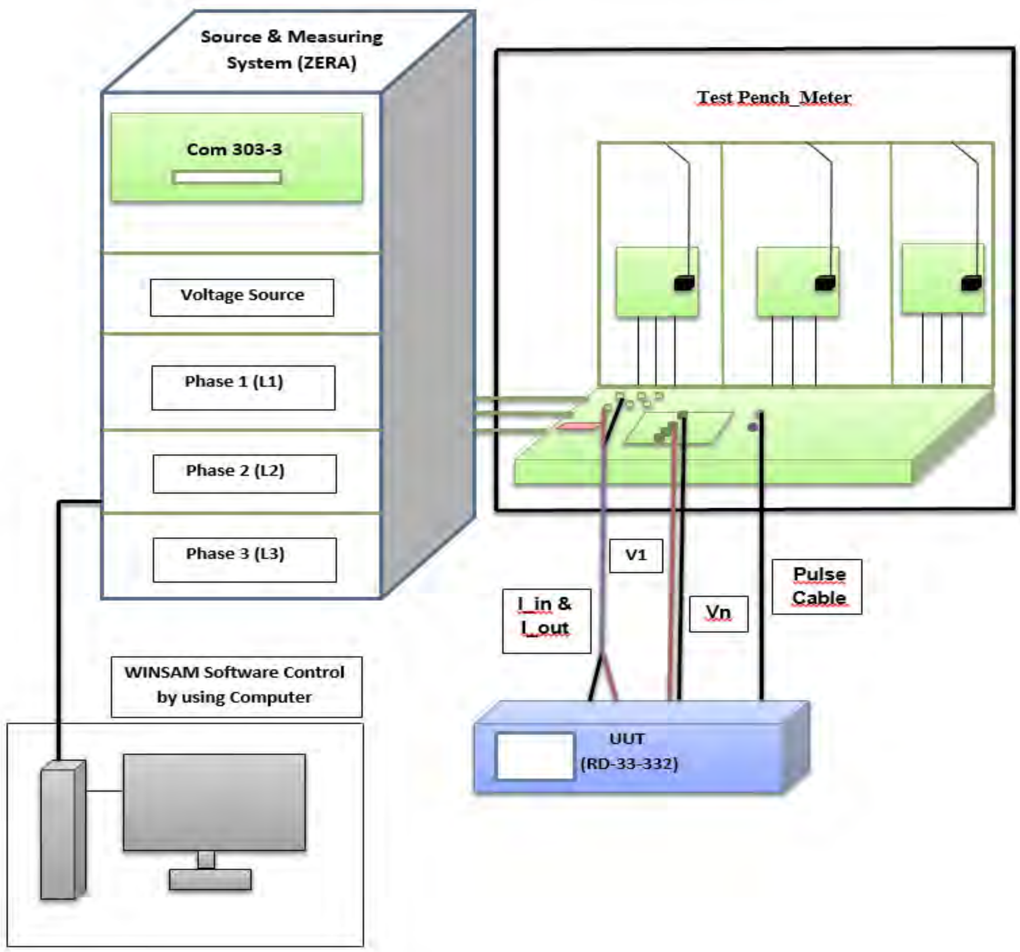

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Figure A1.13 System setup using COM303 of ZERA system

UMTS (Ukraine)

Frequency	Power factor	Relative error of active power measurement, µW/VA	Expanded uncertainty, µW/VA
50 Hz	1.0	1.8	18.5
	0.5 Lag	2.5	26.4
	0.5 Lead	-4.3	26.5
	0.0 Lag	3.7	23.9
	0.0 Lead	-3.9	24.5
53 Hz	1.0	1.0	18.1
	0.5 Lag	4.3	26.3
	0.5 Lead	-4.4	26.4
	0.0 Lag	3.3	23.8
	0.0 Lead	-3.9	24.2

The block diagram of the measurement setup of National AC power measurement standard of UMTS is shown in Figure A1.14. The operating principle is based on directly comparing the AC Power to DC Power by using thermoelectric converters.

The AC voltage and AC current signals from Highly Stable Power Source are applied to the relevant input terminals of the Precision Resistor Voltage Divider and of the Precision AC/DC current shunt. A regulated AC voltage from secondary terminals of the Precision Resistor Voltage Divider and a AC voltage obtained from the selected Precision AC/DC current shunt are then applied to the thermoelectric converters. AC voltage output thermoelectric converters signals are then applied to the DVMs. With the help of software, DVMs are programmed with the calculated appropriate aperture times for the selected samples per period. Each programmed DVM then samples the applied AC voltage signals from thermoelectric converters with the help of trigger signal which is synchronized to the power source. The data from both DVMs are then transferred to the computer via IEEE488.

The DC current and DC voltage signals are generated using a DC Power Source. The DC signals are applied to Precision Resistor Voltage Divider and of the Precision AC/DC current shunt. A regulated DC voltage from secondary terminals of the Precision Resistor Voltage Divider and a DC voltage obtained from the selected Precision AC/DC current shunt are then applied to the thermoelectric converters. DC voltage output thermoelectric converters signals are then applied to the DVMs. With the help of software, DVMs are programmed with the calculated appropriate aperture times for the selected samples per period. Each programmed DVM then samples the applied DC voltage signals from thermoelectric converters with the help of trigger signal which is synchronized to the power source. The data from both DVMs are then transferred to the computer via IEEE488.

When the AC and DC signals are balanced, the AC power is equal to the DC power. All the calculations are made by the software.

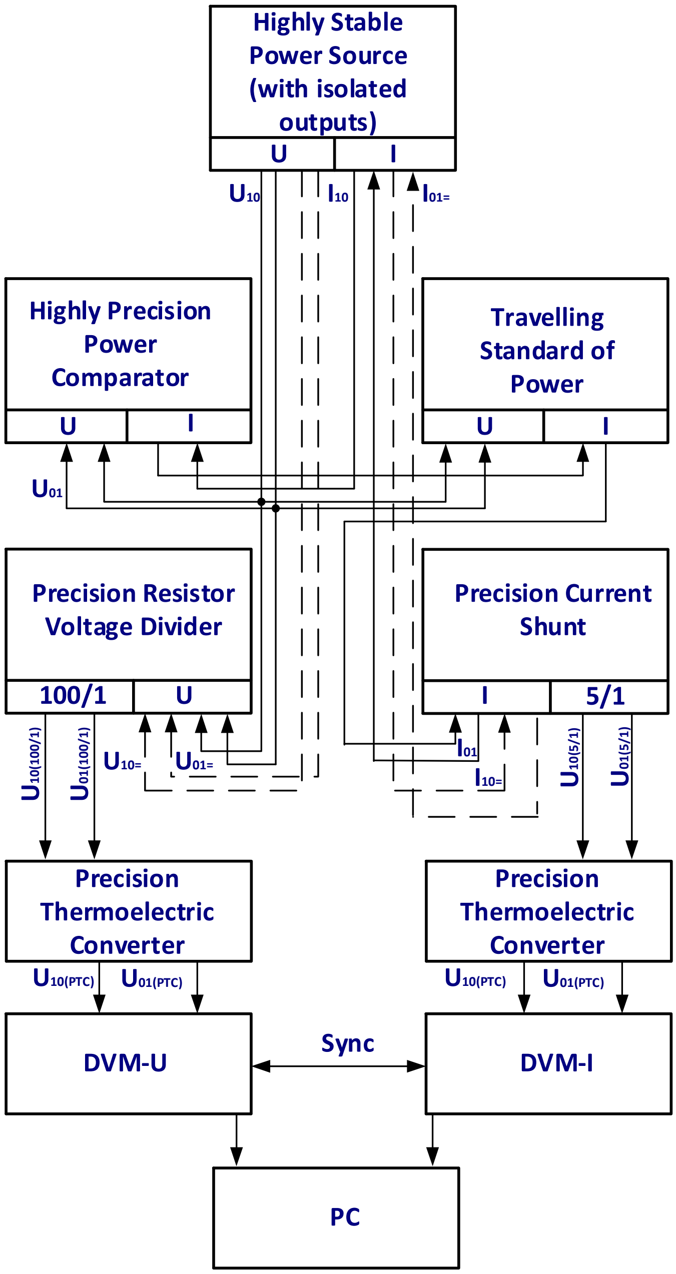

Figure A1.14 National AC power measurement standard of Ukraine

Appendix 2

Reported measurement uncertainty components for NMI participants

BelGIM (Belarus)

PF = 1.0; 50 Hz, µW/VA

i	Quantity (unit)	Distribution	x_i	$\pm r$	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	-1.9	-	3.8	99	1.0	3.8
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
4	Correction due to the frequency dependence uncertainty	rectangular	0.0	4.0	2.3	∞	1.0	2.3
y	Combined standard uncertainty						-1.9	21.0
	Expanded uncertainty (95 %, k = 2)							42.0

PF = 0.5 Lag; 50 Hz, µW/VA

i	Quantity (unit)	Distribution	x_i	$\pm r$	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	2,9	-	4.8	99	1.0	4.8
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
4	Correction due to the frequency dependence uncertainty	rectangular	0.0	4.0	2.3	∞	1.0	2.3
y	Combined standard uncertainty						2.9	21.2
	Expanded uncertainty (95 %, k = 2)							42.4

PF = 0.5 Lead; 50 Hz, µW/VA

i	Quantity (unit)	Distribution	x_i	$\pm r$	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	-5.2	-	6.1	99	1.0	6.1
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
4	Correction due to the frequency dependence uncertainty	rectangular	0.0	4.0	2.3	∞	1.0	2.3
y	Combined standard uncertainty						-5.2	21.5
	Expanded uncertainty (95 %, k = 2)							43.1

PF = 0.0 Lag; 50 Hz, µW/VA

i	Quantity (unit)	Distribution	x_i	± r	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	4,8	-	3.2	99	1.0	3.2
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
4	Correction due to the frequency dependence uncertainty	rectangular	0.0	4.0	2.3	∞	1.0	2.3
y	Combined standard uncertainty						4.8	20.9
	Expanded uncertainty (95 %, k = 2)							41.8

PF = 0.0 Lead; 50 Hz, µW/VA

i	Quantity (unit)	Distribution	x_i	± r	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	4.5	-	8.6	99	1.0	8.6
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
4	Correction due to the frequency dependence uncertainty	rectangular	0.0	4.0	2.3	∞	1.0	2.3
y	Combined standard uncertainty						4.5	22.4
	Expanded uncertainty (95 %, k = 2)							44.8

PF = 1.0; 53 Hz

i	Quantity (unit)	Distribution	x_i	± r	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	-0.9	-	0.9	99	1.0	0.9
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
y	Combined standard uncertainty						-0.9	20.5
	Expanded uncertainty (95 %, k = 2)							41.1

PF = 0.5 Lag; 53 Hz, µW/VA

i	Quantity (unit)	Distribution	x_i	± r	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	-1.8	-	2.0	99	1.0	2.0
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
y	Combined standard uncertainty						-1.8	20.6
	Expanded uncertainty (95 %, k = 2)							41.2

PF = 0.5 Lead; 53 Hz, µW/VA

i	Quantity (unit)	Distribution	x_i	$\pm r$	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	-5.8	-	2.2	99	1.0	2.2
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
y	Combined standard uncertainty						-5.8	20.6
	Expanded uncertainty (95 %, k = 2)							41.3

PF = 0.0 Lag; 53 Hz

i	Quantity (unit)	Distribution	x_i	$\pm r$	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	-3.8	-	1.1	99	1.0	1.1
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
y	Combined standard uncertainty						-3.8	20.6
	Expanded uncertainty (95 %, k = 2)							41.1

PF = 0.0 Lead; 53 Hz

i	Quantity (unit)	Distribution	x_i	$\pm r$	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Measured value	normal	-1.8	-	1.2	99	1.0	1.2
2	Correction due to the RD-33-211 uncertainty	normal	0.0	40.0	20.0	∞	1.0	20.0
3	Correction due to the Stability of Calsourse 200 and Fluke 6100A	rectangular	0.0	8.0	4.6	∞	1.0	4.6
y	Combined standard uncertainty						-1.8	20.6
	Expanded uncertainty (95 %, k = 2)							41.1

VNIIM (Russia)

PF = 1.0, 50 Hz

Main uncertainty components, y_i	Standard uncertainty, $u(y_i)$	Type method A or B of evaluation/probability distribution function	Sensitivity coefficient, c_i	Contribution to the standard uncertainty, μW/VA
Standard deviation of the calibration error of the travelling standard	2.4 μW/VA	A, normal	1.0	2.4
Voltage divider ratio error	$1.3 \cdot 10^{-6}$	B, normal	1.0	1.3
Current shunt resistance	1.4 μOm/Om	B, normal	1.0	1.4
Current shunt self heating error	$0.7 \cdot 10^{-6}$	B, normal	1.0	0.7
AC/DC current shunt	$2.0 \cdot 10^{-6}$	B, normal	1.0	2.0
DVM RMS traceability	2.2 μV/V	B, normal	2.0	4.4
Voltage divider phase error	1.5 μrad	B, normal	0.0	0.0
Current shunt phase error	2.7 μrad	B, normal	0.0	0.0
Phase error of sampling system	2.7 μrad	B, normal	0.0	0.0
Combined standard uncertainty				5.8
Expanded uncertainty (95.45 %, k = 2)				11.5

PF = 0.5, 50 Hz

Main uncertainty components, y_i	Standard uncertainty, $u(y_i)$	Type method A or B of evaluation/probability distribution function	Sensitivity coefficient, c_i	Contribution to the standard uncertainty, μW/VA
Standard deviation of the calibration error of the travelling standard	2.5 μW/VA	A, normal	1.0	2.5
Voltage divider ratio error	$1.3 \cdot 10^{-6}$	B, normal	0.5	0.7
Current shunt resistance	1.4 μOm/Om	B, normal	0.5	0.7
Current shunt self heating error	$0.7 \cdot 10^{-6}$	B, normal	0.5	0.4
AC/DC current shunt	$2.0 \cdot 10^{-6}$	B, normal	0.5	1.0
DVM RMS traceability	2.2 μV/V	B, normal	1.0	2.2
Voltage divider phase error	1.5 μrad	B, normal	0.87	1.3
Current shunt phase error	2.7 μrad	B, normal	0.87	2.3
Phase error of sampling system	2.7 μrad	B, normal	0.87	2.3
Combined standard uncertainty				5.1
Expanded uncertainty (95.45 %, k = 2)				10.2

PF = 0.0, 50 Hz

Main uncertainty components, y_i	Standard uncertainty, $u(y_i)$	Type method A or B of evaluation/probability distribution function	Sensitivity coefficient, c_i	Contribution to the standard uncertainty, μW/VA
Standard deviation of the calibration error of the travelling standard	2.1 μW/VA	A, normal	1.0	2.1
Voltage divider ratio error	$1.3 \cdot 10^{-6}$	B, normal	0.0	0.0
Current shunt resistance	1.4 μOm/Om	B, normal	0.0	0.0
Current shunt self heating error	$0.7 \cdot 10^{-6}$	B, normal	0.0	0.0
AC/DC current shunt	$2.0 \cdot 10^{-6}$	B, normal	0.0	0.0
DVM RMS traceability	2.2 μV/V	B, normal	0.0	0.0
Voltage divider phase error	1.5 μrad	B, normal	1.0	1.5
Current shunt phase error	2.7 μrad	B, normal	1.0	2.7
Phase error of sampling system	2.7 μrad	B, normal	1.0	2.7
Combined standard uncertainty				4.6
Expanded uncertainty (95.45 %, k = 2)				9.2

PF = 1.0, 53 Hz

Main uncertainty components, y_i	Standard uncertainty, $u(y_i)$	Type method A or B of evaluation/probability distribution function	Sensitivity coefficient, c_i	Contribution to the standard uncertainty, μW/VA
Standard deviation of the calibration error of the travelling standard	1.1 μW/VA	A, normal	1.0	1.1
Voltage divider ratio error	$1.3 \cdot 10^{-6}$	B, normal	1.0	1.3
Current shunt resistance	1.4 μOm/Om	B, normal	1.0	1.4
Current shunt self heating error	$0.7 \cdot 10^{-6}$	B, normal	1.0	0.7
AC/DC current shunt	$2.0 \cdot 10^{-6}$	B, normal	1.0	2.0
DVM RMS traceability	1.6 μV/V	B, normal	2.0	3.2
Voltage divider phase error	1.5 μrad	B, normal	0.0	0.0
Current shunt phase error	2.7 μrad	B, normal	0.0	0.0
Phase error of sampling system	1.7 μrad	B, normal	0.0	0.0
Combined standard uncertainty				4.4
Expanded uncertainty (95.45 %, k = 2)				8.9

PF = 0.5, 53 Hz

Main uncertainty components, y_i	Standard uncertainty, $u(y_i)$	Type method A or B of evaluation/probability distribution function	Sensitivity coefficient, c_i	Contribution to the standard uncertainty, µW/VA
Standard deviation of the calibration error of the travelling standard	1.1 µW/VA	A, normal	1.0	1.1
Voltage divider ratio error	$1.3 \cdot 10^{-6}$	B, normal	0.5	0.7
Current shunt resistance	1.4 µOm/Om	B, normal	0.5	0.7
Current shunt self heating error	$0.7 \cdot 10^{-6}$	B, normal	0.5	0.4
AC/DC current shunt	$2.0 \cdot 10^{-6}$	B, normal	0.5	1.0
DVM RMS traceability	1.6 µV/V	B, normal	1.0	1.6
Voltage divider phase error	1.5 µrad	B, normal	0.87	1.3
Current shunt phase error	2.7 µrad	B, normal	0.87	2.4
Phase error of sampling system	1.7 µrad	B, normal	0.87	1.5
Combined standard uncertainty				3.9
Expanded uncertainty (95.45 %, k = 2)				7.8

PF = 0.0, 53 Hz

Main uncertainty components, y_i	Standard uncertainty, $u(y_i)$	Type method A or B of evaluation/probability distribution function	Sensitivity coefficient, c_i	Contribution to the standard uncertainty, µW/VA
Standard deviation of the calibration error of the travelling standard	1.1 µW/VA	A, normal	1.0	1.1
Voltage divider ratio error	$1.3 \cdot 10^{-6}$	B, normal	0.0	0.0
Current shunt resistance	1.4 µOm/Om	B, normal	0.0	0.0
Current shunt self heating error	$0.7 \cdot 10^{-6}$	B, normal	0.0	0.0
AC/DC current shunt	$2.0 \cdot 10^{-6}$	B, normal	0.0	0.0
DVM RMS traceability	1.6 µV/V	B, normal	0.0	0.0
Voltage divider phase error	1.5 µrad	B, normal	1.0	1.5
Current shunt phase error	2.7 µrad	B, normal	1.0	2.7
Phase error of sampling system	1.7 µrad	B, normal	1.0	1.7
Combined standard uncertainty				3.7
Expanded uncertainty (95.45 %, k = 2)				7.4

GEOSTM (Georgia)

PF = 1.0, 50 Hz

Quantity	Value	Standard uncertainty, μW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	599.88542 W						
$\overline{\delta P_S}$	599.87500 W						
$\delta P_X / S$	0.0	0.4	99	normal	1.0	0.4	0.5
$\delta P_{Scal.} / S$	0.0	27.0	∞	normal	1.0	27.0	37.1
$\delta P_{Sred.} / S$	0.0	2.9	50	rectangular	1.0	2.9	3.9
$\delta P_{Sstab.} / S$	0.0	34.7	50	rectangular	1.0	34.7	47.7
$\delta P_{S\phi} / S$	0,0	7.5	200	rectangular	1.0	7.5	10.3
$\delta P_{ST} / S$	0.0	0.3	200	rectangular	1.0	0.3	0.5
$\overline{\delta P_X} / S$	17.3 μW/VA	44.7	ν_{eff} =138	Expanded uncertainty (k = 2): 89.4 μW/VA			

PF = 0.5 Lag, 50 Hz

Quantity	Value	Standard uncertainty, μW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	299.97692 W						
$\overline{\delta P_S}$	299.96800 W						
$\delta P_X / S$	0.0	0.4	99	normal	1.0	0.4	0.4
$\delta P_{Scal.} / S$	0.0	54.0	∞	normal	1.0	54.0	47.2
$\delta P_{Sred.} / S$	0.0	2.9	50	rectangular	1.0	2.9	2.5
$\delta P_{Sstab.} / S$	0.0	34.7	50	rectangular	1.0	34.7	30.4
$\delta P_{S\phi} / S$	0.0	43.9	200	rectangular	0.5	22.0	19.2
$\delta P_{ST} / S$	0.0	0.3	200	rectangular	1.0	0.3	0.3
$\overline{\delta P_X} / S$	14.9 μW/VA	67.9	ν_{eff} =704	Expanded uncertainty (k = 2): 135.8 μW/VA			

PF = 0.5 Lead, 50 Hz

Quantity	Value	Standard uncertainty, μW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	299.93717 W						
$\overline{\delta P_S}$	299.93800 W						
$\delta P_X/S$	0.0	0.3	99	normal	1.0	0.3	0.3
$\delta P_{Scal.}/S$	0.0	54.0	∞	normal	1.0	54.0	47.3
$\delta P_{Sred.}/S$	0.0	2.9	50	rectangular	1.0	2.9	2.5
$\delta P_{Sstab.}/S$	0.0	34.7	50	rectangular	1.0	34.7	30.4
$\delta P_{S\phi}/S$	0.0	43.9	200	rectangular	0.5	22.0	19.2
$\delta P_{ST}/S$	0.0	0.3	200	rectangular	1.0	0.3	0.3
$\overline{\delta P_X}/S$	-1.4 μW/VA	67.9	ν_{eff} =704	Expanded uncertainty (*k* = 2): 135.8 μW/VA			

PF = 0.0 Lag, 50 Hz

Quantity	Value	Standard uncertainty, μW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	0.009562 W						
$\overline{\delta P_S}$	0.006000 W						
$\delta P_X/S$	0.0	0.3	99	normal	1.0	0.3	0.2
$\delta P_{Scal.}/S$	0.0	81.0	∞	normal	1.0	81.0	47.9
$\delta P_{Sred.}/S$	0.0	2.9	50	rectangular	1.0	2.9	1.7
$\delta P_{Sstab.}/S$	0.0	34.7	50	rectangular	1.0	34.7	20.5
$\delta P_{S\phi}/S$	0.0	50.3	200	rectangular	1.0	50.3	29.5
$\delta P_{ST}/S$	0.0	0.3	200	rectangular	1.0	0.3	0.2
$\overline{\delta P_X}/S$	5.8 μW/VA	101.5	ν_{eff} =1739	Expanded uncertainty (*k* = 2): 203.0 μW/VA			

PF = 0.0 Lead, 50 Hz

Quantity	Value	Standard uncertainty, µW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	-0.028752 W						
$\overline{\delta P_S}$	-0.021000 W						
$\delta P_X/S$	0.0	0.3	99	normal	1.0	0.3	0.2
$\delta P_{Scal.}/S$	0.0	81.0	∞	normal	1.0	81.0	47.9
$\delta P_{Sred.}/S$	0.0	2.9	50	rectangular	1.0	2.9	1.7
$\delta P_{Sstab.}/S$	0.0	34.7	50	rectangular	1.0	34.7	20.5
$\delta P_{S\phi}/S$	0.0	50.3	200	rectangular	1.0	50.3	29.5
$\delta P_{ST}/S$	0.0	0.3	200	rectangular	1.0	0.3	0.2
$\overline{\delta P_X}/S$	-12.9 µW/VA	101.5	ν_{eff} =1739	Expanded uncertainty (k = 2): 203.0 µW/VA			

PF = 1.0, 53 Hz

Quantity	Value	Standard uncertainty, µW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	599.94278 W						
$\overline{\delta P_S}$	599.93400 W						
$\delta P_X/S$	0.0	0.2	99	normal	1.0	0.2	0.5
$\delta P_{Scal.}/S$	0.0	27.0	∞	normal	1.0	27.0	37.2
$\delta P_{Sred.}/S$	0.0	2.9	50	rectangular	1.0	2.9	4.0
$\delta P_{Sstab.}/S$	0.0	34.7	50	rectangular	1.0	34.7	47.8
$\delta P_{S\phi}/S$	0,0	7.5	200	rectangular	1.0	7.5	10.3
$\delta P_{ST}/S$	0.0	0.3	200	rectangular	1.0	0.3	0.4
$\overline{\delta P_X}/S$	14.6 µW/VA	44.7	ν_{eff} =138	Expanded uncertainty (k = 2): 89.4 µW/VA			

PF = 0.5 Lag, 53 Hz

Quantity	Value	Standard uncertainty, μW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	299.97609 W						
$\overline{\delta P_S}$	299.96600 W						
$\delta P_X/S$	0.0	0.1	99	normal	1.0	0.1	0.1
$\delta P_{Scal.}/S$	0.0	54.0	∞	normal	1.0	54.0	47.4
$\delta P_{Sred.}/S$	0.0	2.9	50	rectangular	1.0	2.9	2.5
$\delta P_{Sstab.}/S$	0.0	34.7	50	rectangular	1.0	34.7	30.4
$\delta P_{S\phi}/S$	0.0	43.9	200	rectangular	0.5	22.0	19.3
$\delta P_{ST}/S$	0.0	0.3	200	rectangular	1.0	0.3	0.3
$\overline{\delta P_X}/S$	16.8 μW/VA	67.9	ν_{eff} =704	Expanded uncertainty (k = 2): 135.8 μW/VA			

PF = 0.5 Lead, 53 Hz

Quantity	Value	Standard uncertainty, μW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	299.90938 W						
$\overline{\delta P_S}$	299.91400 W						
$\delta P_X/S$	0.0	0.1	99	normal	1.0	0.1	0.1
$\delta P_{Scal.}/S$	0.0	54.0	∞	normal	1.0	54.0	47.4
$\delta P_{Sred.}/S$	0.0	2.9	50	rectangular	1.0	2.9	2.5
$\delta P_{Sstab.}/S$	0.0	34.7	50	rectangular	1.0	34.7	30.4
$\delta P_{S\phi}/S$	0.0	43.9	200	rectangular	0.5	22.0	19.3
$\delta P_{ST}/S$	0.0	0.3	200	rectangular	1.0	0.3	0.3
$\overline{\delta P_X}/S$	-7.5 μW/VA	67.9	ν_{eff} =704	Expanded uncertainty (k = 2): 135.8 μW/VA			

PF = 0.0 Lag, 53 Hz

Quantity	Value	Standard uncertainty, μW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	0.02463 W						
$\overline{\delta P_S}$	0.01800 W						
$\delta P_X / S$	0.0	0.1	99	normal	1.0	0.1	0.1
$\delta P_{Scal.} / S$	0.0	81.0	∞	normal	1.0	81.0	47.8
$\delta P_{Sred.} / S$	0.0	2.9	50	rectangular	1.0	2.9	1.7
$\delta P_{Sstab.} / S$	0.0	34.7	50	rectangular	1.0	34.7	20.5
$\delta P_{S\phi} / S$	0.0	50.3	200	rectangular	1.0	50.3	29.7
$\delta P_{ST} / S$	0.0	0.3	200	rectangular	1.0	0.3	0.2
$\overline{\delta P_X} / S$	11.0 μW/VA	101.5	ν_{eff} =1739	Expanded uncertainty (k = 2): 203.0 μW/VA			

PF = 0.0 Lead, 50 Hz

Quantity	Value	Standard uncertainty, μW/VA	Degrees of freedom	Distribution	Sensitivity coefficient	Uncertainty contribution	Index, %
$\overline{\delta P_X}$	-0.023668 W						
$\overline{\delta P_S}$	-0.013000 W						
$\delta P_X / S$	0.0	0.1	99	normal	1.0	0.1	0.1
$\delta P_{Scal.} / S$	0.0	81.0	∞	normal	1.0	81.0	47.8
$\delta P_{Sred.} / S$	0.0	2.9	50	rectangular	1.0	2.9	1.7
$\delta P_{Sstab.} / S$	0.0	34.7	50	rectangular	1.0	34.7	20.5
$\delta P_{S\phi} / S$	0.0	50.3	200	rectangular	1.0	50.3	29.7
$\delta P_{ST} / S$	0.0	0.3	200	rectangular	1.0	0.3	0.2
$\overline{\delta P_X} / S$	-17.8 μW/VA	101.5	ν_{eff} =1739	Expanded uncertainty (k = 2): 203.0 μW/VA			

Model of measurement function:

$$\Delta P_X = P_X - P_S + \delta P_X + \delta P_{Scal.} + \delta P_{Sred.} + \delta P_{Sstab.} + \delta P_{S\varphi} + \delta P_{ST},$$

$$\frac{\Delta P_X}{S} = \frac{P_X - P_S}{S} + \frac{\delta P_X}{S} + \frac{\delta P_{Scal.}}{S} + \frac{\delta P_{Sred.}}{S} + \frac{\delta P_{Sstab.}}{S} + \frac{\delta P_{S\varphi}}{S} + \frac{\delta P_{ST}}{S},$$

where:

P_X is power measured by РД-33-332, W;

P_S is power measured by COM 3003, W;

S is apparent power, VA;

δP_X is scattering of the measurement results, Type A uncertainty;

$\delta P_{Scal.}$ is uncertainty of calibration of the reference standard;

$\delta P_{Sred.}$ is uncertainty due to limited resolution of the reference standard;

$\delta P_{Sstab.}$ is uncertainty due to limited stability of the reference standard;

$\delta P_{S\varphi}$ is uncertainty due to phase error of the reference standard, only for $\cos\varphi \neq 1$;

δP_{ST} is uncertainty due to the temperature dependence of the reference standard.

CSM (Kyrgyzstan)

PF = 1.0, 50 Hz

i	Quantity (unit), μW/VA	Distribution	x_i	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	$\delta(P_{repeatability})$	Student	-79.0	0.3	249	1.0	0.3
2	$\delta(P_{standard})$	Normal	-20.0	75.0	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	5.5	∞	0.5	2.8
6	Difference between of PF=1 and PF=0	Normal	0.0	0.0	∞	0.5	0.0
Expanded uncertainty (95 %, k = 2)							158.1

PF = 0.5 Lag, 50 Hz

i	Quantity (unit), μW/VA	Distribution	x_i	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	$\delta(P_{repeatability})$	Student	-61.0	0.4	249	1.0	0.4
2	$\delta(P_{standard})$	Normal	-10.0	75.0	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	1.5	∞	0.5	0.8
6	Difference between of PF=1 and PF=0	Normal	0.0	0.0	∞	0.5	0.0
Expanded uncertainty (95 %, k = 2)							158.0

PF = 0.5 Lead, 50 Hz

i	Quantity (unit), μW/VA	Distribution	x_i	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	$\delta(P_{repeatability})$	Student	-73.0	0.4	249	1.0	0.4
2	$\delta(P_{standard})$	Normal	-10.0	75.0	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	5.5	∞	0.5	2.8
6	Difference between of PF=1 and PF=0	Normal	0.0	0.0	∞	0.5	0.0
Expanded uncertainty (95 %, k = 2)							158.0

PF = 0.05 Lag, 50 Hz

i	Quantity (unit), µW/VA	Distribution	x_i	$u(x_i)$, µW/VA	ν_i	c_i	$u_i(y)$, µW/VA
1	$\delta(P_{repeatability})$	Student	-125.0	2.7	249	1.0	2.7
2	$\delta(P_{standard})$	Normal	-20.0	75.0	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	11.5	∞	0.5	5.8
6	Difference between of PF=1 and PF=0	Normal	0.0	23.0	∞	0.5	11.5
Expanded uncertainty (95 %, k = 2)							160.2

PF = 0.05 Lead, 50 Hz

i	Quantity (unit), µW/VA	Distribution	x_i	$u(x_i)$, µW/VA	ν_i	c_i	$u_i(y)$, µW/VA
1	$\delta(P_{repeatability})$	Student	-112.0	3.1	249	1.0	3.1
2	$\delta(P_{standard})$	Normal	-20.0	75.0	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	29.0	∞	0.5	14.5
6	Difference between of PF=1 and PF=0	Normal	0.0	16.5	∞	0.5	8.3
Expanded uncertainty (95 %, k = 2)							161.6

PF = 1.0, 53 Hz

i	Quantity (unit), µW/VA	Distribution	x_i	$u(x_i)$, µW/VA	ν_i	c_i	$u_i(y)$, µW/VA
1	$\delta(P_{repeatability})$	Student	-68.0	0.3	249	1.0	0.3
2	$\delta(P_{standard})$	Normal	-20.0	75.0	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	0.0	∞	0.5	0.0
6	Difference between of PF=1 and PF=0	Normal	0.0	0.0	∞	0.5	0.0
Expanded uncertainty (95 %, k = 2)							158.0

PF = 0.5 Lag, 53 Hz

i	Quantity (unit), µW/VA	Distribution	x_i	$u(x_i)$, µW/VA	v_i	c_i	$u_i(y)$, µW/VA
1	$\delta(P_{repeatability})$	Student	-64.0	0.3	249	1.0	0.3
2	$\delta(P_{standard})$	Normal	-10.0	75.0	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	0.0	∞	0.5	0.0
6	Difference between of PF=1 and PF=0	Normal	0.0	0.0	∞	0.5	0.0
Expanded uncertainty (95 %, k = 2)							158.0

PF = 0.5 Lead, 53 Hz

i	Quantity (unit), µW/VA	Distribution	x_i	$u(x_i)$, µW/VA	v_i	c_i	$u_i(y)$, µW/VA
1	$\delta(P_{repeatability})$	Student	-62.0	0.3	249	1.0	0.3
2	$\delta(P_{standard})$	Normal	-10.0	75.0	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	0.0	∞	0.5	0.0
6	Difference between of PF=1 and PF=0	Normal	0.0	0.0	∞	0.5	0.0
Expanded uncertainty (95 %, k = 2)							158.0

PF = 0.05 Lag, 53 Hz

i	Quantity (unit), µW/VA	Distribution	x_i	$u(x_i)$, µW/VA	v_i	c_i	$u_i(y)$, µW/VA
1	$\delta(P_{repeatability})$	Student	-148.0	0.9	249	1.0	0.9
2	$\delta(P_{standard})$	Normal	-20.0	750	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	0.0	∞	0.5	0.0
6	Difference between of PF=1 and PF=0	Normal	0.0	40.0	∞	0.5	20.0
Expanded uncertainty (95 %, k = 2)							163.0

PF = 0.05 Lead, 53 Hz

i	Quantity (unit), μW/VA	Distribution	x_i	$u(x_i)$, μW/VA	vi	ci	$u_i(y)$, μW/VA
1	$\delta(P_{repeatability})$	Student	-54.0	1.1	249	1.0	1.1
2	$\delta(P_{standard})$	Normal	-20.0	75.0	∞	1.0	75.0
3	$\delta(P_{drift})$	Rectangular	40.0	49.7	∞	0.5	24.8
4	$\delta(P_{resolution})$	Rectangular	1.0	0.6	∞	1.0	0.6
5	Difference between of 50Hz and 53 Hz	Normal	0.0	0.0	∞	0.5	0.0
6	Difference between of PF=1 and PF=0	Normal	0.0	7.0	∞	0.5	3.5
Expanded uncertainty (95 %, k = 2)							158.2

Measurement equation is

$$P_X = P_{EUT} - P_{REF} + \delta(P_{repeatability}) + \delta(P_{standard}) + \delta(P_{drift}) + \delta(P_{resolution}) + \delta(P_{difference\ between\ 50\ Hz\ and\ 53\ Hz}) + \delta(P_{difference\ between\ PF=1\ and\ PF=0}),$$

where:

$\delta(P_{repeatability})$ is repeatability of the mean from the 250;

$\delta(P_{standard})$ is uncertainty of reference meter MT3000;

$\delta(P_{drift})$ is drift of reference meter;

$\delta(P_{resolution})$ is resolution of reference meter MT3000.

UME (Turkey)

PF = 1.0, 50/53 Hz

Source of uncertainty	Standard uncertainty, μW/VA	Probability distribution	Sensitivity coefficient	Uncertainty contribution, μW/VA
Voltage measurement	5	normal	1	5.0
Current measurement	8	normal	1	8.0
Phase measurement	10	normal	0	0.0
Measurement set up	2	rectangular	1	2.0
Standard uncertainty of measurement	4	normal	1	4.0
Combined standard uncertainty				10.4
Expanded uncertainty (k = 2)				20.9

PF = 0.5, 50/53 Hz

Source of uncertainty	Standard uncertainty, μW/VA	Probability distribution	Sensitivity coefficient	Uncertainty contribution, μW/VA
Voltage measurement	5	normal	0.5	2.5
Current measurement	8	normal	0.5	4.0
Phase measurement	10	normal	0.87	8.7
Measurement set up	2	rectangular	1	2.0
Standard uncertainty of measurement	4	normal	1	4.0
Combined standard uncertainty				10.8
Expanded uncertainty (k = 2)				21.7

PF = 0.0, 50/53 Hz

Source of uncertainty	Standard uncertainty, μW/VA	Probability distribution	Sensitivity coefficient	Uncertainty contribution, μW/VA
Voltage measurement	5	normal	0	0.0
Current measurement	8	normal	0	0.0
Phase measurement	10	normal	1	10.0
Measurement set up	2	rectangular	1	2.0
Standard uncertainty of measurement	4	normal	1	4.0
Combined standard uncertainty				11.0
Expanded uncertainty (k = 2)				21.9

SMU (Slovakia)

PF = 1.0, 50 Hz

Source of uncertainty	Standard uncertainty	Probability distribution	Sensitivity coefficient	Contribution to the standard uncertainty, μW/VA
NMI voltage measurement [μW/VA]/V	20.0	normal	1.0	19.6
NMI current measurement [μW/VA]/A	32.0	normal	1.0	31.5
NMI phase measurement [μW/VA]/°	1.0	normal	0.0	0.0
Std uncertainty of measurement [μW/VA]	4.0	normal	1.0	4.0
Combined standard uncertainty				37.3
Expanded uncertainty (95 %, *k* = 2)				74.6

PF = 0.5, 50 Hz

Source of uncertainty	Standard uncertainty	Probability distribution	Sensitivity coefficient	Contribution to the standard uncertainty, μW/VA
NMI voltage measurement [μW/VA]/V	20.0	normal	1.0	19.6
NMI current measurement [μW/VA]/A	32.0	normal	1.0	31.5
NMI phase measurement [μW/VA]/°	23.0	normal	0.87	19.8
Std uncertainty of measurement [μW/VA]	4.0	normal	1.0	4.0
Combined standard uncertainty				42.3
Expanded uncertainty (95 %, *k* = 2)				84.5

PF = 0.01, 50 Hz

Source of uncertainty	Standard uncertainty	Probability distribution	Sensitivity coefficient	Contribution to the standard uncertainty, μW/VA
NMI voltage measurement [μW/VA]/V	20.0	normal	1.0	19.6
NMI current measurement [μW/VA]/A	32.0	normal	1.0	31.5
NMI phase measurement [μW/VA]/°	26.0	normal	1.0	26.2
Std uncertainty of measurement [μW/VA]	4.0	normal	1.0	4.0
Combined standard uncertainty				45.6
Expanded uncertainty (95 %, *k* = 2)				91.2

PF = 1.0, 53 Hz

Source of uncertainty	Standard uncertainty	Probability distribution	Sensitivity coefficient	Contribution to the standard uncertainty, µW/VA
NMI voltage measurement [µW/VA]/V	20.0	normal	1.0	19.5
NMI current measurement [µW/VA]/A	21.0	normal	1.0	20.5
NMI phase measurement [µW/VA]/°	0.0	normal	0.0	0.0
Std uncertainty of measurement [µW/VA]	2.9	normal	1.0	2.9
Combined standard uncertainty				28.4
Expanded uncertainty (95 %, $k = 2$)				56.9

PF = 0.5, 53 Hz

Source of uncertainty	Standard uncertainty	Probability distribution	Sensitivity coefficient	Contribution to the standard uncertainty, µW/VA
NMI voltage measurement [µW/VA]/V	20.0	normal	1.0	19.5
NMI current measurement [µW/VA]/A	21.0	normal	1.0	20.5
NMI phase measurement [µW/VA]/°	23.0	normal	0.87	19.8
Std uncertainty of measurement [µW/VA]	2.9	normal	1.0	2.9
Combined standard uncertainty				34.7
Expanded uncertainty (95 %, $k = 2$)				69.3

PF = 0.01, 53 Hz

Source of uncertainty	Standard uncertainty	Probability distribution	Sensitivity coefficient	Contribution to the standard uncertainty, µW/VA
NMI voltage measurement [µW/VA]/V	20.0	normal	1.0	19.5
NMI current measurement [µW/VA]/A	21.0	normal	1.0	20.5
NMI phase measurement [µW/VA]/°	26.0	normal	1.0	26.2
Std uncertainty of measurement [µW/VA]	2.9.0	normal	1.0	2.9
Combined standard uncertainty				38.7
Expanded uncertainty (95 %, $k = 2$)				77.3

LEM-FEIT (R. Macedonia)

PF = 1.0, 50 Hz

Discription	x_i, µW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, µW/VA
Traveling standard repeated observations	58.3	normal	0.6 µW/VA	99	1.0	0.6
ZERA Calibration certificate	1.0	normal	50.0 µW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 µW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 µW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 µW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 µW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 µW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 µW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 µW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 µW/(VA·°)	0.07
Combined standard uncertainty, µW/VA						57.8
Expanded uncertainty (95 %, k = 2), µW/VA						115.5

PF = 0.5 Lag, 50 Hz

Discription	x_i, µW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, µW/VA
Traveling standard repeated observations	26.5	normal	0.4 µW/VA	99	1.0	0.4
ZERA Calibration certificate	9.0	normal	50.0 µW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 µW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 µW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 µW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 µW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 µW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 µW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 µW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 µW/(VA·°)	0.07
Combined standard uncertainty, µW/VA						57.8
Expanded uncertainty (95 %, k = 2), µW/VA						115.5

PF = 0.5 Lead, 50 Hz

Discription	x_i, µW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, µW/VA
Traveling standard repeated observations	84.6	normal	0.8 µW/VA	99	1.0	0.8
ZERA Calibration certificate	-8.0	normal	50.0 µW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 µW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 µW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 µW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 µW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 µW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 µW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 µW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 µW/(VA·°)	0.07
Combined standard uncertainty, µW/VA						57.8
Expanded uncertainty (95 %, k = 2), µW/VA						115.5

PF = 0.0 Lag, 50 Hz

Discription	x_i, µW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, µW/VA
Traveling standard repeated observations	54.3	normal	1.2 µW/VA	99	1.0	1.2
ZERA Calibration certificate	0.0	normal	50.0 µW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 µW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 µW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 µW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 µW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 µW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 µW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 µW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 µW/(VA·°)	0.07
Combined standard uncertainty, µW/VA						57.8
Expanded uncertainty (95 %, k = 2), µW/VA						115.5

PF = 0.0 Lead, 50 Hz

Discription	x_i, μW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, μW/VA
Traveling standard repeated observations	59.6	normal	0.6 μW/VA	99	1.0	0.6
ZERA Calibration certificate	0.0	normal	50.0 μW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 μW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 μW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 μW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 μW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 μW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 μW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 μW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 μW/(VA·°)	0.07
Combined standard uncertainty, μW/VA						57.8
Expanded uncertainty (95 %, k = 2), μW/VA						115.5

PF = 1.0, 53 Hz

Discription	x_i, μW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, μW/VA
Traveling standard repeated observations	52.6	normal	0.5 μW/VA	99	1.0	0.5
ZERA Calibration certificate	1.0	normal	50.0 μW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 μW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 μW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 μW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 μW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 μW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 μW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 μW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 μW/(VA·°)	0.07
Combined standard uncertainty, μW/VA						57.8
Expanded uncertainty (95 %, k = 2), μW/VA						115.5

PF = 0.5 Lag, 53 Hz

Discription	x_i, μW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, μW/VA
Traveling standard repeated observations	31.9	normal	0.4 μW/VA	99	1.0	0.4
ZERA Calibration certificate	9.0	normal	50.0 μW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 μW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 μW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 μW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 μW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 μW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 μW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 μW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 μW/(VA·°)	0.07
Combined standard uncertainty, μW/VA						57.8
Expanded uncertainty (95 %, k = 2), μW/VA						115.5

PF = 0.5 Lead, 53 Hz

Discription	x_i, μW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, μW/VA
Traveling standard repeated observations	70.4	normal	0.8 μW/VA	99	1.0	0.8
ZERA Calibration certificate	-8.0	normal	50.0 μW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 μW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 μW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 μW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 μW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 μW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 μW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 μW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 μW/(VA·°)	0.07
Combined standard uncertainty, μW/VA						57.8
Expanded uncertainty (95 %, k = 2), μW/VA						115.5

PF = 0.0 Lag, 53 Hz

Discription	x_i, μW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, μW/VA
Traveling standard repeated observations	58.3	normal	0.8 μW/VA	99	1.0	0.8
ZERA Calibration certificate	1.0	normal	50.0 μW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 μW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 μW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 μW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 μW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 μW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 μW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 μW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 μW/(VA·°)	0.07
Combined standard uncertainty, μW/VA						57.8
Expanded uncertainty (95 %, k = 2), μW/VA						115.5

PF = 0.0 Lead, 53 Hz

Discription	x_i, μW/VA	Distribution	$u(x_i)$	v_i	c_i	$u_i(y)$, μW/VA
Traveling standard repeated observations	58.3	normal	0.5 μW/VA	99	1.0	0.5
ZERA Calibration certificate	1.0	normal	50.0 μW/VA	∞	1.0	50.0
Power stability correction of ZERA	10.0	rectangular	1.0 μW/VA	∞	1.0	1.0
Effect of change of nominal frequency	0.0	normal	0.0 μW/VA	∞	1.0	0.0
Temperature drift	1.7	rectangular	0.6 μW/(VA·K)	∞	1 K	0.6
Correction of PF	0.0	rectangular	0.003°	∞	0.01 μW/(VA·°)	28.9
Temperature of traveling standard	0.0	normal	0.5 μW/VA	∞	1.0	0.5
Instability of the power source	0.0	normal	0.4 μW/VA	∞	1.0	0.4
Correction of CALMET frequency	0.0	normal	0.014 Hz	∞	1 μW/(VA·Hz)	0.01
Phase shift correction of CALMET	0.0	normal	0.07°	∞	1 μW/(VA·°)	0.07
Combined standard uncertainty, μW/VA						57.8
Expanded uncertainty (95 %, k = 2), μW/VA						115.5

NIM (China)

PF = 1.0, 50/53 Hz

Source of uncertainty	Type	Distribu-tion	Standard uncertainty, μW/VA	Sensitivity coefficient	Uncertainty contribution, μW/VA	Degrees of freedom
Voltage transfomer ratio	B	normal	2.0	1	2.0	30
Current transfomer ratio	B	normal	2.0	1	2.0	30
DC power	B	normal	3.0	1	3.0	30
Compensation from emf	B	normal	1.0	1	1.0	30
Synchronous with ac power stability	B	normal	1.3	1	1.3	10
AC/DC transfer error of power comparator	B	normal	1.0	1	1.0	30
Temperature coefficient of UUT	B	normal	2.0	1	2.0	30
Repeatability (50 Hz)	A	normal	3.4	1	3.4	10
Repeatability (53 Hz)	A	normal	3.0	1	3.0	10
Root square sum of Type A standard uncertainties (50 Hz)					3.4	10
Root square sum of Type A standard uncertainties (53 Hz)					3.0	10
Root square sum of Type B standard uncertainties					5.0	131
Combined standard uncertainty					6.0	89
Expanded uncertainty (k = 2)					12.0 μW/VA	

PF = 0.5 Lag, 50/53 Hz

Source of uncertainty	Type	Distribu-tion	Standard uncertainty, μW/VA	Sensitivity coefficient	Uncertainty contribution, μW/VA	Degrees of freedom
Voltage transfomer ratio	B	normal	2.0	1	2.0	30
Current transfomer ratio	B	normal	2.0	1	2.0	30
Voltage transfomer angle	B	normal	2.0	1	2.0	30
Current transfomer angle	B	normal	2.0	1	2.0	30
DC power	B	normal	2.0	1	2.0	30
Compensation from emf	B	normal	1.0	1	1.0	30
Synchronous with AC power stability	B	normal	1.3	1	1.3	10
AC/DC transfer error of power comparator	B	normal	1.0	1	1.0	30
Temperature coefficient of UUT	B	normal	1.0	1	1.0	30
Repeatability (50 Hz)	A	normal	2.2	1	2.2	10
Repeatability (53 Hz)	A	normal	2.5	1	2.5	10
Root square sum of Type A standard uncertainties (50 Hz)					2.2	10
Root square sum of Type A standard uncertainties (53 Hz)					2.5	10
Root square sum of Type B standard uncertainties					5.0	199
Combined standard uncertainty					6.0	138
Expanded uncertainty (k = 2)					12.0 μW/VA	

PF = 0.5 Lead, 50/53 Hz

Source of uncertainty	Type	Distribu-tion	Standard uncertainty, μW/VA	Sensitivity coefficient	Uncertainty contribution, μW/VA	Degrees of freedom
Voltage transfomer ratio	B	normal	2.0	1	2.0	30
Current transfomer ratio	B	normal	2.0	1	2.0	30
Voltage transfomer angle	B	normal	2.0	1	2.0	30
Current transfomer angle	B	normal	2.0	1	2.0	30
DC power	B	normal	2.0	1	2.0	30
Compensation from emf	B	normal	1.0	1	1.0	30
Synchronous with AC power stability	B	normal	1.3	1	1.3	10
AC/DC transfer error of power comparator	B	normal	1.0	1	1.0	30
Temperature coefficient of UUT	B	normal	1.0	1	1.0	30
Repeatability (50 Hz)	A	normal	3.1	1	3.1	10
Repeatability (53 Hz)	A	normal	3.0	1	3.0	10
Root square sum of Type A standard uncertainties (50 Hz)					3.1	10
Root square sum of Type A standard uncertainties (53 Hz)					3.0	10
Root square sum of Type B standard uncertainties					5.0	199
Combined standard uncertainty					6.0	102
Expanded uncertainty (*k* = 2)					12.0 μW/VA	

PF = 0.0 Lag, 50/53 Hz

Source of uncertainty	Type	Distribu-tion	Standard uncertainty, μW/VA	Sensitivity coefficient	Uncertainty contribution, μW/VA	Degrees of freedom
Voltage transfomer angle	B	normal	2.0	1	2.0	30
Current transfomer angle	B	normal	2.0	1	2.0	30
Compensation from emf	B	normal	1.0	1	1.0	30
Synchronous with AC power stability	B	normal	1.3	1	1.3	10
AC/DC transfer error of power comparator	B	normal	1.0	1	1.0	30
Repeatability (50 Hz)	A	normal	3.3	1	3.3	10
Repeatability (53 Hz)	A	normal	3.0	1	3.0	10
Root square sum of Type A standard uncertainties (50 Hz)					3.3	10
Root square sum of Type A standard uncertainties (53 Hz)					3.0	10
Root square sum of Type B standard uncertainties					4.0	96
Combined standard uncertainty					5.0	58
Expanded uncertainty (*k* = 2)					10.0 μW/VA	

PF = 0.0 Lead, 50/53 Hz

Source of uncertainty	Type	Distribu-tion	Standard uncertainty, μW/VA	Sensitivity coefficient	Uncertainty contribution, μW/VA	Degrees of freedom
Voltage transfomer angle	B	normal	2.0	1	2.0	30
Current transfomer angle	B	normal	2.0	1	2.0	30
Compensation from emf	B	normal	1.0	1	1.0	30
Synchronous with AC power stability	B	normal	1.3	1	1.3	10
AC/DC transfer error of power comparator	B	normal	1.0	1	1.0	30
Repeatability (50 Hz)	A	normal	3.1	1	3.1	10
Repeatability (53 Hz)	A	normal	3.0	1	3.0	10
Root square sum of Type A standard uncertainties (50 Hz)					3.1	10
Root square sum of Type A standard uncertainties (53 Hz)					3.0	10
Root square sum of Type B standard uncertainties					4.0	96
Combined standard uncertainty					5.0	58
Expanded uncertainty (k = 2)					10.0 μW/VA	

MASM (Mongolia)

PF = 1.0, 50 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	δW_x	3.0	normal	32.0	100	1.0	32.0
2	δW_{SCal}	0.0	normal	5.0	∞	-1.0	-5.0
3	δW_{Sstab}	0.0	rectangular	3.2	∞	-1.0	-3.2
4	δW_{temp}	0.0	rectangular	1.7/K	∞	μW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-μW/(V·A)/100°	-28.9
y	Combined standard uncertainty						43.6
	Expanded uncertainty (95 %, k = 2)						87.1

PF = 0.5 Lag, 50 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	δW_x	34.0	normal	47.0	100	1.0	47.0
2	δW_{SCal}	0.0	normal	25.0	∞	-1.0	-25.0
3	δW_{Sstab}	0.0	rectangular	7.0	∞	-1.0	-7.0
4	δW_{temp}	0.0	rectangular	1.7/K	∞	μW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-μW/(V·A)/100°	-28.9
y	Combined standard uncertainty						61.0
	Expanded uncertainty (95 %, k = 2)						122.0

PF = 0.5 Lead, 50 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	δW_x	-30.0	normal	43.0	100	1.0	43.0
2	δW_{SCal}	0.0	normal	10.0	∞	-1.0	-10.0
3	δW_{Sstab}	0.0	rectangular	7.0	∞	-1.0	-7.0
4	δW_{temp}	0.0	rectangular	1.7/K	∞	μW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-μW/(V·A)/100°	-28.9
y	Combined standard uncertainty						53.3
	Expanded uncertainty (95 %, k = 2)						106.5

PF = 0.0 Lag, 50 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, µW/VA	v_i	c_i	$u_i(y)$, µW/VA
1	δW_x	23.0	normal	1.1	94	1.0	1.1
2	δW_{SCal}	0.0	normal	25.0	∞	-1.0	-25.0
3	δW_{Sstab}	0.0	rectangular	17.3	∞	-1.0	-17.3
4	δW_{temp}	0.0	rectangular	1.7/K	∞	µW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-µW/(V·A)/100°	-28.9
y						Combined standard uncertainty	42.0
						Expanded uncertainty (95 %, k = 2)	84.0

PF = 0.0 Lead, 50 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, µW/VA	v_i	c_i	$u_i(y)$, µW/VA
1	δW_x	-27.0	normal	0.9	94	1.0	0.9
2	δW_{SCal}	0.0	normal	25.0	∞	-1.0	-25.0
3	δW_{Sstab}	0.0	rectangular	17.3	∞	-1.0	-17.3
4	δW_{temp}	0.0	rectangular	1.7/K	∞	µW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-µW/(V·A)/100°	-28.9
y						Combined standard uncertainty	42.0
						Expanded uncertainty (95 %, k = 2)	84.0

PF = 1.0, 53 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, µW/VA	v_i	c_i	$u_i(y)$, µW/VA
1	δW_x	1.0	normal	23.0	100	1.0	23.0
2	δW_{SCal}	0.0	normal	5.0	∞	-1.0	-5.0
3	δW_{Sstab}	0.0	rectangular	3.2	∞	-1.0	-3.2
4	δW_{temp}	0.0	rectangular	1.7/K	∞	µW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-µW/(V·A)/100°	-28.9
y						Combined standard uncertainty	37.4
						Expanded uncertainty (95 %, k = 2)	74.9

PF = 0.5 Lag, 53 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	δW_x	32.0	normal	42.0	100	1.0	42.0
2	δW_{SCal}	0.0	normal	25.0	∞	-1.0	-25.0
3	δW_{Sstab}	0.0	rectangular	7.0	∞	-1.0	-7.0
4	δW_{temp}	0.0	rectangular	1.7/K	∞	μW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-μW/(V·A)/100°	-28.9
y	Combined standard uncertainty						57.2
	Expanded uncertainty (95 %, k = 2)						114.5

PF = 0.5 Lead, 53 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	δW_x	-36.0	normal	22.0	100	1.0	22.0
2	δW_{SCal}	0.0	normal	10.0	∞	-1.0	-10
3	δW_{Sstab}	0.0	rectangular	7.0	∞	-1.0	-7.0
4	δW_{temp}	0.0	rectangular	1.7/K	∞	μW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-μW/(V·A)/100°	-28.9
y	Combined standard uncertainty						38.4
	Expanded uncertainty (95 %, k = 2)						76.7

PF = 0.0 Lag, 53 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	δW_x	27.0	normal	2.7	94	1.0	2.7
2	δW_{SCal}	0.0	normal	25	∞	-1.0	-25.0
3	δW_{Sstab}	0.0	rectangular	17.3	∞	-1.0	-17.3
4	δW_{temp}	0.0	rectangular	1.7/K	∞	μW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-μW/(V·A)/100°	-28.9
y	Combined standard uncertainty						42.1
	Expanded uncertainty (95 %, k = 2)						84.1

PF = 0.0 Lead, 53 Hz

i	Quantity (unit)	x_i	Distribution	$u(x_i)$, μW/VA	v_i	c_i	$u_i(y)$, μW/VA
1	δW_{x}	-33.0	normal	3.2	94	1.0	3.2
2	δW_{SCal}	0.0	normal	25.0	∞	-1.0	-25.0
3	$\delta W_{\mathrm{Sstab}}$	0.0	rectangular	17.3	∞	-1.0	-17.3
4	δW_{temp}	0.0	rectangular	1.7/K	∞	μW/(V·A)K	1.7
5	δW_{φ}	0.0	rectangular	0.00289°	∞	-μW/(V·A)/100°	-28.9
y						Combined standard uncertainty	42.1
						Expanded uncertainty (95 %, k = 2)	84.2

Measurement equation is:

$$\Delta W_X = W_X - (W_S + \Delta W_S) + \delta W_X - \delta W_{SCal} - \delta W_{SStab} - \delta W_{temp} - \delta W_\varphi$$

$$\frac{\Delta W_X}{W_S + \Delta W_S} \cong \left(\frac{W_X}{W_S + \Delta W_S} - 1\right)\left(1 + \frac{\delta W_X}{W_S} - \frac{\delta W_{SCal}}{W_S} - \frac{\delta W_{SStab}}{W_S} - \frac{\delta W_{temp}}{W_S} - \frac{\delta W_\varphi}{W_S}\right)$$

$$P = c \cdot f; \quad W = c \cdot N; \quad f, N = \text{frequency or number of pulses}$$

$$W_X = c_x \cdot N_X; \quad W_S + \Delta W_S = c_S \cdot N_S$$

$$\epsilon = \frac{\Delta W_X}{W_S + \Delta W_S} \cong \left(\frac{c_X \cdot N_X}{c_S \cdot N_S} - 1\right)\left(1 + \frac{\delta W_X}{W_S} - \frac{\delta W_{SCal}}{W_S} - \frac{\delta W_{SStab}}{W_S} - \frac{\delta W_{temp}}{W_S} - \frac{\delta W_\varphi}{W_S}\right)$$

The components have the following meaning:

W_x	indicated power of the DUT;
$W_s + \Delta W_s$	indicated power of the standard, corrected according to the last calibration;
ΔW_x	power difference between the DUT and the standard;
δW_x	scattering of the result;
δW_{SCal}	uncertainty of calibration of the standard;
δW_{Sstab}	uncertainty due to altering of the standard;
δW_{temp}	uncertainty due to temperature dependence of the standard (normally negligible);
δW_φ	uncertainty due to phase error of the standard (relevant only for cos φ = 0);
c_x	power to frequency constant of the DUT;
c_s	power to frequency constant of the standard;
f, N	frequency or number of pulses.

QCC EMI (United Arab Emirates)

PF = 1.0, 50/53 Hz

Uncertainty description	Uncer-tainty, µW/VA	Distribution	Divisor	Sensitivity coefficient, W/VA	Standard uncertainty, µW/VA	V_{eff}
Error repeatability	1.6	normal	1.0	1.0	1.6	24
Sampling software uncertainty	8.4	normal	2.0	1.0	4.2	∞
DVMu calibration uncertainty	3.0	normal	2.0	1.0	1.5	∞
DVMi calibration uncertainty	3.0	normal	2.0	1.0	1.5	∞
MCT calibration uncertainty (in-phase)	2.0	normal	2.0	1.0	1.0	∞
MCT stability (in-phase)	5.0	rectangular	1.7	1.0	2.9	∞
MCT calibration uncertainty (quadrature)	3.2	normal	2.0	0.0	0.0	∞
MCT stability (quadrature)	5.0	rectangular	1.7	0.0	0.0	∞
Shunt DC calibration uncertainty	1.1	normal	2.0	1.0	0.55	∞
Shunt DC stability	2.0	rectangular	1.7	1.0	1.15	∞
Shunt power coefficient	2.0	rectangular	1.7	1.0	1.15	∞
Shunt AC/DCcorr calibration uncertainty	1.0	normal	2.0	1.0	0.5	∞
Shunt AC/DCcorr stability	2.0	rectangular	1.7	1.0	1.15	∞
Shunt phase def ang corr calibration uncertainty	1.1	normal	2.0	0.0	0.0	∞
Shunt phase def ang corr stability	2.0	rectangular	1.7	0.0	0.0	∞
Uncorrected capacitive loading on the shunt	2.0	rectangular	1.7	0.0	0.0	∞
RVD ratio error uncertainty	1.4	normal	2.0	1.0	0.7	∞
RVD ratio error stability	10.0	rectangular	1.7	1.0	5.8	∞
RVD phase error uncertainty	1.4	normal	2.0	0.0	0.0	∞
RVD phase error stability	10.0	rectangular	1.7	0.0	0.0	∞
RVD change with voltage	5.0	rectangular	1.7	1.0	2.9	∞
Frequency counter uncertainty	0.001	normal	2.0	1.0	0.0005	∞
IUT stability	10.0	rectangular	1.7	1.0	5.8	∞
Combined standard uncertainty (V_{eff} = 4500)					10.7 µW/VA	
Expanded uncertainty (k = 2)					21.4 µW/VA	

PF = 0.5 Lag, 50/53 Hz

Uncertainty description	Uncer-tainty, µW/VA	Distribution	Divisor	Sensitivity coefficient, W/VA	Standard uncertainty, µW/VA	V_{eff}
Error repeatability	7.1	normal	1.0	1.0	7.09	24
Sampling software uncertainty	8.4	normal	2.0	1.0	4.2	∞
DVMu calibration uncertainty	3.0	normal	2.0	0.5	0.75	∞
DVMi calibration uncertainty	3.0	normal	2.0	0.5	0.75	∞
MCT calibration uncertainty (in-phase)	2.0	normal	2.0	0.5	0.5	∞
MCT stability (in-phase)	5.0	rectangular	1.7	0.5	1.4	∞
MCT calibration uncertainty (quadrature)	3.2	normal	2.0	0.87	1.4	∞
MCT stability (quadrature)	5.0	rectangular	1.7	0.87	2.5	∞
Shunt DC calibration uncertainty	1.1	normal	2.0	0.5	0.28	∞
Shunt DC stability	2.0	rectangular	1.7	0.5	0.58	∞
Shunt power coefficient	2.0	rectangular	1.7	0.5	0.58	∞
Shunt AC/DCcorr calibration uncertainty	1.0	normal	2.0	0.5	0.25	∞
Shunt AC/DCcorr stability	2.0	rectangular	1.7	0.5	0.58	∞
Shunt phase def ang corr calibration uncertainty	1.1	normal	2.0	0.87	0.48	∞
Shunt phase def ang corr stability	2.0	rectangular	1.7	0.87	1.0	∞
Uncorrected capacitive loading on the shunt	2.0	rectangular	1.7	0.87	1.0	∞
RVD ratio error uncertainty	1.4	normal	2.0	0.5	0.35	∞
RVD ratio error stability	10.0	rectangular	1.7	0.5	2.89	∞
RVD phase error uncertainty	1.4	normal	2.0	0.87	0.61	∞
RVD phase error stability	10.0	rectangular	1.7	0.87	5.0	∞
RVD change with voltage	5.0	rectangular	1.7	0.5	1.4	∞
Frequency counter uncertainty	0.001	normal	2.0	1.0	0.0005	∞
IUT stability	10.0	rectangular	1.7	1.0	5.78	∞
Combined standard uncertainty (V_{eff} = 220)					12.3 µW/VA	
Expanded uncertainty (k = 2)					24.8 µW/VA	

PF = 0.5 Lead, 50/53 Hz

Uncertainty description	Uncer-tainty, µW/VA	Distribution	Divisor	Sensitivity coefficient, W/VA	Standard uncertainty, µW/VA	V_{eff}
Error repeatability	6.5	normal	1.0	1.0	6.5	24
Sampling software uncertainty	8.4	normal	2.0	1.0	4.2	∞
DVMu calibration uncertainty	3.0	normal	2.0	0.5	0.75	∞
DVMi calibration uncertainty	3.0	normal	2.0	0.5	0.75	∞
MCT calibration uncertainty (in-phase)	2.0	normal	2.0	0.5	0.5	∞
MCT stability (in-phase)	5.0	rectangular	1.7	0.5	1.4	∞
MCT calibration uncertainty (quadrature)	3.2	normal	2.0	0.87	1.39	∞
MCT stability (quadrature)	5.0	rectangular	1.7	0.87	2.5	∞
Shunt DC calibration uncertainty	1.1	normal	2.0	0.5	0.28	∞
Shunt DC stability	2.0	rectangular	1.7	0.5	0.58	∞
Shunt power coefficient	2.0	rectangular	1.7	0.5	0.58	∞
Shunt AC/DCcorr calibration uncertainty	1.0	normal	2.0	0.5	0.25	∞
Shunt AC/DCcorr stability	2.0	rectangular	1.7	0.5	0.58	∞
Shunt phase def ang corr calibration uncertainty	1.1	normal	2.0	0.87	0.48	∞
Shunt phase def ang corr stability	2.0	rectangular	1.7	0.87	1.0	∞
Uncorrected capacitive loading on the shunt	2.0	rectangular	1.7	0.87	1.0	∞
RVD ratio error uncertainty	1.4	normal	2.0	0.5	0.35	∞
RVD ratio error stability	10.0	rectangular	1.7	0.5	2.89	∞
RVD phase error uncertainty	1.4	normal	2.0	0.87	0.61	∞
RVD phase error stability	10.0	rectangular	1.7	0.87	5.0	∞
RVD change with voltage	5.0	rectangular	1.7	0.5	1.4	∞
Frequency counter uncertainty	0.001	normal	2.0	1.0	0.0005	∞
IUT stability	10.0	rectangular	1.7	1.0	5.77	∞
Combined standard uncertainty (V_{eff} = 270)					12.0 µW/VA	
Expanded uncertainty (k = 2)					24.2 µW/VA	

PF = 0.0 Lag, 50/53 Hz

Uncertainty description	Uncer-tainty, µW/VA	Distribution	Divisor	Sensitivity coefficient, W/VA	Standard uncertainty, µW/VA	V_{eff}
Error repeatability	0.69	normal	1.0	1.0	0.69	24
Sampling software uncertainty	8.4	normal	2.0	1.0	4.2	∞
DVMu calibration uncertainty	3.0	normal	2.0	0.001	0.001	∞
DVMi calibration uncertainty	3.0	normal	2.0	0.001	0.001	∞
MCT calibration uncertainty (in-phase)	2.0	normal	2.0	0.001	0.001	∞
MCT stability (in-phase)	5.0	rectangular	1.7	0.001	0.0025	∞
MCT calibration uncertainty (quadrature)	3.2	normal	2.0	1.0	1.6	∞
MCT stability (quadrature)	5.0	rectangular	1.7	1.0	2.89	∞
Shunt DC calibration uncertainty	1.1	normal	2.0	0.001	0.001	∞
Shunt DC stability	2.0	rectangular	1.7	0.001	0.001	∞
Shunt power coefficient	2.0	rectangular	1.7	0.001	0.001	∞
Shunt AC/DCcorr calibration uncertainty	1.0	normal	2.0	0.001	0.0004	∞
Shunt AC/DCcorr stability	2.0	rectangular	1.7	0.001	0.001	∞
Shunt phase def ang corr calibration uncertainty	1.1	normal	2.0	1.0	0.55	∞
Shunt phase def ang corr stability	2.0	rectangular	1.7	1.0	1.15	∞
Uncorrected capacitive loading on the shunt	2.0	rectangular	1.7	1.0	1.15	∞
RVD ratio error uncertainty	1.4	normal	2.0	0.001	0.0006	∞
RVD ratio error stability	10.0	rectangular	1.7	0.001	0.005	∞
RVD phase error uncertainty	1.4	normal	2.0	1.0	0.7	∞
RVD phase error stability	10.0	rectangular	1.7	1.0	5.78	∞
RVD change with voltage	5.0	rectangular	1.7	0.001	0.0025	∞
Frequency counter uncertainty	0.001	normal	2.0	1.0	0.0005	∞
IUT stability	10.0	rectangular	1.7	1.0	5.77	∞
Combined standard uncertainty (V_{eff} = 106000)					9.96 µW/VA	
Expanded uncertainty (k = 2)					20.0 µW/VA	

PF = 0.0 Lead, 50/53 Hz

Uncertainty description	Uncer-tainty, μW/VA	Distribution	Divisor	Sensitivity coefficient, W/VA	Standard uncertainty, μW/VA	V_{eff}
Error repeatability	1.4	normal	1.0	1.0	1.38	24
Sampling software uncertainty	8.4	normal	2.0	1.0	4.2	∞
DVMu calibration uncertainty	3.0	normal	2.0	0.001	0.001	∞
DVMi calibration uncertainty	3.0	normal	2.0	0.001	0.001	∞
MCT calibration uncertainty (in-phase)	2.0	normal	2.0	0.001	0.001	∞
MCT stability (in-phase)	5.0	rectangular	1.7	0.001	0.0025	∞
MCT calibration uncertainty (quadrature)	3.2	normal	2.0	1.0	1.6	∞
MCT stability (quadrature)	5.0	rectangular	1.7	1.0	2.89	∞
Shunt DC calibration uncertainty	1.1	normal	2.0	0.001	0.001	∞
Shunt DC stability	2.0	rectangular	1.7	0.001	0.001	∞
Shunt power coefficient	2.0	rectangular	1.7	0.001	0.001	∞
Shunt AC/DCcorr calibration uncertainty	1.0	normal	2.0	0.001	0.0004	∞
Shunt AC/DCcorr stability	2.0	rectangular	1.7	0.001	0.001	∞
Shunt phase def ang corr calibration uncertainty	1.1	normal	2.0	1.0	0.55	∞
Shunt phase def ang corr stability	2.0	rectangular	1.7	1.0	1.15	∞
Uncorrected capacitive loading on the shunt	2.0	rectangular	1.7	1.0	1.15	∞
RVD ratio error uncertainty	1.4	normal	2.0	0.001	0.0006	∞
RVD ratio error stability	10.0	rectangular	1.7	0.001	0.005	∞
RVD phase error uncertainty	1.4	normal	2.0	1.0	0.7	∞
RVD phase error stability	10.0	rectangular	1.7	1.0	5.77	∞
RVD change with voltage	5.0	rectangular	1.7	0.001	0.0025	∞
Frequency counter uncertainty	0.001	normal	2.0	1.0	0.001	∞
IUT stability	10.0	rectangular	1.7	1.0	5.77	∞
Combined standard uncertainty (V_{eff} = 66500)					10.03 μW/VA	
Expanded uncertainty (k = 2)					20.1 μW/VA	

Active power:

$$C_{IUT} = M_{IUT} + \cos(\phi) \times [a_{DVM\_u} + b_{DVM\_i} + a_{Etalon} + b_{Etalon} - a_{RVD} - b_{MCT} - b_{SH\_dc} + b_{SH\_ac-dc} + C_{IND\_iut}]$$
$$+ \sin(\phi) \times [-\beta_{SH} - \alpha_{RVD} + \beta_{MCT}]$$

Reactive power:

$$C_{IUT} = M_{IUT} - \sin(\phi) \times [a_{DVM\_u} + b_{DVM\_i} + a_{Etalon} + b_{Etalon} - a_{RVD} - b_{MCT} - b_{SH\_dc} + b_{SH\_ac-dc} + C_{IND\_iut}]$$
$$- \cos(\phi) \times [-\beta_{SH} - \alpha_{RVD} + \beta_{MCT}]$$

where:

M_{IUT} is the measured correction for the IUT;

ϕ is the phase angle between current and voltage (which determines directly the power factor);

a_{DVM_u} is the correction for Master DVM;

b_{DVM_i} is the correction for the Slave DVM;

a_{Etalon} is the AC-DC voltage correction for the sampling system;

b_{Etalon} is the AC-DC current correction for the sampling system;

a_{RVD} is the ratio error of the RVD;

b_{MCT} is the ratio error of the MCT;

b_{SH_dc} is the DC error of the MCT shunt (suparesistor);

b_{SH_ac-dc} is the shunt AC-DC difference correction;

C_{IND_iut} is the correction for the indicator (Counter) used with the IUT;

β_{SH} is the phase or quadrature error of the shunt, also referred to as phase defect angle;

α_{RVD} is the phase error of the RVD;

β_{MCT} is the phase error of the MCT.

SASO-NMCC (Saudi Arabia)

PF=1.0, 50/53 Hz

Source of Uncertainty	Standard uncertainty (µW/VA)	Probability distribution	Sensitivity coefficient	Uncertainty contribution, µW/VA
Voltage measurement	10.0	Normal	1.0	10.0
Current measurement	16.0	Normal	1.0	16.0
Phase measurement	20.0	Normal	0.0	0.0
Measurement set up	2.0	Rectangular	1.0	2.0
Standard uncertainty of measurement	4.0	Normal	1.0	4.0
			Combined standard uncertainty	19.0
			Expanded uncertainty (k = 2)	39.0

PF=0.5, 50/53 Hz

Source of Uncertainty	Standard uncertainty (µW/VA)	Probability distribution	Sensitivity coefficient	Uncertainty contribution, µW/VA
Voltage measurement	10.0	Normal	0.5	5.0
Current measurement	16.0	Normal	0.5	8.0
Phase measurement	20.0	Normal	0.87	17.0
Measurement set up	2.0	Rectangular	1.0	2.0
Standard uncertainty of measurement	4.0	Normal	1.0	4.0
			Combined standard uncertainty	20.0
			Expanded uncertainty (k = 2)	40.0

PF=0.0, 50/53 Hz

Source of Uncertainty	Standard uncertainty (µW/VA)	Probability distribution	Sensitivity coefficient	Uncertainty contribution, µW/VA
Voltage measurement	10.0	Normal	0.0	0.0
Current measurement	16.0	Normal	0.0	0.0
Phase measurement	20.0	Normal	1.0	20.0
Measurement set up	2.0	Rectangular	1.0	2.0
Standard uncertainty of measurement	4.0	Normal	1.0	4.0
			Combined standard uncertainty	21.0
			Expanded uncertainty (k = 2)	41.0

NIS (Egypt)

PF = 1.0, 50 Hz

Main uncertainty components, *y*	Standard uncertainty, μW/VA	Type A or B of evaluation/distribution function	Sensitivity coefficient, C_i	Uncertainty contribution, μW/VA	Degree of freedom
Readings repeatability of the calibration system	1.1	A, normal	1	1.1	9
Standard calibration uncertainty of NIS	15.0	B, normal	1	15.0	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	0.4	B, rectangular	1	0.4	∞
Effect of change in the applied frequency (50/53) Hz	0.2	B, rectangular	1	0.2	∞
Temperature coefficient of traveling standard	1.8E-5	B, rectangular	1	1.8E-05	∞
Effect of "short term stability" of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				1.1	9
Root square sum of type B standard uncertainties				17.9	∞
Combined standard uncertainty				17.9	3E+05
Expanded uncertainty (95 %, $k = 2$)				35.8	
Active power error				-7.8	

PF = 0.5 Lag, 50 Hz

Main uncertainty components, *y*	Standard uncertainty, μW/VA	Type A or B of evaluation/distribution function	Sensitivity coefficient, C_i	Uncertainty contribution, μW/VA	Degree of freedom
Readings repeatability of the calibration system	2.3	A, normal	1	2.3	9
Standard calibration uncertainty of NIS	15.0	B, normal	1	15.0	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	0.6	B, rectangular	1	0.6	∞
Effect of change in the applied frequency (50/53) Hz	14.3	B, rectangular	1	14.3	∞
Temperature coefficient of traveling standard	3.7E-5	B, rectangular	1	3.7E-05	∞
Effect of "short term stability" of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				2.3	9
Root square sum of type B standard uncertainties				23	∞
Combined standard uncertainty				23.1	6E+04
Expanded uncertainty (95 %, $k = 2$)				46.2	
Active power error				15.8	

PF = 0.5 Lead, 50 Hz

Main uncertainty components, y	Standard uncertainty, µW/VA	Type A or B of evaluation/distribution function	Sensitivity coefficient, C_i	Uncertainty contribution, µW/VA	Degree of freedom
Readings repeatability of the calibration system	2.6	A, normal	1	2.6	9
Standard calibration uncertainty of NIS	15	B, normal	1	15	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	0.2	B, rectangular	1	0.2	∞
Effect of change in the applied frequency (50/53) Hz	-8.8	B, rectangular	1	-8.8	∞
Temperature coefficient of traveling standard	5E-5	B, rectangular	1	5E-05	∞
Effect of “short term stability” of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				2.6	9
Root square sum of type B standard uncertainties				20	∞
Combined standard uncertainty				20.2	2E+04
Expanded uncertainty (95 %, k = 2)				40.4	
Active power error				21.2	

PF = 0.0 Lag, 50 Hz

Main uncertainty components, y	Standard uncertainty, µW/VA	Type A or B of evaluation/distribution function	Sensitivity coefficient, C_i	Uncertainty contribution, µW/VA	Degree of freedom
Readings repeatability of the calibration system	6.0	A, normal	1	4.4	9
Standard calibration uncertainty of NIS	15.0	B, normal	1	15.0	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	1.0	B, rectangular	1	1.0	∞
Effect of change in the applied frequency (50/53) Hz	-3.2	B, rectangular	1	-3.2	∞
Temperature coefficient of traveling standard	1E-4	B, rectangular	1	1E-04	∞
Effect of “short term stability” of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				6.0	9
Root square sum of type B standard uncertainties				18.7	∞
Combined standard uncertainty				19.6	2E+03
Expanded uncertainty (95 %, k = 2)				39.2	
Active power error				-25.8	

PF = 0.0 Lead, 50 Hz

Main uncertainty components, *y*	Standard uncertainty, µW/VA	Type A or B of evaluation/distri-bution function	Sensitivity coefficient, C_i	Uncertainty contribution, µW/VA	Degree of freedom
Readings repeatability of the calibration system	3.6	A, normal	1	3.6	9
Standard calibration uncertainty of NIS	15.0	B, normal	1	15.0	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	1.0	B, rectangular	1	1.0	∞
Effect of change in the ap-plied frequency (50/53) Hz	-1.2	B, rectangular	1	-1.2	∞
Temperature coefficient of traveling standard	5.4E-5	B, rectangular	1	5.4E-05	∞
Effect of “short term stability” of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				3.6	9
Root square sum of type B standard uncertainties				18.2	∞
Combined standard uncertainty				18.6	3E+03
Expanded uncertainty (95 %, *k* = 2)				37.2	
Active power error				-25.5	

PF = 1.0, 53 Hz

Main uncertainty components, *y*	Standard uncertainty, µW/VA	Type A or B of evaluation/distri-bution function	Sensitivity coefficient, C_i	Uncertainty contribution, µW/VA	Degree of freedom
Readings repeatability of the calibration system	1.1	A, normal	1	1.1	9
Standard calibration uncertainty of NIS	15.0	B, normal	1	15.0	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	0.4	B, rectangular	1	0.4	∞
Temperature coefficient of traveling standard	1.8E-5	B, rectangular	1	1.8E-05	∞
Effect of “short term stability” of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				1.1	9
Root square sum of type B standard uncertainties				17.8	∞
Combined standard uncertainty				17.9	3E+05
Expanded uncertainty (95 %, *k* = 2)				35.8	
Active power error				-7.6	

PF = 0.5 Lag, 53 Hz

Main uncertainty components, *y*	Standard uncertainty, μW/VA	Type A or B of evaluation/distribution function	Sensitivity coefficient, C_i	Uncertainty contribution, μW/VA	Degree of freedom
Readings repeatability of the calibration system	2.0	A, normal	1	2.0	9
Standard calibration uncertainty of NIS	15.0	B, normal	1	15.0	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	0.6	B, rectangular	1	0.6	∞
Temperature coefficient of traveling standard	7E-5	B, rectangular	1	7E-05	∞
Effect of “short term stability” of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				2.0	9
Root square sum of type B standard uncertainties				17.9	∞
Combined standard uncertainty				18.0	3E+04
Expanded uncertainty (95 %, $k = 2$)				36.1	
Active power error				30.1	

PF = 0.5 Lead, 53 Hz

Main uncertainty components, *y*	Standard uncertainty, μW/VA	Type A or B of evaluation/distribution function	Sensitivity coefficient, C_i	Uncertainty contribution, μW/VA	Degree of freedom
Readings repeatability of the calibration system	3.6	A, normal	1	3.6	9
Standard calibration uncertainty of NIS	15.0	B, normal	1	15.0	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	0.2	B, rectangular	1	0.2	∞
Temperature coefficient of traveling standard	3E-5	B, rectangular	1	3E-05	∞
Effect of “short term stability” of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				3.6	9
Root square sum of type B standard uncertainties				18.2	∞
Combined standard uncertainty				18.5	3E+03
Expanded uncertainty (95 %, $k = 2$)				37.1	
Active power error				12.4	

PF = 0.0 Lag, 53 Hz

Main uncertainty components, *y*	Standard uncertainty, µW/VA	Type A or B of evaluation/distri-bution function	Sensitivity coefficient, C_i	Uncertainty contribution, µW/VA	Degree of freedom
Readings repeatability of the calibration system	6.7	A, normal	1	6.7	9
Standard calibration uncertainty of NIS	15	B, normal	1	15	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	1.0	B, rectangular	1	1.0	∞
Temperature coefficient of traveling standard	9.3E-5	B, rectangular	1	9.3E-05	∞
Effect of "short term stability" of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				6.7	9
Root square sum of type B standard uncertainties				19.1	∞
Combined standard uncertainty				20.2	3E+02
Expanded uncertainty (95 %, *k* = 2)				40.4	
Active power error				-24.7	

PF = 0.0 Lead, 53 Hz

Main uncertainty components, *y*	Standard uncertainty, µW/VA	Type A or B of evaluation/distri-bution function	Sensitivity coefficient, C_i	Uncertainty contribution, µW/VA	Degree of freedom
Readings repeatability of the calibration system	7.7	A, normal	1	4.8	9
Standard calibration uncertainty of NIS	15.0	B, normal	1	15.0	∞
Resolution of the calibration system display	0.3	B, rectangular	1	0.3	∞
Drift of NIS standard since last calibration	1.0	B, rectangular	1	1.0	∞
Temperature coefficient of traveling standard	5.2E-5	B, rectangular	1	5.2E-05	∞
Effect of "short term stability" of the applied power	9.6	B, rectangular	1	9.6	∞
Root square sum of type A standard uncertainties				4.8	9
Root square sum of type B standard uncertainties				18.5	∞
Combined standard uncertainty				19.1	1E+03
Expanded uncertainty (95 %, *k* = 2)				38.2	
Active power error				-30.7	

UMTS (Ukraine)

PF = 1.0, 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	1.4	0.5	99	1	0.5
2	Standard deviation of the mean of electric power reproduction	normal	0.1	1.5	99	1	1.5
3	Corrections due to the phase measurement	normal	0.0	1.9	∞	1	1.9
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	1	1.5
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	3.2	∞	1	3.2
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	2.5	∞	1	2.5
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							1.8
y	Combined standard uncertainty, µW/VA						9.2
	Expanded uncertainty (95 %, k = 2), µW/VA						18.5

PF = 0.5 Lag, 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	2.0	2.0	99	1	2.0
2	Standard deviation of the mean of electric power reproduction	normal	0.1	3.0	99	1	3.0
3	Corrections due to the phase measurement	normal	0.1	7.0	∞	0.87	6.1
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	1	1.5
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	6.0	∞	1	6.0
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	5.0	∞	1	5.0
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							2.5
y	Combined standard uncertainty, µW/VA						13.2
	Expanded uncertainty (95 %, k = 2), µW/VA						26.4

PF = 0.5 Lead, 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	-4.8	2.5	99	1	2.5
2	Standard deviation of the mean of electric power reproduction	normal	0.1	3.0	99	1	3.0
3	Corrections due to the phase measurement	normal	0.1	7.0	∞	0.87	6.1
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	1	1.5
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	6.0	∞	1	6.0
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	5.0	∞	1	5.0
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							-4.3
y	Combined standard uncertainty, μW/VA						13.3
	Expanded uncertainty (95 %, k = 2), μW/VA						26.5

PF = 0.0 Lag, 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	3.2	3.2	99	1	3.2
2	Standard deviation of the mean of electric power reproduction	normal	0.1	3.0	99	1	3.0
3	Corrections due to the phase measurement	normal	0.1	7.0	∞	0	0.0
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	1	1.5
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	6.0	∞	1	6.0
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	5.0	∞	1	5.0
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							3.7
$\boldsymbol{y}$	Combined standard uncertainty, μW/VA						12.0
	Expanded uncertainty (95 %, k = 2), μW/VA						23.9

PF = 0.0 Lead, 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	-4.4	4.1	99	1	4.1
2	Standard deviation of the mean of electric power reproduction	normal	0.1	3.0	99	1	3.0
3	Corrections due to the phase measurement	normal	0.1	7.0	∞	0	0.0
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	1	1.5
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	6.0	∞	1	6.0
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	5.0	∞	1	5.0
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							-3.9
y	Combined standard uncertainty, µW/VA						12.2
	Expanded uncertainty (95 %, k = 2), µW/VA						24.5

PF = 1.0, 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	0.6	0.5	99	1	0.5
2	Standard deviation of the mean of electric power reproduction	normal	0.1	1.5	99	1	1.5
3	Corrections due to the phase measurement	normal	0.0	0.0	∞	1	0.0
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	1	1.5
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	3.2	∞	1	3.2
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	2.5	∞	1	2.5
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							1.0
y	Combined standard uncertainty, μW/VA						9.0
	Expanded uncertainty (95 %, k = 2), μW/VA						18.1

PF = 0.5 Lag, 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	3.8	2.3	99	1	2.3
2	Standard deviation of the mean of electric power reproduction	normal	0.1	3.0	99	1	3.0
3	Corrections due to the phase measurement	normal	0.1	7.0	∞	0.87	6.1
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	0.001	0.0
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	6.0	∞	1	6.0
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	5.0	∞	1	5.0
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							4.3
$\boldsymbol{y}$	Combined standard uncertainty, µW/VA						13.2
	Expanded uncertainty (95 %, k = 2), µW/VA						26.3

PF = 0.5 Lead, 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	-4.9	2.6	99	1	2.6
2	Standard deviation of the mean of electric power reproduction	normal	0.1	3.0	99	1	3.0
3	Corrections due to the phase measurement	normal	0.1	7.0	∞	0.87	6.1
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	0	0.0
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	6.0	∞	1	6.0
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	5.0	∞	1	5.0
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							-4.4
y	Combined standard uncertainty, µW/VA						13.2
	Expanded uncertainty (95 %, k = 2), µW/VA						26.4

PF = 0.0 Lag, 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	2.8	3.3	99	1	3.3
2	Standard deviation of the mean of electric power reproduction	normal	0.1	3.0	99	1	3.0
3	Corrections due to the phase measurement	normal	0.1	7.0	∞	0.001	0.0
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	0.001	0.0
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	6.0	∞	1	6.0
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	5.0	∞	1	5.0
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							3.3
$\boldsymbol{y}$	Combined standard uncertainty, µW/VA						11.9
	Expanded uncertainty (95 %, k = 2), µW/VA						23.8

PF = 0.0 Lead, 53 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1	Mean value of the observation of the differences between the travelling standard and the reference value	normal	-4.4	4.0	99	1	4.0
2	Standard deviation of the mean of electric power reproduction	normal	0.1	3.0	99	1	3.0
3	Corrections due to the phase measurement	normal	0.1	7.0	∞	0.001	0.0
4	Corrections due to the frequency measurement	rectangular	0.0	1.5	∞	0.001	0.0
5	Corrections due to the drift of temperature measurements	normal	0.0	0.5	∞	1	0.5
6	Corrections due to the AC current measurements	normal	0.1	6.0	∞	1	6.0
7	Corrections due to the AC voltage amplitude measurements	normal	0.1	5.0	∞	1	5.0
8	Corrections due to the thermal converter AC-DC difference (current channel)	normal	0.1	5.0	∞	1	5.0
9	Corrections due to the thermal converter AC-DC difference (voltage channel)	normal	0.0	5.0	∞	1	5.0
10	Corrections due to the influence of temperature coefficient on travelling standard (voltage)	normal	0.0	0.8	∞	1	0.8
11	Corrections due to the influence of temperature coefficient on travelling standard (direct AC current)	normal	0.0	1.5	∞	1	1.5
12	Corrections due to the influence of temperature coefficient on travelling standard (power)	normal	0.0	2.5	∞	1	2.5
13	Corrections due to the influence of temperature coefficient on travelling standard (phase angle)	normal	0.0	0.1	∞	1	0.1
14	Corrections due to the influence of temperature coefficient on travelling standard (frequency)	normal	0.0	0.1	∞	1	0.1
15	Short term stability	normal	0.0	0.5	∞	1	0.5
16	Long term stability (for the one operation year)	normal	0.0	1.0	∞	1	1.0
X_i							-3.9
$\boldsymbol{y}$	Combined standard uncertainty, µW/VA						12.1
	Expanded uncertainty (95 %, k = 2), µW/VA						24.2

Measurement equation is:

$$P_x = P_0 + \delta P_r + \delta P_{CPM} + \delta P_{CFM} + \delta P_{CDTM} + \delta P_{CACCM} + \delta P_{CACVAM} + \delta P_{CACDCI} +$$
$$+\delta P_{CACDCU} + \delta P_{CTCU} + \delta P_{CTCI} + \delta P_{CTCP} + \delta P_{CTCPA} + \delta P_{CTCF} + \delta P_{STS} + \delta P_{LTS}.$$

where:

P_0 – mean value of the observation of the differences between the travelling standard and the reference value;

δP_r – standard deviation of the mean of electric power reproduction;

δP_{CPM} – corrections due to the phase measurement;

δP_{CFM} – corrections due to the frequency measurement;

δP_{CDTM} – corrections due to the drift of temperature measurements;

δP_{CACCM} – corrections due to the AC current measurements;

δP_{CACVAM} – corrections due to the AC voltage amplitude measurements;

δP_{CACDCI} – corrections due to the thermal converter AC-DC difference (current channel);

δP_{CACDCU} – corrections due to the thermal converter AC-DC difference (voltage channel);

δP_{CTCU} – corrections due to the influence of temperature coefficient on travelling standard (voltage);

δP_{CTCI} – corrections due to the influence of temperature coefficient on travelling standard (direct AC current);

δP_{CTCP} – corrections due to the influence of temperature coefficient on travelling standard (power);

δP_{CTCPA} – corrections due to the influence of temperature coefficient on travelling standard (phase angle);

δP_{CTCF} – corrections due to the influence of temperature coefficient on travelling standard (frequency);

δP_{STS} – short term stability;

δP_{LTS} – long term stability (for the one operation year).

Appendix 3

Technical protocol of comparison

TECHNICAL PROTOCOL on COOMET 695/UA/16 Key Comparison of Power (COOMET.EM-K5)

(Edition 1)

O. Velychko, S. Karpenko

Pilot laboratory: SE "Ukrmetrteststandard"
4, Metrologichna Str., 03143, Kyiv, Ukraine
E-mail: velychko@ukrcsm.kiev.ua

Coordinator of comparison:

__________________ O. Velychko

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Kyiv, Ukraine

Table of Content

1 Introduction

To support the Calibration and Measurement Capabilities (CMCs) declared by members of COOMET in the framework of the CIPM-MRA, SE "Ukrmetrteststandard" (UMTS) is going to organize COOMET key comparison of the unit of electric power for electrical standards of low-frequency 50/60 Hz power. Electrical standards of low-frequency 50/60 Hz power will be compared at 7 National Metrology Institutes (NMIs) from COOMET and EURAMET to establish the relationship between the electrical units of AC power at these laboratories.

COOMET.EM-K5 key comparison will be linked to CCEM-K5 Key comparison.

UMTS is proposed to be the pilot laboratory, which would be responsible for providing the travelling standard, coordinating the schedule, collecting and analyzing the comparison data, and preparing the draft report.

NIM and VNIIM proposed to be the linking NMIs for the linking process between CCEM-K5 key comparison and the COOMET.EM-K5 key comparison. Relevance of the comparison results are expected at the level of better than 0.005%.

The results of this comparison will be described. The differences between almost all laboratory's values and the reference values will be within the expanded measurement uncertainties at a coverage factor $k = 2$ [1].

2 Participants and time schedule of the comparison

Each participant is given 2 weeks to perform the measurements of electrical standard of low-frequency (50/60 Hz) power and 1 week to transfer the meter to the coordination laboratory. The participants and the time schedule of the comparison are given in Table 1 and Table 2. There are 10 participants in this comparison. Participants should have the traveling standard delivered to the address of the participant scheduled to perform measurements after themselves according to the schedule.

Table 1 List of participants of the comparison

№	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., 03143, Kyiv, Ukraine	O. Velychko	velychko@ukrcsm.kiev.ua Tel./Fax: +38 044 526 0335
2	National Institute of Metrology	NIM	No. 18, Bei San Huan Dong Rd., 100013, Beijing, China	W. Lei	wl@nim.ac.cn Tel.: +86 10 6452 4531 Fax: +86 10 6421 8629
3	D.I. Mendeleyev institute for Metrology	VNIIM	Moskovsky pr., 19, St. Petersburg, 190005, Russia	G. Gubler	g.b.gubler@vniim.ru Tel.:+7 812 251 7444

№	NMI	Abbreviation of NMI	Address	Contact person	e-mail, phone, fax
4	TÜBITAK Ulusal Metroloji Enstitüsü	UME	TÜBİTAK Gebze Yerleskesi Baris Mah., Dr. Zeki Acar Cad. No. 1 41470, Gebze Kocaeli, Turkey	H. Çayci	huseyin.cayci@tubitak.gov.tr Tel.: +90 262 679 5000
5	Slovensky Metrologicky Ustav	SMU	63, Karloveská Str., 84104 Bratislava, Slovakia	J. Slučiak	sluciak@smu.gov.sk Tel.: +602 94235
6	Belarussian State Institute of Metrology	BelGIM	93, Starovilen-sky Ave, 220053, Minsk, Belarus	E. Kazakova	yarmolovich@belgim.by Tel.: +375 17 223-15-10
8	Kazakhstan Institute of Metrology	KazInMetr	11, Orynbor Str., 010000, Astana, Kazakhstan	N. Mynbaev	mynbaev-n@mail.ru Tel.: 8 702 00 00 667
7	Georgian National Agency for Standards and Metrology	GEOSTM	67 Chargali Str., 0178, Tbilisi, Georgia	N. Mika-nadze, M. Gelovani	nino_mikanadze@yahoo.com elmetrology@gmail.com Tel.: +995 32 261 77 57

Table 2 The list of dates of measurements

Abbreviation of NMI	Dates of measurements	Dates of delivery
UMTS	05–09.09.2016	12.09.2016
BelGIM	19–30.09.2016	03.10.2016
UMTS	10.10–02.12.2016	05.12.2016
UME	30.01–10.02.2017	13.02.2017
UMTS	20–24.02.2017	27.02.2017
GeoSTM	10–21.04.2017	24.04.2017
UMTS	01– 05.05.2017	08.05.2017
VNIIM	22.05–02.06.2017	05.06.2017
UMTS	19–23.06.2017	26.06.2017
SMU	17–28.07.2017	31.07.2017

Abbreviation of NMI	Dates of measurements	Dates of delivery
UMTS	07–18.09.2017	21.09.2017
NIM	09–20.10.2017	23.10.2017
UMTS	30.10.–10.11.2017	13.11.2017
KazInMetr	20.11.–01.12.2017	04.12.2017
UMTS	11.12.–22.12.2017	

3. Financial aspects and insurance

Each laboratory participating in the comparisons should be at their own expense to perform all the measurements and send travelling standard back to the pilot laboratory (including transportation costs, insurance costs and customs).

In addition, each laboratory participating in the comparisons should be at their own expense to cover all costs from the moment of arrival travelling standard in the country, up to the moment of sending back to the pilot laboratory.

Expenses may include (but are not limited to): charges at check travelling standard (customs fees, brokerage services, transportation within the country) and the costs of returning the standard pilot laboratory.

The appraised cost of selected travelling standard is Radian Research RD-33-332 (serial number 301308) is 20,000 Euro.

4. Travelling standard and measurement instruction

4.1. Description of the travelling standard

Selected travelling standard is Radian Research RD-33-332 (serial number 301308). The RD-33-332 has a guaranteed accuracy of 0.01%.

Appearance of RD-33-332 is shown on Figure 1.

Figure 1 Travelling standard RD-33-332

Travelling standard RD-33-332 is three-phase electric power meter, works on principles of digital processing of electrical current and voltage signals.

Main characteristics of travelling standard RD-33-332:
input voltage: 30…525 V (RMS);
input current: 0,2…120 A (RMS);
frequency of the input voltage and current signals: 45…65 Hz;
constant of the frequency output: 125 000 000 pulse/kWh;
supply voltage: 60…525 V (RMS);
working range of the temperature: –20 °C…40 °C;
keeping range of the temperature: –25 °C...80 °C;
working range of the humidity: 0...95%;
dimensions: 444.5×172×131 mm;
weight: 6.21 kg.

Terminal block of the travelling standard RD-33-332 is shown on Figure 2.

Figure 2 Terminal block of travelling standard RD-33-332

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

Specification of equipment that will be sent to participants on Key Comparison (KC) of Power COOMET 695/UA/16 (COOMET.EM-K5) is shown in Table 3.

Table 3 The specification of equipment that will be sent to participants on KC of Power

No.	Name of equipment	Quantity
1	Selected travelling standard is Radian Research RD-33-332 (serial number 301308, inventory number 59836) (Figure 1)	1 piece
2	Power cable (Figure 3)	1 piece
3	Current cable (Figure 4)	2 pieces
4	Voltage cable (Figure 5)	2 pieces
5	Pulse cable (Figure 6)	1 piece
6	Clamping nuts for connection current cables of travelling standard RD-33-332 (Figure 7)	6 pieces
7	Container of travelling standard RD-33-332 (Figure 8)	1 piece

Figure 3 Power cable of travelling standard RD-33-332

Figure 4 Current cables for connection travelling standard RD-33-332

Figure 5 Voltage cables for connection travelling standard RD-33-332

Figure 6 Pulse cable for connection travelling standard RD-33-332

Figure 7 Clamping nuts for connection current cables of travelling standard RD-33-332

Also to each of partisipant will be send “Operations Manual RD-33 Portatable Three-phase Electricity Standard” and Contract.

4.2 Unpacking and packing

Travelling standard will be transported in a container, which is designed for safe transportation of the standard Figure 8.

Figure 8 Container of travelling standard RD-33-332

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: 600 mm x 450 mm x 290 mm. The weight of container (with the content) is about 15 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 RD-33-332 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 RD-33-332 is strictly prohibited. If some defects of travelling standard are found, the participating laboratory should have immediately informed 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 9 [2].

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

Figure 9 Sample form for the information of arrival of travelling standard RD-33-332

The participating laboratory should inform the pilot laboratory about departure of travelling standard by using the form shown on Figure 10 [2].

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

Figure 10 Sample form for the information of departure of travelling standard RD-33-332

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.

5. Description of the method of measurement

5.1 Operations before measurements

The RD-33-332 measurement principle is based upon the fundamentals of a high-speed charge-balance integrating analog to digital signal converter.

The RD-33-332 Dytronic utilizes two separate A/D converters. One accepts a current signal and is linked with two current references. The other accepts a voltage signal and is linked with two voltage references. These of course are for the analog voltage and current inputs of the RD-33-332. Both operate independently to provide the digital signal processor with signals accurate enough to meet the requirements of a true portable electricity standard. Gain error, charge timer resolution, signal to noise ratio and signal distortion were major areas dealt with and improved in development

Before the measurements, it is necessary to familiarize design features and work principles of travelling standard by using technical description (user manual) of RD-33-332. Connection travelling standard in accordance with the scheme is shown on Figure 11.

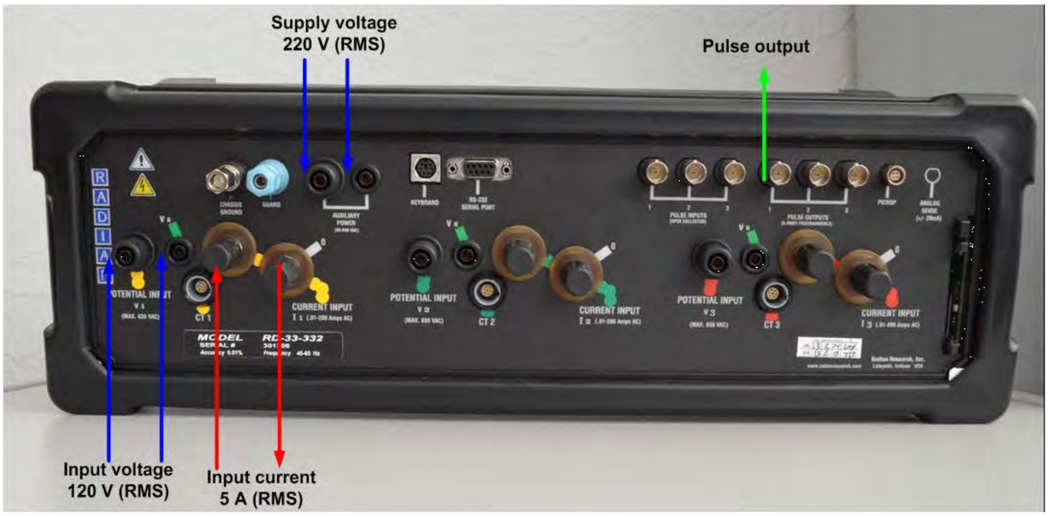

Figure 11 Connection scheme for travelling standard RD-33-332

To carry out measurements on Key Comparison of Power COOMET 695/UA/16 (COOMET.EM-K5) all the participants need to use a single-phase switching circuit (phase A). And as the reference of output signal is used frequency output. Which is programmed to issue pulses used for phase A.

Recommended time of measurement at one point 100 seconds. Otherwise each of the participants can set less time of measurement at one point.

5.2 Measurements

Before the measurements of active power in the RD-33-332 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 hours 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 in Table 4.

Table 4 The measurement points and condition of measurements

Unit	Value of the unit
Voltage	120 V ± 0.2 %
Current	5 A ± 0.2 %
Power factor	1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, 0.0 Lead deviation from the nominal value not exceeding ± 0.1%
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

5.3 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) and 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 (Table 5) should include such number of influencing quantities and their uncertainties, which ensures the highest level measurements of electrical power for each of the laboratories.

Table 5 Uncertainty budget for indirect means PF = , f = Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1							
2							
$\boldsymbol{y}$	Std uncertainty of measurement						
		Conf. level = 95 %				k = 2	
		=					

Attention! If any NMI wants to measure electric power by direct means (when the NMI reference system is based on the measurement of voltage, current and phase angle) than main uncertainty components and example schemes to report the uncertainty budget is shown in Table 6.

Table 6 Uncertainty budget for direct means PF = , *f* = Hz

Source of uncertainty	Standard uncertainty (μW/VA)	Probability distribution	Sensitivity coefficient	Contribution to the Standard uncertainty (μW/VA)
NMI voltage measurement				
NMI current measurement				
NMI phase measurement				
Measurement				
Std uncertainty of measurement				
Standard uncertainty				
Conf. level = 95 %				*k* = 2
Expanded uncertainty				

6. The measurement report

Each participating laboratory of the comparisons shall provide a report within 6 weeks from the date of departure travelling standard to the next participant.

The report shall be sent to the coordinator of comparisons by e-mail: velychko@ukrcsm.kiev.ua

The report shall include:
description of measurement methods;
description of the measurement circuit and used the standard possibilities of electricity;
confirmation of the traceability of the measurements (if participating laboratories has its own electric power units playback system, or must provide proof of traceability from another lab).
temperature and humidity in the laboratory during the measurement;
measurement results: certain amendments travelling standard values (5 values) for frequencies 50 Hz, 53 Hz, power factor: 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, and 0.0 Lead;
values of the respective standard uncertainties, the effective values of the degrees of freedom and expanded uncertainty;
detailed budget of uncertainty, which will be included in a report on the comparisons.

If between the measurements of any member, provided the pilot laboratory and preliminary comparisons reference value is detected a significant difference, it will be reported to the appropriate party. No other information on the measurement results will not be reported.

7. Report on comparisons

7.1 The key comparison reference value and the degrees of equivalence

This protocol has been prepared following the guidelines of the CCEM as given in [6]. The principles of the method of computation of the reference value are as follows:

1. The key comparison reference value (KCRV) and the degrees of equivalence among the participants for the CCEM.EM-K5 key comparison shall be determined according to the procedure agreed upon by the CCEM for the CCEM-K5 Comparison 50/60 Hz Power (1996-1999) [7].

2. For the calculation of the KCRV, the weighted mean over the participating laboratories will be used. If the uncertainty contribution of a participant due to the traceability to another NMI participating in this comparison amounts to a substantial part of the overall uncertainty value, the

result will not be taken into account in the calculation of the KCRV.

3. The degree of equivalence among the participating laboratories shall be expressed quantitatively by two terms:
the difference of the participating laboratory from the key comparison reference value;
the uncertainty of this difference at a 95.45 % level of confidence.

4. In order to compare the results of the different participants, including the pilot laboratory, each of the participants should report a single measurement result for each of the testing points shown in Table 4.

5. The bilateral degrees of equivalence. As requested per the CCEM, the bilateral degrees of equivalence among the participating laboratories in a key comparison will not be explicitly shown, but the formula for obtaining them will be included, thus allowing the participating laboratories to calculate their bilateral degree of equivalence from the data resulting from the difference between the participating laboratories and the KCRV.

7.2 Reports

Preliminary and final reports on the results of comparisons will be prepared by the pilot laboratory. The report will be prepared by the pilot laboratory within 4 months after the end of the measurement, and sent to the participants. The report is only for the participants of comparisons and is confidential. The report should be directed to the pilot laboratory for 2 months from the date of distribution of the Draft A. Comments will be considered in the Draft B. Draft B will be completed within 6 months after the end of the measurement. The final report will be prepared within 1 month from the receipt of the comments on the Draft B.

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/14: 2016 Guidelines for evaluating data Key comparisons COOMET.
[6] W. Moore et al., An international comparison of power meter calibrations conducted in 1987, IEEE Trans. Instrum. Meas. IM 48, no. 2, pp. 418-421, April 1989.
[7] N. Oldham, Thomas Nelson, Nien Fan Zhang, and Hung-kung Liu, Final Report of CCEM-K5 Comparison of 50/60 Hz Power, June 2002.