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

Final Report on
GULFMET Supplementary Comparison of High Voltage Transformer Measuring Systems (GULFMET.EM-S6)

Oleh Velychko, Valeriy Kikalo (SE “Ukrmetrteststandard”, Ukraine),
Huseyin Cayci, Burak Ayhan (UME, Turkey),
Saad Bin Qoud (SASO-NMCC, Saudi Arabia)

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

July 2022
Kyiv, Ukraine

Table of contents

1 Introduction

The GULFMET Supplementary Comparison (SC) of High Voltage Transformer Measuring Systems (comparison identifier – GULFMET.EM-S6) was conducted from November 2020 to December 2021.

This project for comparing of High Voltage Transformer Measuring Systems was conducted between counties which are member laboratories of regional metrology organizations GULFMET, COOMET and EURAMET. In this comparison three national metrology institutes (NMI) take part: SE “Ukrmetrteststandard” (UMTS, Ukraine), SASO-NMCC (Saudi Arabia) and UME (Turkey).

The State Enterprise “All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer” (SE “Ukrmetr-teststandard”), 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 of report, etc.

2 Participants

List of participating NMIs, countries of origin is show in Table 1.

Table 1 List of participating NMIs, countries of origin 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
SASO-NMCC – Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi – National Measurements and Calibration Center	Saudi Arabia	GULFMET
UME – TÜBITAK Ulusal Metroloji Enstitüsü	Turkey	EURAMET

List of participants contact information is show in Table 2.

Table 2 List of participant contact information

NMI address	Contact name, e-mail, tel. and fax number
State Enterprise “All-Ukrainian State Scientific and Production Center of Standardization, Metrology, Certification and Protection of Consumer” (SE “Ukrmetrteststandard” – **UMTS),** 4, Metrologichna Str., 03143, Kyiv-143, **Ukraine**	Oleh Velychko velychko@ukrcsm.kiev.ua Tel./fax: +38 044 526 0335

NMI address	Contact name, e-mail, tel. and fax number
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, **Kingdom of Saudi Arabia**	Saad Bin Qoud s.qoud@saso.gov.sa Tel: +966 56 902 7551
TÜBITAK Ulusal Metroloji Enstitüsü (**UME**), TÜBİTAK Gebze Yerleskesi Baris Mah., Dr. Zeki Acar Cad. No. 1 41470, Gebze Kocaeli, **Turkey**	Huseyin Cayci huseyin.cayci@tubitak.gov.tr Tel.: +90 262 679 5000

3 Travelling standards and measurement instructions

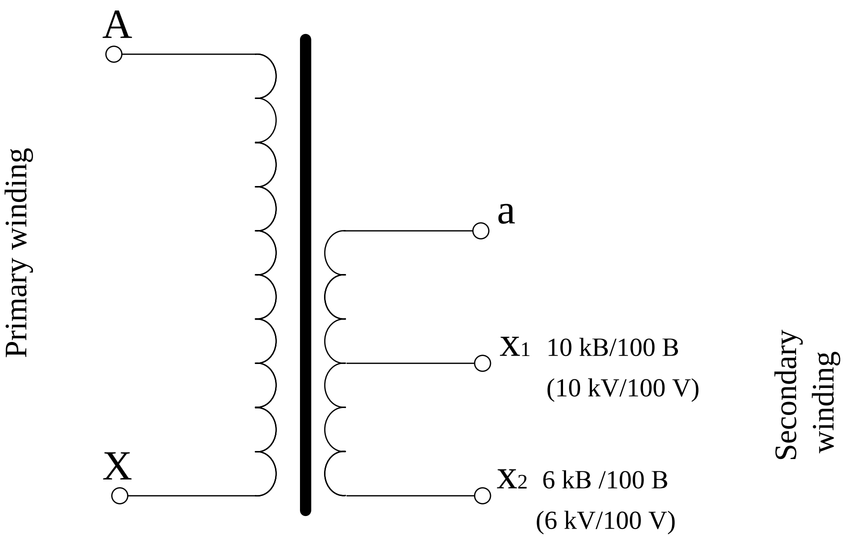
3.1 Description of travelling standard

The selected travelling standards are:

- voltage transformer ПЭТН-6/10 (“ТРАНСФОРМАТОР НАПРЯЖЕНИЯ ПЭТН-6/10”) (Figure 1);

- voltage transformer НЛЛ-35 (“ТРАНСФОРМАТОР НАПРЯЖЕНИЯ НЛЛ-35”) (Figure 2).

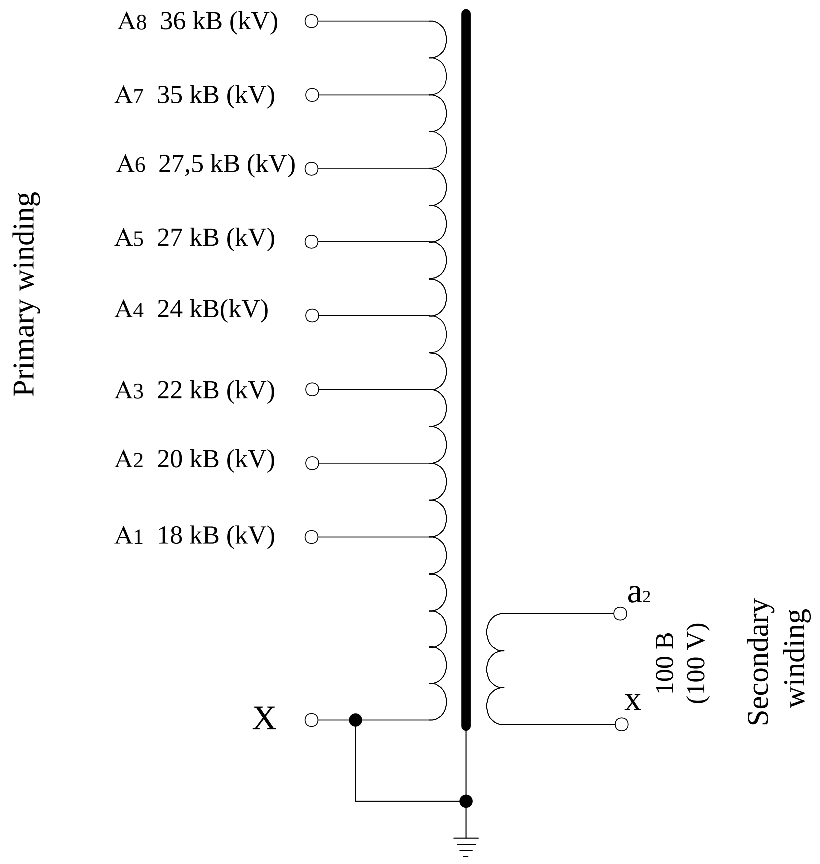
a



b

Figure 1 The photo (*a*) and the electrical scheme (*b*) of the travelling standard ПЭТН-6/10

a



b

Figure 2 The photo (*a*) and the electrical scheme (*b*) of the travelling standard НЛЛ-35

Main characteristics of travelling standards:

voltage transformer ПЭТН-6/10:

- primary rated voltages 6 kV and 10 kV;
- secondary rated voltage 100 V;
- working frequencies 50 Hz and 60 Hz;
- burden 0 V·A (open circuit – burden must be more than 100 kΩ);

voltage transformer НЛЛ-35:

- primary rated voltages 22 kV and 35 kV;
- secondary rated voltage 100 V;
- working frequencies 50 Hz and 60 Hz;
- burden 0 V·A (open circuit – burden must be more than 100 kΩ).

3.2 Measurements

Measurements must be performed under the following conditions:

- temperature: 23 °C ± 3 °C;

- relative humidity: from 30 % to 70 %;

- supply frequencies: 50 Hz ± 0.5 Hz and 60 Hz ± 0.6 Hz with a sinusoidal waveform.

The participants should inform the pilot laboratory if the above conditions cannot be met.

The data to be recorded at each measurement:

- date of measurement;

- air temperature and relative humidity environment;

- burden value (in VA or in kΩ) and its PF.

If measurements are carried out within a few days, then measured value together with the measurement date shall be given for each measurement day.

Comparison of national standards is provided by means of measuring of travelling standards metrological characteristics (ratio error ε_u and phase displacement δ_u) per them. Measurements are performed at the values of primary voltage 40, 80, 100 and 120 % of each primary nominal voltage (U_n) at frequencies of 50 Hz and 60 Hz and at load fixed for travelling standard.

Each NMI participant provides up to ten observations at each operation voltage. Each NMI participant presents arithmetical mean of ten observations and uncertainty in measurements as a result of measurement.

4 Uncertainty of measurement

Uncertainty of the measurements should be calculated according to the GUM [1] and EA-4/02 [2]. With the results of measurements should be given a model that describes how the measurement result was obtained considering all influencing quantities.

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 3) should include such number of influencing quantities and their uncertainties, which ensures the high-level measurements for the laboratory.

The components of the uncertainty budget should be expressed as standard uncertainties. The main components of the uncertainty budget are:

- standard uncertainty obtained as a result of an experiment from N independent measurements;

- uncertainty of the standard of the NMI laboratory, by means of which the value of the travelling standard is determined;

- uncertainty caused by the corrections.

Participants in the comparisons may include additional sources of uncertainty.

Table 3 Uncertainty budget

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1							
…							
y	Std uncertainty of measurement						
		Confidential level = %				k =	
		Expanded uncertainty =					

5 Traceability to the SI1

The traceability to the SI of standards was provided to pilot NMI. UMTS and UME made high voltage measurements of 50 Hz, SASO-NMCC made high voltage measurements of 60 Hz only. UMTS measurements are traceable to UMTS. SASO-NMCC and UME measurements are traceable to UME. Traceability route for each participating NMI given in Table 4.

Table 4 Traceability route for each participating NMI

NMI	Country	Traceability Route
UMTS	Ukraine	UMTS
SASO-NMCC	Saudi Arabia	UME
UME	Turkey	UME

6 Behaviour of the travelling standards

The UMTS as pilot laboratory has performed repeated measurements on the TSs ПЭТН-6/10 and НЛЛ-35 during the course of this comparison. TS ПЭТН-6/10 and НЛЛ-35 provides extreme linearity coupled with extreme stability.

The first day of starting GULFMET.EM-S6 comparison was 28 November 2020 and finished 20 December 2021. UMTS has performed repeated measurements on TS for 12 months and 22 days. During the course of comparison, the drift effect was calculated.

The average values x_{av} and standard deviation σ for ratio error ε_I and phase displacement δ_I are given in Table 5 at frequencies 50 Hz and 60 Hz. The drifts were small for all measurement points, so they can be neglected.

Table 5 The average values x_{av} and standard deviation σ for ratio error and phase displacement

Nominal primary voltage	Percentage of nominal primary voltage	Average values x_{av} for ratio error ε_U	Standard deviation σ for ratio error ε_U	Average values x_{av} for phase displacement δ_U	Standard deviation σ for phase displacement δ_U
kV	%	%	%	crad	crad
Frequency 50 Hz					
6	40	0.0001	0.0003	0.0001	0.0002
	80	0.0003		0.0001	
	100	0.0002		0.0001	
	120	0.0002		0.0002	
10	40	0.0003	0.0003	0.0003	0.0003
	80	0.0003		0.0001	
	100	0.0003		0.0001	
	120	0.0002		0.0002	
22	40	0.0007	0.0006	0.0001	0.0011
	80	0.0002		0.0004	
	100	0.0006		0.0004	
	120	0.0003		0.0008	
35	40	0.0002	0.0002	0.0028	0.0033
	80	0.0002		0.0039	
	100	0.0001		0.0023	
	120	0.0002		0.0042	
Frequency 60 Hz					
6	40	0.0001	0.0001	0.0032	0.0053
	80	0.0001		0.0019	
	100	0.0001		0.0017	
	120	0.0001		0.0015	
10	40	0.0001	0.0001	0.0024	0.0041
	80	0.0001		0.0017	
	100	0.0001		0.0013	
	120	0.0001		0.0009	
22	40	0.0002	0.0003	0.0004	0.0060
	80	0.0000		0.0002	
	100	0.0001		0.0003	
	120	0.0001		0.0004	

Nominal primary voltage	Percentage of nominal primary voltage	Average values x_{av} for ratio error ε_U	Standard deviation σ for ratio error ε_U	Average values x_{av} for phase displacement δ_U	Standard deviation σ for phase displacement δ_U
kV	%	%	%	crad	crad
35	40	0.0002	0.0004	0.0050	0.0052
	80	0.0004		0.0057	
	100	0.0003		0.0058	
	120	0.0004		0.0060	

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 energy. The report included a description of the measurement method (facilities and methodology), the traceability to the SI, and the results, associated uncertainty and number of degrees of freedom.

All measurement results and expended uncertainties, and additional parameters for measurement were identified with the serial number of measures energy and nominal value (Appendix 1).

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
UMTS1, Ukraine	28.11.2020
SASO-NMCC, Saudi Arabia	17–31.05.2021
UMTS2, Ukraine	12.08.2021
UME, Turkey	01–25.10.2021
UMTS3, Ukraine	20.12.2021

The additional parameters for measurement of the NMI participants are show in Table 7.

Table 7 The additional parameters for measurement of the NMI participants

Parameter	Value	Absolute expanded uncertainty
UMTS, Ukraine		
Frequency, Hz	50 and 60	0.005
Temperature, °C	22.0…24.0	0.3
Relative humidity, %	40…70	2.0

Parameter	Value	Absolute expanded uncertainty
SASO-NMCC, Saudi Arabia		
Frequency, Hz	60	0.005
Temperature, °C	22.5…23.6	0.5
Relative humidity, %	40…55	3.5
UME, Turkey		
Frequency, Hz	50 and 60	0.005
Temperature, °C	23.5…24.5	0.5
Relative humidity, %	40…50	3.5

The ratio error ε_U and phase displacement δ_U, and its standard uncertainties reported by the participants are given in Appendix 1 for frequencies 50/60 Hz. The value for UMTS is measurement result calculated as simple average value. Detailed uncertainty budgets from all participants are given in Appendix 2.

7.2 Calculation of the reference values and its uncertainties

The key comparison reference values (RV) x_{ref} are calculated as the mean of participant results with GULFMET.EM-S6 data are given by

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

with combine standard uncertainties

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

Reference values and expanded uncertainties for frequencies 50/60 Hz for all measurements are given in Tables 8.

Table 8 Reference values and expanded uncertainties for 50/60 Hz for all measurements

Nominal primary voltage	Percentage of nominal primary voltage	RV for ratio error ε_U	Expanded uncertainty for RV of ratio error $u(\varepsilon_U)$	RV for phase displace-ment δ_U	Expanded uncertainty for RV of phase displacement $u(\delta_U)$
kV	%	%	%	crad	crad
Frequency 50 Hz					
6	40	-0.0040	0.0015	0.0085	0.0017
	80	-0.0032		0.0051	
	100	-0.0029		0.0040	
	120	-0.0027		0.0034	

Nominal primary voltage	Percentage of nominal primary voltage	RV for ratio error ε_U	Expanded uncertainty for RV of ratio error $u(\varepsilon_U)$	RV for phase displace-ment δ_U	Expanded uncertainty for RV of phase displacement $u(\delta_U)$
kV	%	%	%	crad	crad
10	40	-0.0018	0.0015	0.0056	0.0017
	80	-0.0013		0.0027	
	100	-0.0012		0.0020	
	120	-0.0011		0.0021	
22	40	0.0460	0.0015	-0.0218	0.0017
	80	0.0516		-0.0269	
	100	0.0531		-0.0278	
	120	0.0538		-0.0286	
35	40	0.0411	0.0015	-0.0045	0.0017
	80	0.0482		-0.0065	
	100	0.0499		-0.0061	
	120	0.0509		-0.0063	
Frequency 60 Hz					
6	40	-0.0021	0.0015	0.0066	0.0017
	80	-0.0014		0.0041	
	100	-0.0012		0.0032	
	120	-0.0010		0.0026	
10	40	0.0000	0.0015	0.0041	0.0017
	80	0.0005		0.0018	
	100	0.0006		0.0013	
	120	0.0006		0.0010	
22	40	0.0367	0.0015	-0.0307	0.0017
	80	0.0426		-0.0349	
	100	0.0440		-0.0358	
	120	0.0449		-0.0364	
35	40	0.0392	0.0015	-0.0075	0.0017
	80	0.0468		-0.0090	
	100	0.0487		-0.0090	
	120	0.0497		-0.0087	

7.3 Degrees of equivalence

Only one value is reported for NMI participants. Degrees of equivalence (DoE) of the NMI participants are reported with respect to the measurements at 50/60 Hz.

The DoE of *i*-th NMI and its combined standard uncertainties with respect to the RV is estimated as [3]

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

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

Additionally, the performance indicator E_n is calculated as:

$$E_{ni} = \frac{|D_i|}{2u(D_i)} \le 1.0 \tag{5}$$

All DoE and its uncertainties are given in Table 9 for ratio error ε_U and Table 10 for phase displacement δ_U.

Table 9 DoE and its uncertainties of the NMI participants for ratio error ε_U

Nominal primary voltage	Percentage of nominal primary voltage	DoE			Expanded uncertainty		
		UMTS	SASO-NMCC	UME	UMTS	SASO-NMCC	UME
kV	%	%	%	%	%	%	%
Frequency 50 Hz							
6	40	0.0003		-0.0002	0.0028		0.0025
	80	0.0006		-0.0004	0.0028		0.0025
	100	0.0005		-0.0004	0.0028		0.0025
	120	0.0005		-0.0004	0.0028		0.0025
10	40	-0.0001		0.0001	0.0028		0.0025
	80	0.0001		0.0000	0.0028		0.0025
	100	0.0000		0.0000	0.0028		0.0025
	120	0.0000		0.0000	0.0028		0.0025
22	40	-0.0003		0.0002	0.0028		0.0025
	80	-0.0003		0.0002	0.0028		0.0025
	100	-0.0002		0.0002	0.0028		0.0025
	120	-0.0004		0.0002	0.0028		0.0025
35	40	0.0008		-0.0005	0.0028		0.0025
	80	0.0011		-0.0007	0.0028		0.0025
	100	0.0009		-0.0006	0.0028		0.0025
	120	0.0010		-0.0007	0.0028		0.0025

Nominal primary voltage	Percentage of nominal primary voltage	DoE			Expanded uncertainty		
		UMTS	SASO-NMCC	UME	UMTS	SASO-NMCC	UME
kV	%	%	%	%	%	%	%
Frequency 60 Hz							
6	40	-0.0003	0.0001	0.0002	0.0028	0.0145	0.0025
	80	-0.0001	0.0024	0.0000	0.0028	0.0145	0.0025
	100	0.0000	0.0022	0.0000	0.0028	0.0145	0.0025
	120	-0.0001	0.0010	0.0000	0.0028	0.0145	0.0025
10	40	-0.0005	0.0000	0.0003	0.0028	0.0145	0.0025
	80	-0.0003	0.0015	0.0001	0.0028	0.0145	0.0025
	100	-0.0003	0.0014	0.0001	0.0028	0.0145	0.0025
	120	-0.0002	0.0014	0.0001	0.0028	0.0145	0.0025
22	40	-0.0007	0.0003	0.0004	0.0028	0.0145	0.0025
	80	-0.0004	0.0014	0.0003	0.0028	0.0145	0.0025
	100	-0.0004	0.0020	0.0002	0.0028	0.0145	0.0025
	120	-0.0004	0.0011	0.0002	0.0028	0.0145	0.0025
35	40	0.0003	0.0008	-0.0003	0.0028	0.0145	0.0025
	80	0.0004	0.0022	-0.0004	0.0028	0.0145	0.0025
	100	0.0004	0.0023	-0.0004	0.0028	0.0145	0.0025
	120	0.0004	0.0013	-0.0003	0.0028	0.0145	0.0025

Table 10 DoE and its uncertainties of the NMI participants for phase displacement δ_U

Nominal primary voltage	Percentage of nominal primary voltage	DoE			Expanded uncertainty		
		UMTS	SASO-NMCC	UME	UMTS	SASO-NMCC	UME
kV	%	crad	crad	crad	crad	crad	crad
Frequency 50 Hz							
6	40	-0.0005		0.0002	0.0034		0.0026
	80	0.0000		0.0000	0.0034		0.0026
	100	0.0003		-0.0001	0.0034		0.0026
	120	0.0003		-0.0001	0.0034		0.0026
10	40	-0.0001		0.0000	0.0034		0.0026
	80	0.0003		-0.0001	0.0034		0.0026
	100	0.0005		-0.0002	0.0034		0.0026
	120	0.0007		-0.0003	0.0034		0.0026

Nominal primary voltage	Percentage of nominal primary voltage	DoE			Expanded uncertainty		
		UMTS	SASO-NMCC	UME	UMTS	SASO-NMCC	UME
kV	%	crad	crad	crad	crad	crad	crad
22	40	-0.0001		0.0001	0.0034		0.0026
	80	0.0003		-0.0001	0.0034		0.0026
	100	0.0002		-0.0001	0.0034		0.0026
	120	0.0004		-0.0002	0.0034		0.0026
35	40	0.0003		-0.0002	0.0034		0.0026
	80	0.0011		-0.0005	0.0034		0.0026
	100	0.0024		-0.0010	0.0034		0.0026
	120	0.0013		-0.0006	0.0034		0.0026
Frequency 60 Hz							
6	40	-0.0028	0.0004	0.0012	0.0034	0.0145	0.0026
	80	-0.0019	-0.0001	0.0008	0.0034	0.0145	0.0026
	100	-0.0014	-0.0012	0.0007	0.0034	0.0145	0.0026
	120	-0.0012	-0.0006	0.0006	0.0034	0.0145	0.0026
10	40	-0.0018	0.0009	0.0008	0.0034	0.0145	0.0026
	80	-0.0012	0.0002	0.0005	0.0034	0.0145	0.0026
	100	-0.0009	0.0007	0.0004	0.0034	0.0145	0.0026
	120	-0.0007	0.0000	0.0003	0.0034	0.0145	0.0026
22	40	0.0000	-0.0013	0.0000	0.0034	0.0145	0.0026
	80	0.0001	-0.0001	-0.0001	0.0034	0.0145	0.0026
	100	0.0000	-0.0012	0.0000	0.0034	0.0145	0.0026
	120	-0.0002	-0.0016	0.0001	0.0034	0.0145	0.0026
35	40	0.0011	-0.0035	-0.0004	0.0034	0.0145	0.0026
	80	0.0018	-0.0030	-0.0007	0.0034	0.0145	0.0026
	100	0.0018	-0.0030	-0.0008	0.0034	0.0145	0.0026
	120	0.0019	-0.0043	-0.0008	0.0034	0.0145	0.0026

E_n values of the NMI participants for ratio error ε_U and for phase displacement δ_U are given in Table 11. E_n number for all NMIs for all measurement points satisfy equation (5) and take values from 0.00 to 0.82.

Table 11 E_n values of the NMI participants for ratio error ε_U and for phase displacement δ_U

Nominal primary voltage, kV	Percentage of nominal primary voltage, %	E_n values for ratio error ε_U			E_n values for phase displacement δ_U		
		UMTS	SASO-NMCC	UME	UMTS	SASO-NMCC	UME
Frequency 50 Hz							
6	40	0.11		0.08	0.15		0.08
	80	0.21		0.16	0.00		0.00
	100	0.18		0.16	0.09		0.04
	120	0.18		0.16	0.09		0.04
10	40	0.04		0.04	0.03		0.00
	80	0.04		0.00	0.09		0.04
	100	0.00		0.00	0.15		0.08
	120	0.00		0.00	0.21		0.12
22	40	0.11		0.08	0.03		0.04
	80	0.11		0.08	0.09		0.04
	100	0.07		0.08	0.06		0.04
	120	0.14		0.08	0.12		0.08
35	40	0.28		0.20	0.09		0.08
	80	0.39		0.28	0.32		0.19
	100	0.32		0.24	0.71		0.38
	120	0.35		0.28	0.38		0.23
Frequency 60 Hz							
6	40	0.11	0.01	0.08	0.82	0.03	0.46
	80	0.04	0.17	0.00	0.56	0.01	0.31
	100	0.00	0.15	0.00	0.41	0.08	0.27
	120	0.04	0.07	0.00	0.35	0.04	0.23
10	40	0.18	0.00	0.12	0.53	0.06	0.31
	80	0.11	0.10	0.04	0.35	0.01	0.19
	100	0.11	0.10	0.04	0.26	0.05	0.15
	120	0.07	0.10	0.04	0.21	0.00	0.12
22	40	0.25	0.02	0.16	0.00	0.09	0.00
	80	0.14	0.10	0.12	0.03	0.01	0.04
	100	0.14	0.14	0.08	0.00	0.08	0.00
	120	0.14	0.08	0.08	0.06	0.11	0.04

Nominal primary voltage, kV	Percentage of nominal primary voltage, %	E_n values for ratio error ε_U			E_n values for phase displacement δ_U		
		UMTS	SASO-NMCC	UME	UMTS	SASO-NMCC	UME
35	40	0.11	0.06	0.12	0.32	0.24	0.15
	80	0.14	0.15	0.16	0.53	0.21	0.27
	100	0.14	0.16	0.16	0.53	0.21	0.31
	120	0.14	0.09	0.12	0.56	0.30	0.31

8 Summary

A supplementary comparison of High Voltage Transformer Measuring Systems been conducted between participating NMIs from three regional metrological organizations (GULFMET and COOMET, EURAMET). 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. In this comparison, the NMI participants report about three NMIs for realization the traceability of the unit of high voltage.

References

[1] JCGM 100:2008 Evaluation of measurement data. – Guide to the expression of uncertainty in measurement.

[2] EA-4/02M:2022 Evaluation of the Uncertainty of Measurement in calibration.

[3] COOMET R/GM/19:2016 Guidelines on COOMET supplementary comparison evaluation.

Appendix 1

Reported measurement results for each NMI laboratory

SASO-NMCC (Saudi Arabia)

Measurement results for voltage transformers given in the Table A1.1.

Table A1.1 Measurement results for voltage transformers

Frequen-cy	Nominal primary voltage	Percentage of nominal primary voltage	Ratio error ε_U	Combined uncertainty for ratio error $u(\varepsilon_U)$	Phase displacement δ_U	Combined uncertainty for phase displacement $u(\delta_U)$
Hz	kV	%	%	%	crad	crad
60	6	40	-0.002	0.0072	0.007	0.0072
		80	0.001		0.004	
		100	0.001		0.002	
		120	0.000		0.002	
	10	40	0.000	0.0072	0.005	0.0072
		80	0.002		0.002	
		100	0.002		0.002	
		120	0.002		0.001	
	22	40	0.037	0.0072	-0.032	0.0072
		80	0.044		-0.035	
		100	0.046		-0.037	
		120	0.046		-0.038	
	35	40	0.040	0.0072	-0.011	0.0072
		80	0.049		-0.012	
		100	0.051		-0.012	
		120	0.051		-0.013	

The appropriate primary voltage values are applied to the voltage transformer under test and the standard voltage transformer using a voltage source at 60 Hz. The ratio error and phase displacement values between secondary voltages of the transformers are measured with most precision microprocessor-based Voltage Transformer Bridge. Figure A1.1 shows the measurement setup of SASO NMCC.

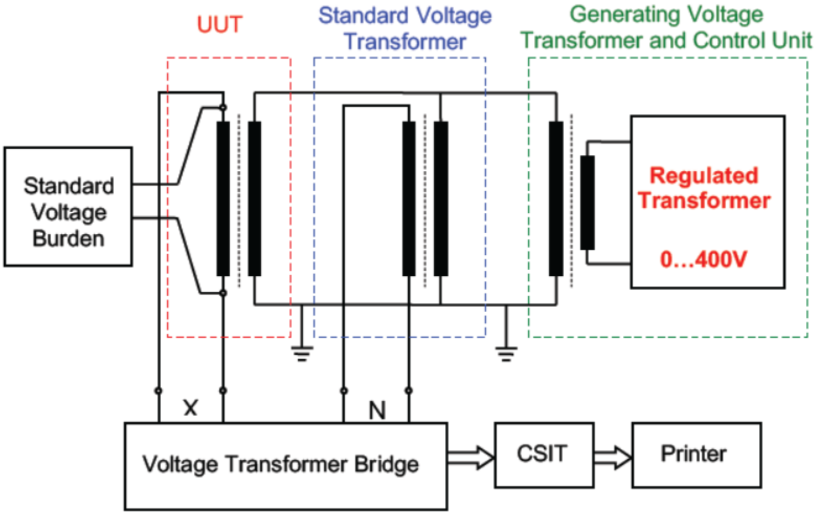


Figure A1.1 Measurement setup of SASO NMCC

The symbols and definitions stated are in accordance with IEC 61869-3.

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

$$\varepsilon_X(\%) = \frac{K_u U_S - U_p}{U_p} 100,$$

where

K_n is rated transformation ratio;

U_p is actual primary voltage;

U_s is actual secondary voltage when U_p is applied under the conditions of measurement.

Z_B Burden: The impedance of the secondary circuit in ohms and power-factor. The burden is usually expressed as the apparent power in volt-amperes absorbed at a specified power-factor and at the rated secondary voltage.

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

δ is symbol, in order not to cause confusion, is used with the italic format (δ).

Saad BinQoud, Rashed Alroumie, Mohammed Almutairi.

UMTS (Ukraine)

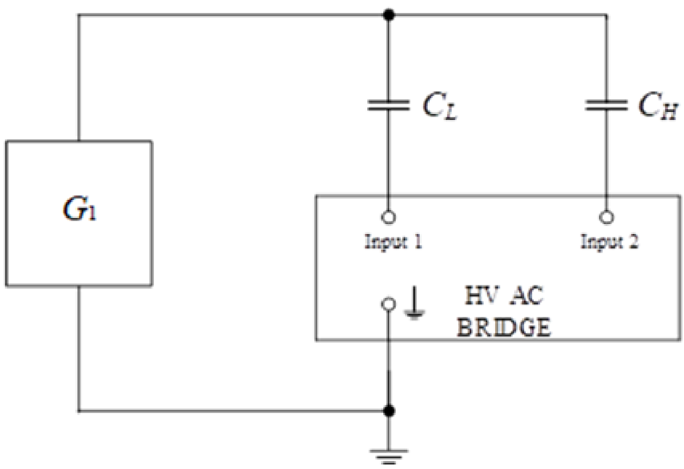
Measurement results for voltage transformers given in the Table A1.2.

Table A1.2 Measurement results for voltage transformers

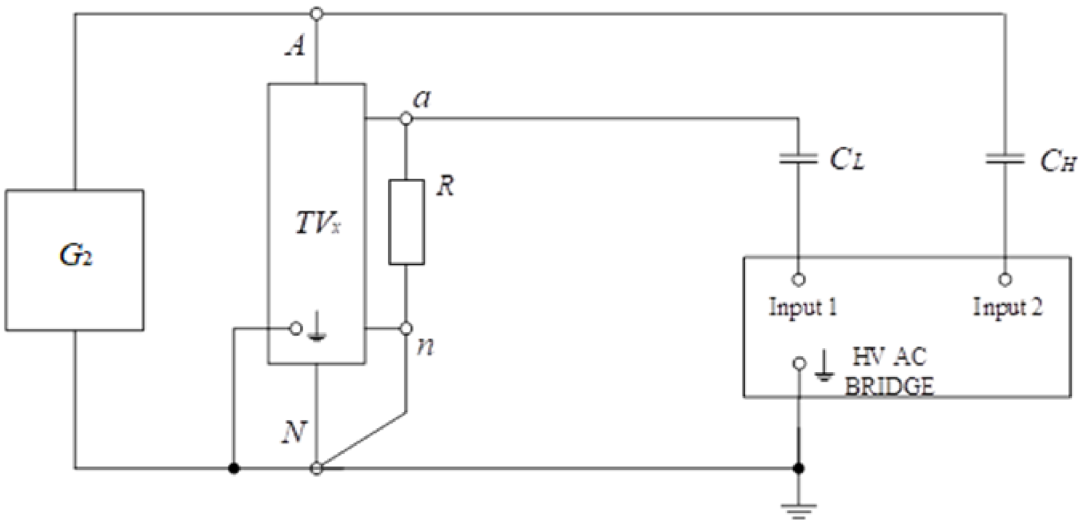
Frequen-cy	Nominal primary voltage	Percentage of nominal primary voltage	Ratio error ε_U	Combined uncertainty for ratio error $u(\varepsilon_U)$	Phase displacement δ_U	Combined uncertainty for phase displacement $u(\delta_U)$
Hz	kV	%	%	%	crad	crad
50	6	40	-0.0037	0.0012	0.0080	0.0015
		80	-0.0026		0.0051	
		100	-0.0024		0.0043	
		120	-0.0022		0.0037	
	10	40	-0.0019	0.0012	0.0055	0.0015
		80	-0.0012		0.0030	
		100	-0.0012		0.0025	
		120	-0.0011		0.0028	
	22	40	0.0457	0.0012	-0.0219	0.0015
		80	0.0513		-0.0266	
		100	0.0529		-0.0276	
		120	0.0534		-0.0282	
	35	40	0.0419	0.0012	-0.0042	0.0015
		80	0.0493		-0.0054	
		100	0.0508		-0.0037	
		120	0.0519		-0.0050	
60	6	40	-0.0024	0.0012	0.0038	0.0015
		80	-0.0015		0.0022	
		100	-0.0012		0.0018	
		120	-0.0011		0.0014	
	10	40	-0.0005	0.0012	0.0023	0.0015
		80	0.0002		0.0006	
		100	0.0003		0.0004	
		120	0.0004		0.0003	
	22	40	0.0360	0.0012	-0.0307	0.0015
		80	0.0422		-0.0348	
		100	0.0436		-0.0358	
		120	0.0445		-0.0366	

Frequency	Nominal primary voltage	Percentage of nominal primary voltage	Ratio error ε_U	Combined uncertainty for ratio error $u(\varepsilon_U)$	Phase displacement δ_U	Combined uncertainty for phase displacement $u(\delta_U)$
Hz	kV	%	%	%	crad	crad
50	35	40	0.0395	0.0012	-0.0064	0.0015
		80	0.0472		-0.0072	
		100	0.0491		-0.0072	
		120	0.0501		-0.0068	

TSs ratio error and phase displacement measurements were made via the current comparator method using a high voltage AC bridge and two measuring capacitors. The measurement schemes are shown in Fig. A1.2.



a



b

Fig. A1.2 Schemes for measuring the TSs ratio error and phase displacement

G1 is AC voltage source to 1000 V; *G2* is AC high voltage source; *R* is burden device for voltage transformer (if necessary); *TVx* is traveling standard; C_L is low-voltage measuring capacitor; C_H is high-voltage measuring capacitor; HV AC BRIDGE is high voltage AC bridge

The measurements are carried out in two stages. At the first stage (Fig. A1.2, *a*), the measuring capacitors C_L and C_H are connected in parallel and connected to a voltage source of 1000 V. Using a high-voltage bridge HV AC BRIDGE, the ratio of the values of the capacitances of the capacitors and the difference between their tangent's delta are measured. At the second stage Fig. A1.2, *b*), the high-voltage capacitor is connected to the input of the voltage transformer – TS, and the low-voltage capacitor is connected to the output of the voltage transformer – TS. The operating voltage is applied to the voltage transformer. In this case, using a high-voltage bridge, the ratio of currents through the capacitors and the difference in their phases are measured. The ratio error and phase displacement of the voltage transformer – TS are calculated using the results of all the above measurement operations. All measurement and calculation operations in both measurement steps are performed automatically by the bridge. The final measurement results of ratio error and phase displacement are observed on the digital display of the bridge.

A set of measurements consists of measuring each percentage values at least 10 times by adjusting the voltage from minimum up to highest test point, and then continue by measuring the points in descending order.

The high voltage AC bridge, the high-voltage measuring capacitor and the low-voltage measuring capacitor are part of the State primary standard of the unit of the transformation scale coefficient of the alternating voltage (National standard). The design of the high voltage AC bridge allows its self-calibration using the primary reference calibration procedure. The high-voltage measuring capacitor and the low-voltage measuring capacitor are calibrated on the National standard of the electric capacitance unit. Due to this, SE “Ukrmeterteststandard” has its own AC voltage ratio error and phase displacement unit’s playback system.

• **High voltage AC bridge** is a precision device of the CA7100M1 type. It is designed and manufactured specifically for use as part of the National standard. At the heart of its construction and principle of operation lies a current comparator. It is a fully automatic measuring device controlled by a microprocessor.

• **High-voltage measuring capacitor** is a three-electrode gas-filled capacitor type MCP600. The maximum operating voltage of the capacitor is 600 kV. It has very low dielectric losses ($tg\ \delta \leq 5 \cdot 10^{-6}$). Also, it has a very small dependence of capacitance on the applied voltage (less than $3 \cdot 10^{-6}$). Working electrical isolation is provided by SF6 gas.

• **Low-voltage measuring capacitor** is a three-electrode vacuum insulated capacitor type CA6002. The maximum operating voltage of the capacitor is 2 kV. It has very low dielectric losses ($tg\ \delta \leq 2 \cdot 10^{-6}$). The maximum dependence of its capacitance on the operating voltage is $3 \cdot 10^{-6}$.

UME (Turkey)

Measurement results for voltage transformers given in the Table A1.3.

Table A1.3 Measurement results for voltage transformers

Frequency	Nominal primary voltage	Percentage of nominal primary voltage	Ratio error ε_U	Combined uncertainty for ratio error $u(\varepsilon_U)$	Phase displacement δ_U	Combined uncertainty for phase displacement $u(\delta_U)$
Hz	kV	%	%	%	crad	crad
50	6	40	-0.0042	0.0010	0.0087	0.0010
		80	-0.0036		0.0051	
		100	-0.0033		0.0039	
		120	-0.0031		0.0033	
	10	40	-0.0017	0.0010	0.0056	0.0010
		80	-0.0013		0.0026	
		100	-0.0012		0.0018	
		120	-0.0011		0.0018	
	22	40	0.0462	0.0010	-0.0217	0.0010
		80	0.0518		-0.0270	
		100	0.0533		-0.0279	
		120	0.0540		-0.0288	
	35	40	0.0406	0.0010	-0.0047	0.0010
		80	0.0475		-0.0070	
		100	0.0493		-0.0071	
		120	0.0502		-0.0069	
60	6	40	-0.0019	0.0010	0.0078	0.0010
		80	-0.0014		0.0049	
		100	-0.0012		0.0039	
		120	-0.0010		0.0032	
	10	40	0.0003	0.0010	0.0049	0.0010
		80	0.0006		0.0023	
		100	0.0007		0.0017	
		120	0.0007		0.0013	
	22	40	0.0371	0.0010	-0.0307	0.0010
		80	0.0429		-0.0350	
		100	0.0442		-0.0358	
		120	0.0451		-0.0363	

Frequen-cy	Nominal primary voltage	Percentage of nominal primary voltage	Ratio error ε_U	Combined uncertainty for ratio error $u(\varepsilon_U)$	Phase displacement δ_U	Combined uncertainty for phase displacement $u(\delta_U)$
Hz	kV	%	%	%	crad	crad
60	35	40	0.0389	0.0010	-0.0079	0.0010
		80	0.0464		-0.0097	
		100	0.0483		-0.0098	
		120	0.0494		-0.0095	

The calibration of the voltage transformer is performed in two steps shown in the Figure A1.3 according to “Calibration Instruction of Voltage Transformer” (TLM-05-G1PE-04-06) by using High Voltage Capacitance Bridge (HVCB) based on the current comparator and standard capacitors.

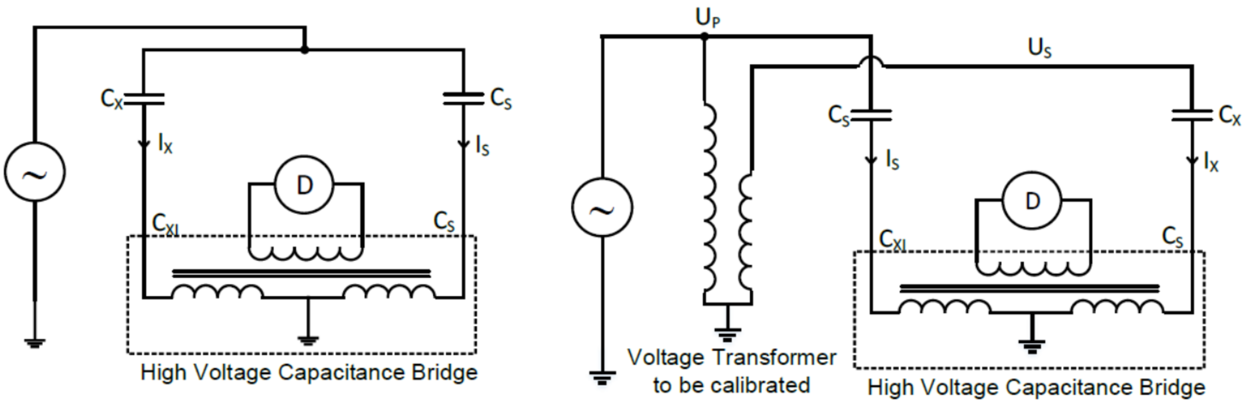


Figure A1.3 Measurement circuit for Step 1 (a) and Step 2 (b)

In the Step 1, the capacitance ratio and the dissipation factor between two low-loss standard capacitors are measured by means of comparing the currents passing through the capacitors by HVCB while the same voltage is applied to the capacitors. In the Step 2, these capacitors are connected in parallel with the primary and secondary windings of the voltage transformer and again capacitance ratio and a dissipation factor are measured by HVCB. The ratio error and phase displacement of the voltage transformer are calculated by using the capacitance ratio and dissipation factor values measured in the first and second steps.

The measurement circuit consists of three parts:

• **Power Supply**: The primary test voltage has been provided with a semi-automatic voltage source consisting of the step-up voltage transformer and electronic power source.

• **Standard Capacitors**: Standard capacitors are mainly used by National Metrology Institutes as reference standard capacitance and tangent delta. The capacitors allow high dielectric voltages through its bulbous structure and it is always composed of three main electrodes (1) A high voltage electrode receiving the high voltage, (2) An low voltage measurement electrode Cn isolated from the previous high voltage one by a dielectric gas under pressure, usually SF6, (3) A guard electrode finally to perfectly define the measurement made by the previous electrode Cn and eliminate all the parasitic capacitance by grounding them or by using a guard circuit specific to the installation.

• **High Voltage Capacitance Bridge**: The HVCB is a microprocessor-controlled, current comparator based, automated capacitance bridge with metrology capabilities. The capacitance ratio and the dissipation factor measurement functions of the HVCB are calibrated according to “Calibration Instruction of Voltage Transformer Bridge” (TLM-05- G1PE-04-08). For the calibration of capacitance ratio, the capacitance ratios of low-loss capacitors with the same capacitance values are compared by using the HVCB. Subsequently, these capacitors are connected in parallel to obtain various reference capacitance ratios and the HVCB readings are compared with the reference capacitance ratios. A Dissipation Factor Standard with selectable fixed values is used for dissipation factor calibration of HVCB. It is connected to either X or S inputs in series with standard capacitors and the HVCB readings are compared with the selected values of the Dissipation Factor Standard.

The procedure given in the technical protocol for the connections of the travelling standards was considered in the measurements.

Five sets of measurements have been performed for each nominal primary voltage stated in the technical protocol. A set of measurements consists of measuring each percentage values at least 10 times by adjusting the voltage from minimum up to highest test point, and then continue by measuring the points in descending order.

Dr. Burak Ayhan, Hüseyin Çayci, Eray Saral.

burak.ayhan@tubitak.gov.tr

Appendix 2

Reported measurement uncertainty components for each NMI laboratory

SASO-NMCC (Saudi Arabia)

The uncertainty budget given shows the contributions associated with the measurements made on ratio error and phase displacement form 6 kV to 35 kV/100 V at 120 %, 100 %, 80 %, 40 % at a burden of 0 VA, at a frequency of 60 Hz and an ambient temperature (23 ± 2) °C.

The uncertainty budget given in the Table A2.1 shows the uncertainty contributions associated with the ratio error measurements of voltage transformers.

Table A2.1 Uncertainty budget for ratio error

Symbol	Description	Unit	Value	Probability distribution	Factor	Sensitivity coefficient	Uncertainty contribution
ε_{Xi}	Repeatability	ppm	0.78	Normal	1.000	1	0.61 $(ppm)^2$
$\delta\varepsilon_{XRcal\ vt}$	Calibration effect (standard voltage transformer)	ppm	100	Normal	0.500	1	2500.00 $(ppm)^2$
$\delta\varepsilon_{XRcal\ ts}$	Calibration effect (for bridge)	ppm	50	Normal	0.500	1	625.00 $(ppm)^2$
$\delta\varepsilon_{XRd\ vt}$	Drift (for standard voltage transformer)	ppm	50	Rectangular	0.577	1	833.33 $(ppm)^2$
$\delta\varepsilon_{XRd\ vt}$	Drift (for bridge)	ppm	50	Rectangular	0.577	1	833.33 $(ppm)^2$
$\delta\varepsilon_{XRtc}$	Temperature effect	ppm	5	Rectangular	0.577	1	8.33 $(ppm)^2$
$\delta\varepsilon_{XBurden}$	Burden effect	ppm	5	Rectangular	0.577	1	8.33 $(ppm)^2$
$\delta\varepsilon_{XConfig}$	Configuration effect	ppm	20	Normal	0.500	1	100.00 $(ppm)^2$
$\delta\varepsilon_{XVoltage}$	Applied voltage effect	ppm	20	Rectangular	0.577	1	133.33 $(ppm)^2$
$\delta\varepsilon_{XFreq}$	Frequency effect	ppm	5	Rectangular	0.577	1	133.33 $(ppm)^2$
						Total variance $u(eX)^2$	5175.61 $(ppm)^2$
						Combined uncertainty $u(eX)$	71.94 (ppm)
						Expanded uncertainty (k = 2, 95 %)	144 (ppm)

Model function for ratio error measurements:

$$\varepsilon_X = \varepsilon_{Xi} + \delta\varepsilon_{XRcal\,vt} + \delta\varepsilon_{XRcal\,ts} + \delta\varepsilon_{XRd\,vt} + \delta\varepsilon_{XRd\,ts} + \delta\varepsilon_{XRtc} + \delta\varepsilon_{XBurden} + \delta\varepsilon_{XConfig} + \delta\varepsilon_{XVoltage} + \delta\varepsilon_{XFreq}\,.$$

The uncertainty budget given in the Table A2.2 shows the uncertainty contributions associated with the phase displacement measurements of voltage transformers.

Table A2.2 Uncertainty budget for phase displacement

Symbol	Description	Unit	Value	Probability distribution	Factor	Sensitivity coefficient	Uncertainty contribution
δ_{Xi}	0.098 (µrad)2	µrad	0.3	Normal	1	1	0.098 (µrad)^2
$\delta\delta_{XRcal\,vt}$	2500.00 (µrad)2	µrad	100	Normal	0.5	1	2500.00 (µrad)^2
$\delta\delta_{XRcal\,ts}$	625.00 (µrad)2	µrad	50	Normal	0.5	1	625.00 (µrad)^2
$\delta\delta_{XRd\,vt}$	833.33 (µrad)2	µrad	50	Rectangular	0.577	1	833.33 (µrad)^2
$\delta\delta_{XRd\,ts}$	833.33 (µrad)2	µrad	50	Rectangular	0.577	1	833.33 (µrad)^2
$\delta\delta_{XRtc}$	8.33 (µrad)2	µrad	5	Rectangular	0.577	1	8.33 (µrad)^2
$\delta\delta_{XBurden}$	8.33 (µrad)2	µrad	5	Rectangular	0.577	1	8.33 (µrad)^2
$\delta\delta_{XConfig}$	100.00 (µrad)2	µrad	20	Normal	0.5	1	100.00 (µrad)^2
$\delta\delta_{XVoltage}$	133.33 (µrad)2	µrad	20	Rectangular	0.577	1	133.33 (µrad)^2
$\delta\delta_{XFreq}$	133.33 (µrad)2	µrad	20	Rectangular	0.577	1	133.33 (µrad)^2
Total variance $u(eX)^2$							5175.10 (µrad)^2
Combined uncertainty $u(eX)$							71.9 µrad
Expanded uncertainty (k = 2, 95 %)							143.9 µrad

Model function for phase displacement measurements:

$$\delta_X = \delta_{Xi} + \delta\delta_{XRcal\,vt} + \delta\delta_{XRcal\,ts} + \delta\delta_{XRd\,vt} + \delta\delta_{XRd\,ts} + \delta\delta_{XRtc} + \delta\delta_{XBurden} + \delta\delta_{XConfig} + \delta\delta_{XVoltage} + \delta\delta_{XFreq}\,.$$

Saad BinQoud, Rashed Alroumie, Mohammed Almutairi.

UMTS (Ukraine)

The uncertainty budget given in the Table A2.2 and A2.3 shows the uncertainty contributions associated with the ratio error and phase displacement measurements of voltage transformers.

Table A2.2 Uncertainty budget for ratio error

Source of uncertainty	Defini-tion	Type	Probability distribution	Standard uncertainty value, %	Sensitivity coefficient	Contribution to the total standard uncertainty, %
Calibration effect of the high voltage AC bridge	ε_b	B	Rectangular	0.001	0.577	0.000577
Dependence of the capacitance of the high-voltage capacitor on the operating voltage	ε_{ch}	B	Rectangular	0.0003	0.577	0.000173
Dependence of the capacitance of the low-voltage capacitor on the operating voltage	ε_{cl}	B	Rectangular	0.0003	0.577	0.00173
Standard deviation of measurement results	$S_{U\varepsilon}$	A	Normal	0.0003	1.000	0.0003
	Total standard uncertainty $u_{I\varepsilon}$ = 0.000906 %					
	Confidential level = 95 %			Coverage factor = 2.0		
	Expanded uncertainty $U_{U\varepsilon}$ = 0.0018 %					
	Declared uncertainty $U_{U\varepsilon}$ = 0.0024 %					

Measurement equation for ratio error is: $\varepsilon_{\mathrm{X}} = \varepsilon_{\mathrm{Xi}} + S_{U\varepsilon} + \delta\varepsilon_b + \delta\varepsilon_{ch} + \delta\varepsilon_{cl}$.

Table A2.3 Uncertainty budget for phase displacement

Source of uncertainty	Defini-tion	Type	Probability distribution	Standard uncertainty value, crad	Sensitivity coefficient	Contribution to the total standard uncertainty, crad
Calibration effect of the high voltage AC bridge	δ_b	B	Rectangular	0.0017	0.577	0.00098
Dependence of the tg δ of the high-voltage capacitor on the operating voltage	δ_{ch}	B	Rectangular	0.0003	0.577	0.00017
Dependence of the tg δ of the low-voltage capacitor on the operating voltage	δ_{cl}	B	Rectangular	0.0003	0.577	0.00017
Standard deviation of measurement results	$S_{U\delta}$	A	Normal	0.0003	1.000	0.0003
	Total standard uncertainty $u_{I\varepsilon}$ = 0.00144 crad					
	Confidential level = 95 %			Coverage factor = 2.0		
	Expanded uncertainty $U_{U\varepsilon}$ = 0.00288 crad					
	Declared uncertainty $U_{U\varepsilon}$ = 0.0030 crad					

Measurement equation for phase displacement is: $\delta_{\mathrm{X}} = \delta_{\mathrm{Xi}} + S_{U\delta} + \delta\delta_b + \delta\delta_{ch} + \delta\delta_{cl}$

UME (Turkey)

The uncertainty budget given in the Table A2.4 and A2.5 shows the uncertainty contributions associated with the ratio error and phase displacement measurements of voltage transformers.

Table A2.4 Uncertainty budget for ratio error

Quantity	Standard uncertainty (%)	Type	Probability distribution	Sensitivity coefficient	Uncertainty contribution (%)
Calibration effect of HVCB	0.0010	B	normal	1	0.0005
Drift of HVCB	0.0005	B	rectangular	1	0.000289
Voltage dependence of Standard Capacitors	0.0010	B	rectangular	1	0.000577
Temperature dependence of Standard Capacitors	0.0004	B	rectangular	1	0.000231
Resolution	0.00005	B	rectangular	1	0.000029
Circuit configuration, setting	0.0005	B	normal	1	0.00025
Repeatability	0.0003	A	normal	1	0.0003
Combined uncertainty					0.00093
Expanded uncertainty (*U*) (*k* = 2)					0.00186
Declared uncertainty (*U*) (*k* = 2)					0.0020

Table A2.5 Uncertainty budget for phase displacement

Quantity	Standard uncertainty (crad)	Type	Probability distribution	Sensitivity coefficient	Uncertainty contribution (crad)
Calibration effect of HVCB	0.0010	B	normal	1	0.0005
Drift of HVCB	0.0005	B	rectangular	1	0.000289
Voltage dependence of Standard Capacitors	0.0005	B	rectangular	1	0.000289
Temperature dependence of Standard Capacitors	0.0002	B	rectangular	1	0.000115
Resolution	0.00005	B	rectangular	1	0.000029
Circuit configuration, setting	0.0005	B	normal	1	0.00025
Repeatability	0.0003	A	normal	1	0.0003
Combined uncertainty					0.00076
Expanded uncertainty (*U*) (*k* = 2)					0.00152
Declared uncertainty (*U*) (*k* = 2)					0.0020

The contributions for the “Calibration effects of the HVCB” take into account any error of the HVCB used in calibration of the transfer standard.

The value for repeatability is the standard deviation of the mean for each individual set of measurements.

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%. The standard uncertainty of measurement has been determined in accordance with GUM and EA-4/02.

Dr. Burak Ayhan, Hüseyin Çayci, Eray Saral.

burak.ayhan@tubitak.gov.tr

Appendix 3

Technical Protocol of Comparison

State Enterprise “All-Ukrainian state research and production center
of standardization, metrology, certification consumers’ right protection”
(SE “Ukrmeterteststandard”)

TECHNICAL PROTOCOL
on Supplementary Comparison of
High Voltage Transformer Measuring Systems
(GULFMET.EM-S6)

Oleh Velychko, Valeriy Kikalo

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

Coordinator of comparison: Oleh Velychko

January 2020
Kyiv, Ukraine

Table of Content

1 Introduction

The GULFMET Supplementary Comparison (SC) of high voltage transformer measuring systems (comparison identifier – GULFMET.EM-S6) will be in the framework of GULFMET project from January to June, 2020.

This project for comparing of national voltage ratio standards will be between countries which are member laboratories of GULFMET, EURAMET and COOMET regional metrology organizations. In this comparison take part three national metrology institutes (NMI): SE "Ukrmetrteststandard" (UMTS, Ukraine); SASO-NMCC (Saudi Arabia); UME (Turkey).

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 will be the comparison coordinator. The pilot laboratory is responsible for providing the travelling standards, coordinating the schedule, collecting and analyzing the comparison data, preparing the draft report, etc.

2 Participants and time schedule of the comparison

Each participant is given 2 weeks to perform the measurements of travelling standards and 1 week to transfer standards to the pilot laboratory. The NMI participants and the time schedule of the comparison are given in Table 1 and Table 2. There are three NMI participants in this comparison. Participants should have the traveling standards delivered to the address of the participant scheduled to perform measurements after themselves according to the schedule.

Table 1 List of NMI 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 protecttion" (SE "Ukrmetrteststandard") – **pilot**	**UMTS**	4, Metrologichna Str., 03143, Kyiv, Ukraine	Oleh Velychko	velychko@ukrcsm.kiev.ua Tel./Fax: +38 044 526 0335
2	Saudi Standards, Metrology and Quality Organization of The Kingdom of Saudi – National Measurements and Calibration Center	**SASO-NMCC**	Front king Saud University Riyadh 11471, P.O. Box 3437 Kingdom of Saudi Arabia	Saad Bin Qoud	s.qoud@saso.gov.sa Tel: +966 56 902 7551

№	NMI	**Abbreviation of NMI**	Address	Contact person	e-mail, phone, fax
3	TÜBITAK Ulusal Metroloji Enstitüsü	**UME**	TÜBİTAK Gebze Yerleskesi Baris Mah., Dr. Zeki Acar Cad. No. 1 41470, Gebze Kocaeli, Turkey	Huseyin Çayci	huseyin.cayci@tubitak.gov.tr Tel.: +90 262 679 5000

Table 2 List of dates of measurements

Abbreviation of NMI	Dates of measurements	Dates of delivery
UMTS	02–27.03.2020	30.03.2020
UME	06–17.04.2020	20.04.2020
UMTS	27.04–29.05.2020	01.06.2020
SASO-NMCC	07–18.06.2020	21.06.2020
UMTS	29.06–10.07.2020	-

3. Financial aspects and insurance

Each NMI participant of comparison should be at their own expense to perform all the measurements and send travelling standards back to the pilot laboratory (including transportation costs, insurance costs and customs).

In addition, each NMI participant of comparison should be at their own expense to cover all costs from the moment of arrival travelling standards 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 standards (customs fees, brokerage services, transportation within the country) and the costs of returning the standards to the pilot laboratory.

4. Travelling standards and measurement instruction

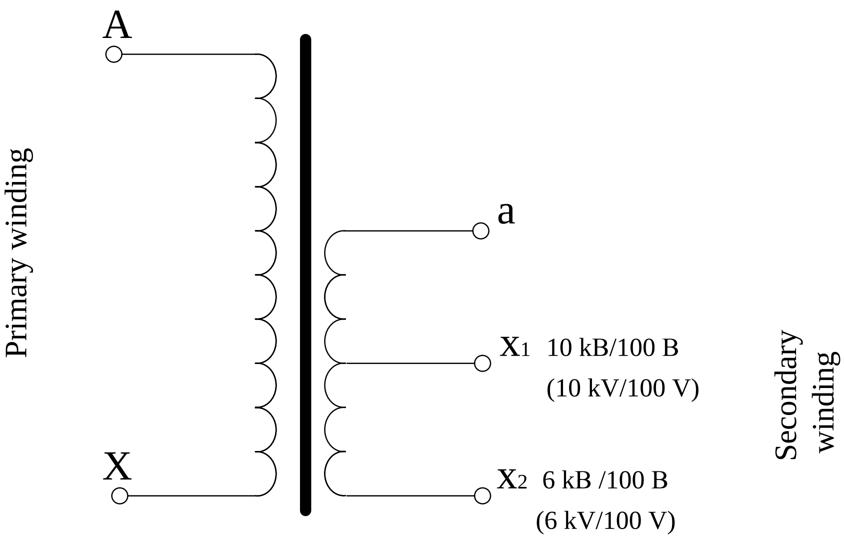
4.1. Description of travelling standards

The selected travelling standards are:

voltage transformer ПЭТН-6/10 (“ТРАНСФОРМАТОР НАПРЯЖЕНИЯ ПЭТН-6/10”) (Figure 1);

voltage transformer НЛЛ-35 (“ТРАНСФОРМАТОР НАПРЯЖЕНИЯ НЛЛ-35”) (Figure 2).

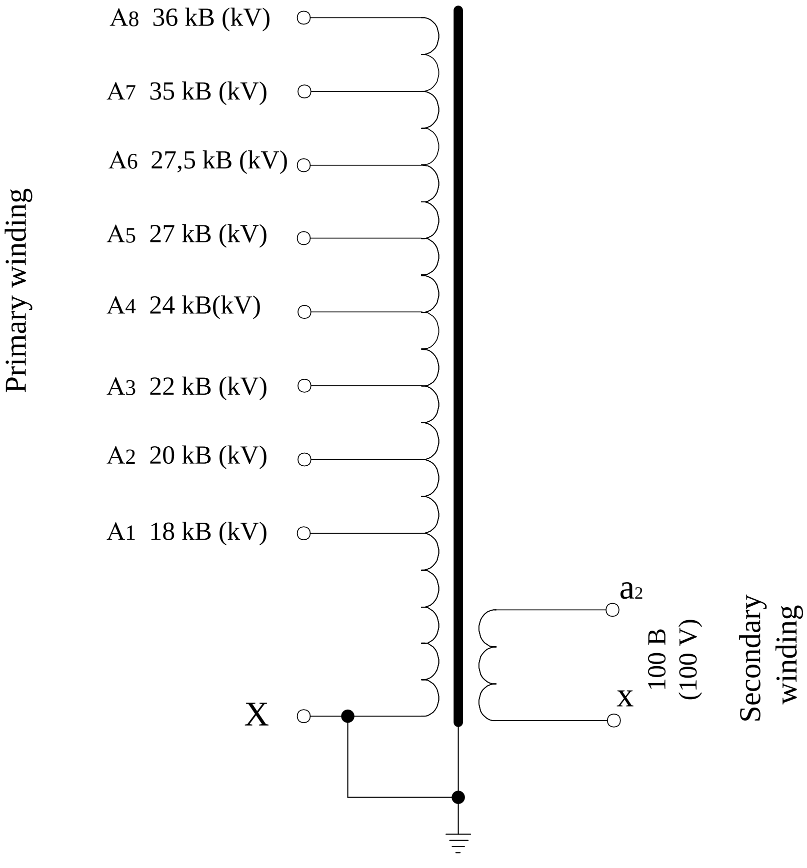
a



b

Figure 1 The photo (*a*) and the electrical scheme (*b*) of the travelling standard ПЭТН-6/10

a



b

Figure 2 The photo (*a*) and the electrical scheme (*b*) of the travelling standard НЛЛ-35

Main characteristics of travelling standards:
voltage transformer ПЭТН-6/10:
- primary rated voltages 6 kV and 10 kV;
- secondary rated voltage 100 V;
- working frequencies 50 Hz and 60 Hz;
- burden 0 V·A (open circuit – burden must be more than 100 kΩ);

voltage transformer НЛЛ-35:
- primary rated voltages 22 kV and 35 kV;
- secondary rated voltage 100 V;
- working frequencies 50 Hz and 60 Hz;
- burden 0 V·A (open circuit – burden must be more than 100 kΩ).

4.2 Handling of travelling standards

Travelling standards will be transported in the transport box which is designed for safe transportation. Upon arrival the participants must check the transport box to make sure that all the parts are present according to the list. The travelling standards will be neatly stacked in a transport box (Figure 3 and Figure 4).

Linear dimensions of transport box according to Figure 3 are: 390x390x250 mm. Weight of this transport box (together with the content) is about 14 kg.

Linear dimensions of transport box according to Figure 4 are: 590x440x570 mm. Weight of this transport box (together with the content) is about 95 kg.

Figure 3 Transport box for travelling standard ПЭТН-6/10

Figure 4 Transport box for travelling standard НЛЛ-35

If the damage of any transport box is found travelling standard must be packed in new transport box which will provide the necessary protection during transporting.

Travelling standards must be carefully removed from the transport box. Opening the corpus of travelling standards is strictly prohibited. If noticed any malfunction of travelling standards, the NMI participants should immediately notify the pilot laboratory by fax or email. If travelling standards are needed to be repaired the NMI participant must send travelling standards to the pilot laboratory.

NMI participants must inform the pilot laboratory by fax or e-mail about the arrival of travelling standards by using the form shown on Figure 5.

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

Figure 5 Sample form for the information of arrival of travelling standards

The NMI participants should inform the pilot laboratory about departure of travelling standards by using the form shown on Figure 6.

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

Figure 6 Sample form for the information of departure of travelling standards

After the measurements, NMI participant of comparison must send the travelling standards to the pilot laboratory. NMI participants in the comparison are responsible for arranging shipment of travelling standards to the pilot laboratory.

IMPORTANT: The travelling standard НЛЛ-35 must be fixed in the transport box using special fasteners that arrive at the participant along with the transport box.

5. Description of the method of measurement

5.1 Operations before measurements

After power up of travelling standards in NMI participant it will be stabilizing for 2 days.

To connect travelling standards NMI participants can use any adapters but participants should take into account all relevant adjustments. Before the measurements, it is necessary to familiarize design features and work principles of travelling standards by using technical description.

5.2 Measurements

Measurements must be performed under the following conditions:
- temperature: 23 °C ± 3 °C;
- relative humidity: from 30 % to 70 %;
- supply frequencies: 50 Hz ± 0.5 Hz and 60 Hz ± 0.6 Hz with a sinusoidal waveform.

The participants should inform the pilot laboratory if the above conditions cannot be met.

The data to be recorded at each measurement:
- date of measurement;
- air temperature and relative humidity environment;
- burden value (in VA or in kΩ) and its PF.

If measurements are carried out within a few days, then measured value together with the measurement date shall be given for each measurement day.

Comparison of national standards is provided by means of measuring of travelling standards metrological characteristics (ratio error ε_u and phase displacement δ_u) per them. Measurements are performed at the values of primary voltage 40, 80, 100 and 120 % of each primary nominal voltage (U_N) on a frequencies of 50 Hz and 60 Hz and at load fixed for travelling standard.

Each NMI participant provides up to ten observations at each operation voltage. Each NMI participant presents arithmetical mean of ten observations and uncertainty in measurements as a result of measurement.

5.3 Measurement uncertainties

Uncertainty of the measurements should be calculated according to the GUM – Guide to the expression of uncertainty in measurement JCGM 100:2008 [1] (GUM 1995 with minor corrections). With the results of measurements should be given a model that describes how the measurement result was obtained considering all influencing quantities.

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 3) should include such number of influencing quantities and their uncertainties, which ensures the highest-level measurements for the laboratory.

Table 3 Uncertainty budget

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	v_i	c_i	$u_i(y)$
1							
…							
y	Std uncertainty of measurement						
		Confidential level = %				k =	
		Expanded uncertainty =					

The components of the uncertainty budget should be expressed as standard uncertainties. The main components of the uncertainty budget are:

- standard uncertainty obtained as a result of an experiment from N independent measurements;

- uncertainty of the standard of the NMI laboratory, by means of which the value of the travelling standard is determined;

- uncertainty caused by the corrections.

Participants in the comparisons may include additional sources of uncertainty.

6. The measurement report

6.1 General information

Each NMI participant of the comparisons shall provide a report within six weeks from the date of departure travelling standards to the pilot laboratory. For quick detection of possible problems with the travelling standards a brief report shall be sent immediately after the measurements.

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

The report shall include:

- description of measurement method(s);

- description of the measurement circuit and used the standard possibilities;

- confirmation of the metrological traceability (if NMI participant has its own units playback system, or must provide proof of traceability from another laboratory).

- temperature and humidity in the laboratory during the measurement;

- measurement results;

- values of the respective standard uncertainties;

- detailed budget of uncertainty, which will be included in a report on the comparisons.

If the corrections affecting the measurement result were applied, then they must be described in the report.

If between the measurements of any NMI participant, 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.

If any NMI laboratory has difficulties in fulfilling one or more of the requirements listed in this protocol, instead of not taking part in the comparison, this NMI laboratory is recommended to contact the coordinator of the comparisons and find a way out of this situation.

6.2 Measurement results

GULFMET.EM-S6 comparison.

Name of NMI participant: ____________________________________

Country: ____

Dates of measurements: from _________ to _________.

Frequency	Nominal primary voltage	Percentage of nominal primary voltage	Ratio error ε_U	Total standard uncertainty for ratio error $u(\varepsilon_U)$	Phase displacement δ_U	Total standard uncertainty for phase displacement $u(\delta_U)$
Hz	kV	%	%	%	crad	crad
50	6	40				
		80				
		100				
		120				
	10	40				
		80				
		100				
		120				
	22	40				
		80				
		100				
		120				

Frequency	Nominal primary voltage	Percentage of nominal primary voltage	Ratio error ε_U	Total standard uncertainty for ratio error $u(\varepsilon_U)$	Phase displacement δ_U	Total standard uncertainty for phase displacement $u(\delta_U)$
Hz	kV	%	%	%	crad	crad
50	35	40				
		80				
		100				
		120				
60	6	40				
		80				
		100				
		120				
	10	40				
		80				
		100				
		120				
	22	40				
		80				
		100				
		120				
	35	40				
		80				
		100				
		120				

7. The report on comparison

Preliminary and final reports on the results of comparison will be prepared by the pilot laboratory. The report will be prepared by the pilot laboratory within 1 month after the end of the measurement, and sent to the NMI participants. The report is only for the NMI participants of comparisons and is confidential.

Notes. The report should be directed to the pilot laboratory for 1 month from the date of distribution of the Draft A. Comments will be considered in the Draft B. Draft B will be completed within 1 month 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] JCGM 100:2008 Evaluation of measurement data – Guide to the expression of uncertainty in measurement.