Final Report

EURAMET.EM-S43

(EURAMET Project No: 1492)

Bilateral supplementary comparison of high voltage transformer measuring systems

Burak Ayhan[1], Peter Räther[2], Hüseyin Cayci[1], Enrico Mohns[2]

[1]TÜBİTAK Ulusal Metroloji Enstitüsü (TÜBİTAK UME), Türkiye (Pilot Laboratory)
[2] Physikalisch-Technische Bundesanstalt (PTB), Germany

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1. Introduction

A bilateral comparison was organized between TÜBİTAK UME and PTB in the field of high voltage transformer measurements. The comparison was registered as EURAMET Project No: EM 1492 and EURAMET.EM-S43 in the BIPM key comparison database.

A new High Voltage Transformer Measuring System has been established to improve the existing measurement uncertainty and to extend the existing measurement range at TÜBİTAK UME. The purpose of the comparison was to demonstrate the improvement and extension of the measurement capabilities of the TÜBİTAK UME in the field of high voltage transformer measurements.

The voltage ratio errors and phase displacements of each ratio of the travelling standards were determined at the defined frequencies, the burdens and a power factor, using each participant's standard measuring method and equipment.

The comparison was carried out in accordance with the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons [1].

2. Organisation of the comparison

2.1. Pilot institute

This comparison was piloted by TÜBİTAK UME. The travelling standards were provided by TÜBİTAK UME. TÜBİTAK UME was responsible for monitoring the performance of travelling standards during the circulation and for the evaluation and reporting of the comparison results.

2.2. Participating institutes

The participating institutes are listed in Table 1.

Table 1. List of participants

Acronym of Institute	Country	Contact Person	Shipping Address
TÜBİTAK UME	Türkiye	Burak AYHAN burak.ayhan@tubitak.gov.tr Tel: +90 262 679 50 00	TÜBİTAK Ulusal Metroloji Enstitüsü (UME) TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, Türkiye
PTB	Germany	Peter Räther Peter.Raether@ptb.de Tel: +49(531)-592-2339	Physikalisch-Technische Bundesanstalt - PTB Bundesallee 100 38116 Braunschweig - Germany

2.3. Comparison schedule

The comparison was organized in a single loop of two laboratories to allow close monitoring of the behaviour of the travelling standards. Each participant had 4 weeks to carry out the measurements and transportation. A large delay, compared to the planned schedule, occurred mainly due to the customs procedures. The actual time schedule is given in Table 2.

Table 2. The actual time schedule for the comparison

Institute	Country	Measurement Dates
TÜBİTAK UME	Türkiye	05.08.2021 – 11.08.2021
PTB	Germany	22.11.2021 – 23.11.2021
TÜBİTAK UME	Türkiye	23.08.2022 – 29.08.2022

3. Travelling standards

The travelling standards are:

- Voltage transformer NVRD 40

Voltage transformer NVRD 40 is a multi-ratio voltage transformer with rated primary voltages from 3 kV to 33 kV, secondary voltages of 100 V, 110V, 120 V, 100 / √3 V, 110 / √3 V, 120 / √3 V, rated burden of 3 VA (PF=1). The nominal operating frequencies of the standard are 50 Hz and 60 Hz.

Voltage transformer NVRD 40 with the serial number of 2/14/1189 was manufactured by EPRO.

Voltage transformer NVRD 40 was shipped in a custom-built transportation case with dimensions 64 cm × 98 cm × 77 cm. The weight of the packed travelling standard in its case is 282 kg.

Voltage transformer NVRD 40 and its transportation case are illustrated in Figure 1.

Figure 1. Travelling standard and transportation case of NVRD 40

- Voltage transformer TSVT-110

Voltage transformer TSVT-110 is a two-stage voltage transformer with rated primary voltage 110 / √3 kV, secondary voltage of 100 V. Nominal operating frequencies of the standard are 50 Hz and 60 Hz.

Voltage transformer TSVT-110 with the serial number of 2021010 was manufactured by CEPRI. Voltage transformer TSVT-110 consists of SF6 gas (4 bar) for high voltage isolation.

Voltage transformer TSVT-110 was shipped in a custom-built transportation case with dimensions 92 cm × 95 cm × 150 cm. The weight of the packed travelling standard in its case is 352 kg.

Voltage transformer TSVT-110 and its transportation case are illustrated in Figure 2.

Figure 2. Travelling standard and transportation case of TSVT-110

4. Measurement instructions

4.1. Conditions of the measurements

Comparison measurements were performed by measuring the following ratios: primary (3000 V, 6000 V, 10000 V, 30000 V and 110000/√3 V) / secondary 100 V.

While the voltage ratios of 30, 60, 100 and 300 were measured with a burden of 3333 Ω at unity power factor, the voltage ratio of 1100/√3 was measured with a burden of 13000 Ω at unity power factor.

Measurements were carried out at 120 %, 100 %, 80 %, 60 % and 40 % of the rated primary voltage.

Comparison was performed at two test frequencies of 50.2 Hz and 60 Hz.

TÜBİTAK UME and PTB followed their usual measurement procedure corresponding to their best measurement capabilities.

4.2. Quantities to be measured

Quantities to be measured are voltage error ε_u (preferably in %) and phase displacement δ_u (preferably in crad) of the travelling standard for each of its rated transformation ratios and for a number of excitation voltages expressed as a percentage of rated primary voltage. Voltage error is defined as the error which a transformer introduces into the measurement of a voltage and which arises when the actual transformation ratio is not equal to the rated transformation ratio. The voltage error ε_u is given by the formula:

$$\varepsilon_u = \frac{K_n U_s - U_p}{U_p}$$

where U_p is the actual primary voltage, and U_s is the actual secondary voltage when U_p is applied under the conditions of measurement. The rated transformation ratio K_n is

$$K_n = \frac{U_{pn}}{U_{sn}}$$

where U_{pn} is the rated primary voltage, and U_{sn} is the rated secondary voltage.

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

5. Reported results

5.1. General information and data

A full measurement report containing all relevant data and uncertainty estimates was forwarded to the coordinator within two weeks of completing measurements. The report included a description of the measurement method (facilities and methodology), the traceability to the SI, and the results, the associated uncertainty and the number of degrees of freedom. The measurement method and uncertainty budgets of each participant are given in Appendix A and B respectively. The additional parameters for measurements of each participant are presented in Table 3.

Table 3. The additional parameters for measurement of each participant

NMI	Parameter	Value	Absolute expanded uncertainty
TÜBİTAK UME	Frequency, Hz	50 and 60	0.005
	Temperature, °C	22±0.5	0.3
	Relative humidity, %	45±10	2
PTB	Frequency, Hz	50 and 60	0.001
	Temperature, °C	23±3	0.1
	Relative humidity, %	50±20	4

5.2. Measurement results

5.2.1. Measurement results of TÜBİTAK UME

Measurement results of TÜBİTAK UME for voltage transformers are given in Table 4.

Table 4. Measurement results of TÜBİTAK UME

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	Ratio error ε_u	Expanded uncertainty for ratio error $U(\varepsilon_u)$	Phase displacement δ_u	Expanded uncertainty for phase displacement $U(\delta_u)$
Hz	V	V	Ω	%	%	%	crad	crad
50.2	3000	100	3333	120	-0.0015	0.0020	-0.0011	0.0020
				100	-0.0020	0.0020	-0.0007	0.0020
				80	-0.0026	0.0020	0.0006	0.0020
				60	-0.0031	0.0020	0.0020	0.0020
				40	-0.0036	0.0020	0.0049	0.0020
	6000	100	3333	120	-0.0013	0.0020	-0.0010	0.0020
				100	-0.0018	0.0020	-0.0005	0.0020
				80	-0.0025	0.0020	0.0007	0.0020
				60	-0.0030	0.0020	0.0021	0.0020
				40	-0.0036	0.0020	0.0050	0.0020
	10000	100	3333	120	-0.0012	0.0020	-0.0035	0.0020
				100	-0.0016	0.0020	-0.0043	0.0020
				80	-0.0024	0.0020	-0.0037	0.0020
				60	-0.0030	0.0020	-0.0025	0.0020
				40	-0.0031	0.0020	-0.0001	0.0020
	30000	100	3333	120	-0.0031	0.0020	-0.0018	0.0020
				100	-0.0035	0.0020	-0.0014	0.0020
				80	-0.0041	0.0020	-0.0004	0.0020
				60	-0.0044	0.0020	0.0010	0.0020
				40	-0.0045	0.0020	0.0035	0.0020
	110000/√3	100	13000	120	-0.0257	0.0020	-0.0025	0.0020
				100	-0.0257	0.0020	-0.0023	0.0020
				80	-0.0257	0.0020	-0.0021	0.0020
				60	-0.0258	0.0020	-0.0019	0.0020
				40	-0.0258	0.0020	-0.0018	0.0020
60	3000	100	3333	120	0.0003	0.0020	-0.0045	0.0020
				100	-0.0002	0.0020	-0.0038	0.0020
				80	-0.0008	0.0020	-0.0026	0.0020
				60	-0.0013	0.0020	-0.0010	0.0020
				40	-0.0017	0.0020	0.0013	0.0020

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	Ratio error ε_u	Expanded uncertainty for ratio error $U(\varepsilon_u)$	Phase displacement δ_u	Expanded uncertainty for phase displacement $U(\delta_u)$
Hz	V	V	Ω	%	%	%	crad	crad
60	6000	100	3333	120	0.0003	0.0020	-0.0044	0.0020
				100	-0.0002	0.0020	-0.0037	0.0020
				80	-0.0007	0.0020	-0.0024	0.0020
				60	-0.0012	0.0020	-0.0009	0.0020
				40	-0.0016	0.0020	0.0015	0.0020
	10000	100	3333	120	0.0000	0.0020	-0.0081	0.0020
				100	-0.0006	0.0020	-0.0078	0.0020
				80	-0.0011	0.0020	-0.0068	0.0020
				60	-0.0014	0.0020	-0.0054	0.0020
				40	-0.0012	0.0020	-0.0036	0.0020
	30000	100	3333	120	0.0003	0.0020	-0.0056	0.0020
				100	-0.0001	0.0020	-0.0051	0.0020
				80	-0.0006	0.0020	-0.0040	0.0020
				60	-0.0009	0.0020	-0.0025	0.0020
				40	-0.0008	0.0020	-0.0004	0.0020
	110000/√3	100	13000	120	-0.0260	0.0020	-0.0030	0.0020
				100	-0.0260	0.0020	-0.0030	0.0020
				80	-0.0260	0.0020	-0.0028	0.0020
				60	-0.0261	0.0020	-0.0027	0.0020
				40	-0.0260	0.0020	-0.0026	0.0020

5.2.2. Measurement results of PTB

Measurement results of PTB for voltage transformers are given in Table 5.

Table 5. Measurement results of PTB

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	Ratio error ε_u	Expanded uncertainty for ratio error $U(\varepsilon_u)$	Phase displacement δ_u	Expanded uncertainty for phase displacement $U(\delta_u)$
Hz	V	V	Ω	%	%	%	crad	crad
50.2	3000	100	3333	120	-0.0006	0.0010	-0.0005	0.0010
				100	-0.0011	0.0010	0.0000	0.0010
				80	-0.0018	0.0010	0.0012	0.0010
				60	-0.0025	0.0010	0.0028	0.0010
				40	-0.0035	0.0010	0.0056	0.0010

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	Ratio error ε_u	Expanded uncertainty for ratio error $U(\varepsilon_u)$	Phase displacement δ_u	Expanded uncertainty for phase displacement $U(\delta_u)$
Hz	V	V	Ω	%	%	%	crad	crad
50.2	6000	100	3333	120	0.0002	0.0010	-0.0005	0.0010
				100	-0.0003	0.0010	-0.0001	0.0010
				80	-0.0010	0.0010	0.0010	0.0010
				60	-0.0017	0.0010	0.0027	0.0010
				40	-0.0027	0.0010	0.0054	0.0010
	10000	100	3333	120	0.0000	0.0010	-0.0026	0.0010
				100	-0.0004	0.0010	-0.0033	0.0010
				80	-0.0010	0.0010	-0.0029	0.0010
				60	-0.0018	0.0010	-0.0017	0.0010
				40	-0.0022	0.0010	0.0004	0.0010
	30000	100	3333	120	-0.0012	0.0010	-0.0019	0.0010
				100	-0.0017	0.0010	-0.0015	0.0010
				80	-0.0024	0.0010	-0.0006	0.0010
				60	-0.0029	0.0010	0.0008	0.0010
				40	-0.0034	0.0010	0.0033	0.0010
	110000/√3	100	13000	120	-0.0254	0.0010	-0.0012	0.0010
				100	-0.0254	0.0010	-0.0012	0.0010
				80	-0.0255	0.0010	-0.0011	0.0010
				60	-0.0256	0.0010	-0.0011	0.0010
				40	-0.0258	0.0010	-0.0010	0.0010
60	3000	100	3333	120	0.0001	0.0010	-0.0040	0.0010
				100	-0.0004	0.0010	-0.0033	0.0010
				80	-0.0010	0.0010	-0.0022	0.0010
				60	-0.0016	0.0010	-0.0006	0.0010
				40	-0.0024	0.0010	0.0017	0.0010
	6000	100	3333	120	0.0009	0.0010	-0.0042	0.0010
				100	0.0004	0.0010	-0.0034	0.0010
				80	-0.0002	0.0010	-0.0024	0.0010
				60	-0.0008	0.0010	-0.0009	0.0010
				40	-0.0016	0.0010	0.0014	0.0010
	10000	100	3333	120	0.0005	0.0010	-0.0070	0.0010
				100	0.0000	0.0010	-0.0068	0.0010
				80	-0.0006	0.0010	-0.0061	0.0010
				60	-0.0011	0.0010	-0.0049	0.0010
				40	-0.0011	0.0010	-0.0031	0.0010

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	Ratio error ε_u	Expanded uncertainty for ratio error $U(\varepsilon_u)$	Phase displacement δ_u	Expanded uncertainty for phase displacement $U(\delta_u)$
Hz	V	V	Ω	%	%	%	crad	crad
60	30000	100	3333	120	0.0008	0.0010	-0.0055	0.0010
				100	0.0003	0.0010	-0.0049	0.0010
				80	-0.0002	0.0010	-0.0039	0.0010
				60	-0.0005	0.0010	-0.0026	0.0010
				40	-0.0007	0.0010	-0.0006	0.0010
	110000/√3	100	13000	120	-0.0257	0.0010	-0.0017	0.0010
				100	-0.0257	0.0010	-0.0017	0.0010
				80	-0.0258	0.0010	-0.0017	0.0010
				60	-0.0259	0.0010	-0.0016	0.0010
				40	-0.0261	0.0010	-0.0015	0.0010

5.3. Calculation of Comparison Reference Values and associated uncertainties

The Comparison Reference Value (CRV) is calculated separately for each parameter. The CRV is considered as an estimation of the measurand according to the measurements provided by the participating laboratories. This estimation, x_{ref}, is determined as a weighted mean of the provided results where the weights are the inverse values of the squares of the associated standard uncertainties [2].

The weighted mean x_{ref} of the data set and the associated expanded uncertainty $U(x_{ref})$ are obtained from

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

and

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

The comparison reference values and expanded uncertainties for all measurements are given in Table 6.

Table 6. Comparison reference values and expanded uncertainties for all measurements

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	CRV for ratio error ε_{ref}	Expanded uncertainty of CRV for ratio error $U(\varepsilon_{ref})$	CRV for phase displacement δ_{ref}	Expanded uncertainty of CRV for phase displacement $U(\delta_{ref})$
Hz	V	V	Ω	%	%	%	crad	crad
50.2	3000	100	3333	120	-0.0008	0.0009	-0.0006	0.0009
				100	-0.0013	0.0009	-0.0001	0.0009
				80	-0.0020	0.0009	0.0011	0.0009
				60	-0.0026	0.0009	0.0026	0.0009
				40	-0.0035	0.0009	0.0055	0.0009
	6000	100	3333	120	-0.0001	0.0009	-0.0006	0.0009
				100	-0.0006	0.0009	-0.0002	0.0009
				80	-0.0013	0.0009	0.0009	0.0009
				60	-0.0020	0.0009	0.0026	0.0009
				40	-0.0029	0.0009	0.0053	0.0009
	10000	100	3333	120	-0.0002	0.0009	-0.0028	0.0009
				100	-0.0006	0.0009	-0.0035	0.0009
				80	-0.0013	0.0009	-0.0031	0.0009
				60	-0.0020	0.0009	-0.0019	0.0009
				40	-0.0024	0.0009	0.0003	0.0009
	30000	100	3333	120	-0.0016	0.0009	-0.0019	0.0009
				100	-0.0021	0.0009	-0.0015	0.0009
				80	-0.0027	0.0009	-0.0006	0.0009
				60	-0.0032	0.0009	0.0008	0.0009
				40	-0.0036	0.0009	0.0033	0.0009
	110000/√3	100	13000	120	-0.0255	0.0009	-0.0015	0.0009
				100	-0.0255	0.0009	-0.0014	0.0009
				80	-0.0255	0.0009	-0.0013	0.0009
				60	-0.0256	0.0009	-0.0013	0.0009
				40	-0.0258	0.0009	-0.0012	0.0009
60	3000	100	3333	120	0.0001	0.0009	-0.0041	0.0009
				100	-0.0004	0.0009	-0.0034	0.0009
				80	-0.0010	0.0009	-0.0023	0.0009
				60	-0.0015	0.0009	-0.0007	0.0009
				40	-0.0023	0.0009	0.0016	0.0009
	6000	100	3333	120	0.0008	0.0009	-0.0042	0.0009
				100	0.0003	0.0009	-0.0035	0.0009
				80	-0.0003	0.0009	-0.0024	0.0009
				60	-0.0009	0.0009	-0.0009	0.0009
				40	-0.0016	0.0009	0.0014	0.0009

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	CRV for ratio error ε_{ref}	Expanded uncertainty of CRV for ratio error $U(\varepsilon_{ref})$	CRV for phase displacement δ_{ref}	Expanded uncertainty of CRV for phase displacement $U(\delta_{ref})$
Hz	V	V	Ω	%	%	%	crad	crad
60	10000	100	3333	120	0.0004	0.0009	-0.0072	0.0009
				100	-0.0001	0.0009	-0.0070	0.0009
				80	-0.0007	0.0009	-0.0062	0.0009
				60	-0.0012	0.0009	-0.0050	0.0009
				40	-0.0011	0.0009	-0.0032	0.0009
	30000	100	3333	120	0.0007	0.0009	-0.0055	0.0009
				100	0.0002	0.0009	-0.0049	0.0009
				80	-0.0003	0.0009	-0.0039	0.0009
				60	-0.0006	0.0009	-0.0026	0.0009
				40	-0.0007	0.0009	-0.0006	0.0009
	110000/√3	100	13000	120	-0.0258	0.0009	-0.0020	0.0009
				100	-0.0258	0.0009	-0.0020	0.0009
				80	-0.0258	0.0009	-0.0019	0.0009
				60	-0.0259	0.0009	-0.0018	0.0009
				40	-0.0261	0.0009	-0.0017	0.0009

5.4. Calculation of degrees of equivalence

The results of the comparison are reported as the degrees of equivalence (DoE) and the CRV.

The degrees of equivalence of each participant are calculated as:

$$D_i = x_i - x_{ref} \quad (3)$$

Where $x_i$is the results of the participant and x_{ref} is the CRV.

The expanded uncertainty of the degree of equivalence for a participant's result $U(D_i)$ is calculated as:

$$U^2(D_i) = U^2(x_i) + U^2(x_{ref}) \quad (4)$$

For each participant's result, the normalized error (E_n) is calculated as:

$$E_n = \frac{|D_i|}{U(D_i)} \quad (5)$$

The participant results are regarded as satisfactory if $E_n \leq 1$.

The DoE of each participant and the associated expanded uncertainties are presented in Table 7 for ratio error measurements and Table 8 for phase displacement measurements.

Table 7. DoE and its uncertainties of the participants for ratio error measurements

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	DoE of TÜBİTAK UME $D(\varepsilon_u)$	DoE of PTB $D(\varepsilon_u)$	Expanded uncertainty of DoE for TÜBİTAK UME $U(D(\varepsilon_u))$	Expanded uncertainty of DoE for PTB $U(D(\varepsilon_u))$
Hz	V	V	Ω	%	%	%	%	%
50.2	3000	100	3333	120	-0.0007	0.0002	0.0022	0.0013
				100	-0.0007	0.0002	0.0022	0.0013
				80	-0.0006	0.0002	0.0022	0.0013
				60	-0.0005	0.0001	0.0022	0.0013
				40	-0.0001	0.0000	0.0022	0.0013
	6000	100	3333	120	-0.0012	0.0003	0.0022	0.0013
				100	-0.0012	0.0003	0.0022	0.0013
				80	-0.0012	0.0003	0.0022	0.0013
				60	-0.0010	0.0003	0.0022	0.0013
				40	-0.0007	0.0002	0.0022	0.0013
	10000	100	3333	120	-0.0010	0.0002	0.0022	0.0013
				100	-0.0010	0.0002	0.0022	0.0013
				80	-0.0011	0.0003	0.0022	0.0013
				60	-0.0010	0.0002	0.0022	0.0013
				40	-0.0007	0.0002	0.0022	0.0013
	30000	100	3333	120	-0.0015	0.0004	0.0022	0.0013
				100	-0.0014	0.0004	0.0022	0.0013
				80	-0.0014	0.0003	0.0022	0.0013
				60	-0.0012	0.0003	0.0022	0.0013
				40	-0.0009	0.0002	0.0022	0.0013
	110000/√3	100	13000	120	-0.0002	0.0001	0.0022	0.0013
				100	-0.0002	0.0001	0.0022	0.0013
				80	-0.0002	0.0000	0.0022	0.0013
				60	-0.0002	0.0000	0.0022	0.0013
				40	0.0000	0.0000	0.0022	0.0013
60	3000	100	3333	120	0.0002	0.0000	0.0022	0.0013
				100	0.0002	0.0000	0.0022	0.0013
				80	0.0002	0.0000	0.0022	0.0013
				60	0.0002	-0.0001	0.0022	0.0013
				40	0.0006	-0.0001	0.0022	0.0013
	6000	100	3333	120	-0.0005	0.0001	0.0022	0.0013
				100	-0.0005	0.0001	0.0022	0.0013
				80	-0.0004	0.0001	0.0022	0.0013
				60	-0.0003	0.0001	0.0022	0.0013
				40	0.0000	0.0000	0.0022	0.0013

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	DoE of TÜBİTAK UME $D(\varepsilon_u)$	DoE of PTB $D(\varepsilon_u)$	Expanded uncertainty of DoE for TÜBİTAK UME $U(D(\varepsilon_u))$	Expanded uncertainty of DoE for PTB $U(D(\varepsilon_u))$
Hz	V	V	Ω	%	%	%	%	%
60	10000	100	3333	120	-0.0004	0.0001	0.0022	0.0013
				100	-0.0005	0.0001	0.0022	0.0013
				80	-0.0004	0.0001	0.0022	0.0013
				60	-0.0002	0.0001	0.0022	0.0013
				40	-0.0001	0.0000	0.0022	0.0013
	30000	100	3333	120	-0.0004	0.0001	0.0022	0.0013
				100	-0.0003	0.0001	0.0022	0.0013
				80	-0.0003	0.0001	0.0022	0.0013
				60	-0.0003	0.0001	0.0022	0.0013
				40	-0.0001	0.0000	0.0022	0.0013
	110000/√3	100	13000	120	-0.0002	0.0001	0.0022	0.0013
				100	-0.0002	0.0001	0.0022	0.0013
				80	-0.0002	0.0000	0.0022	0.0013
				60	-0.0002	0.0000	0.0022	0.0013
				40	0.0001	0.0000	0.0022	0.0013

Table 8. DoE and its uncertainties of the participants for phase displacement measurements

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	DoE of TÜBİTAK UME $D(\delta_u)$	DoE of PTB $D(\delta_u)$	Expanded uncertainty of DoE for TÜBİTAK UME $U(D(\delta_u))$	Expanded uncertainty of DoE for PTB $U(D(\delta_u))$
Hz	V	V	Ω	%	crad	crad	crad	crad
50.2	3000	100	3333	120	-0.0005	0.0001	0.0022	0.0013
				100	-0.0006	0.0001	0.0022	0.0013
				80	-0.0005	0.0001	0.0022	0.0013
				60	-0.0006	0.0002	0.0022	0.0013
				40	-0.0006	0.0001	0.0022	0.0013
	6000	100	3333	120	-0.0004	0.0001	0.0022	0.0013
				100	-0.0003	0.0001	0.0022	0.0013
				80	-0.0002	0.0001	0.0022	0.0013
				60	-0.0005	0.0001	0.0022	0.0013
				40	-0.0003	0.0001	0.0022	0.0013
	10000	100	3333	120	-0.0007	0.0002	0.0022	0.0013
				100	-0.0008	0.0002	0.0022	0.0013
				80	-0.0006	0.0002	0.0022	0.0013
				60	-0.0006	0.0002	0.0022	0.0013
				40	-0.0004	0.0001	0.0022	0.0013

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	DoE of TÜBİTAK UME $D(\delta_u)$	DoE of PTB $D(\delta_u)$	Expanded uncertainty of DoE for TÜBİTAK UME $U(D(\delta_u))$	Expanded uncertainty of DoE for PTB $U(D(\delta_u))$
Hz	V	V	Ω	%	crad	crad	crad	crad
50.2	30000	100	3333	120	0.0001	0.0000	0.0022	0.0013
				100	0.0001	0.0000	0.0022	0.0013
				80	0.0002	0.0000	0.0022	0.0013
				60	0.0002	0.0000	0.0022	0.0013
				40	0.0002	0.0000	0.0022	0.0013
	110000/√3	100	13000	120	-0.0010	0.0003	0.0022	0.0013
				100	-0.0009	0.0002	0.0022	0.0013
				80	-0.0008	0.0002	0.0022	0.0013
				60	-0.0006	0.0002	0.0022	0.0013
				40	-0.0006	0.0002	0.0022	0.0013
60	3000	100	3333	120	-0.0004	0.0001	0.0022	0.0013
				100	-0.0004	0.0001	0.0022	0.0013
				80	-0.0003	0.0001	0.0022	0.0013
				60	-0.0003	0.0001	0.0022	0.0013
				40	-0.0003	0.0001	0.0022	0.0013
	6000	100	3333	120	-0.0002	0.0000	0.0022	0.0013
				100	-0.0002	0.0001	0.0022	0.0013
				80	0.0000	0.0000	0.0022	0.0013
				60	0.0000	0.0000	0.0022	0.0013
				40	0.0001	0.0000	0.0022	0.0013
	10000	100	3333	120	-0.0009	0.0002	0.0022	0.0013
				100	-0.0008	0.0002	0.0022	0.0013
				80	-0.0006	0.0001	0.0022	0.0013
				60	-0.0004	0.0001	0.0022	0.0013
				40	-0.0004	0.0001	0.0022	0.0013
	30000	100	3333	120	-0.0001	0.0000	0.0022	0.0013
				100	-0.0002	0.0000	0.0022	0.0013
				80	-0.0001	0.0000	0.0022	0.0013
				60	0.0001	0.0000	0.0022	0.0013
				40	0.0002	0.0000	0.0022	0.0013
	110000/√3	100	13000	120	-0.0010	0.0003	0.0022	0.0013
				100	-0.0010	0.0003	0.0022	0.0013
				80	-0.0009	0.0002	0.0022	0.0013
				60	-0.0009	0.0002	0.0022	0.0013
				40	-0.0009	0.0002	0.0022	0.0013

E_N values of each participant for ratio error and phase displacement measurements are given in Table 9.

Table 9. E_N values of the participants for ratio error and phase displacement measurements

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	E_N value of TÜBİTAK UME for ratio error $E_n(\varepsilon_u)$	E_N value of PTB for ratio error $E_n(\varepsilon_u)$	E_N value of TÜBİTAK UME for phase displacement $E_n(\delta_u)$	E_N value of PTB for phase displacement $E_n(\delta_u)$
Hz	V	V	Ω	%				
50.2	3000	100	3333	120	0.32	0.15	0.23	0.07
				100	0.32	0.15	0.27	0.07
				80	0.27	0.15	0.23	0.07
				60	0.23	0.07	0.27	0.15
				40	0.05	0.00	0.27	0.07
	6000	100	3333	120	0.55	0.22	0.18	0.07
				100	0.55	0.22	0.14	0.07
				80	0.55	0.22	0.09	0.07
				60	0.46	0.22	0.23	0.07
				40	0.32	0.15	0.14	0.07
	10000	100	3333	120	0.46	0.15	0.32	0.15
				100	0.46	0.15	0.36	0.15
				80	0.50	0.22	0.27	0.15
				60	0.46	0.15	0.27	0.15
				40	0.32	0.15	0.18	0.07
	30000	100	3333	120	0.68	0.30	0.05	0.00
				100	0.64	0.30	0.05	0.00
				80	0.64	0.22	0.09	0.00
				60	0.55	0.22	0.09	0.00
				40	0.41	0.15	0.09	0.00
	110000/√3	100	13000	120	0.09	0.07	0.46	0.22
				100	0.09	0.07	0.41	0.15
				80	0.09	0.00	0.36	0.15
				60	0.09	0.00	0.27	0.15
				40	0.00	0.00	0.27	0.15
60	3000	100	3333	120	0.09	0.00	0.18	0.07
				100	0.09	0.00	0.18	0.07
				80	0.09	0.00	0.14	0.07
				60	0.09	0.07	0.14	0.07
				40	0.27	0.07	0.14	0.07
	6000	100	3333	120	0.23	0.07	0.09	0.00
				100	0.23	0.07	0.09	0.07
				80	0.18	0.07	0.00	0.00
				60	0.14	0.07	0.00	0.00
				40	0.00	0.00	0.05	0.00

Frequency f	Nominal primary voltage U_{pn}	Nominal secondary voltage U_{sn}	Burden Z_b	Percentage of nominal primary voltage U_p/U_{pn}	E_N value of TÜBİTAK UME for ratio error $E_n(\varepsilon_u)$	E_N value of PTB for ratio error $E_n(\varepsilon_u)$	E_N value of TÜBİTAK UME for phase displacement $E_n(\delta_u)$	E_N value of PTB for phase displacement $E_n(\delta_u)$
Hz	V	V	Ω	%				
60	10000	100	3333	120	0.18	0.07	0.41	0.15
				100	0.23	0.07	0.36	0.15
				80	0.18	0.07	0.27	0.07
				60	0.09	0.07	0.18	0.07
				40	0.05	0.00	0.18	0.07
	30000	100	3333	120	0.18	0.07	0.05	0.00
				100	0.14	0.07	0.09	0.00
				80	0.14	0.07	0.05	0.00
				60	0.14	0.07	0.05	0.00
				40	0.05	0.00	0.09	0.00
	110000/√3	100	13000	120	0.09	0.07	0.46	0.22
				100	0.09	0.07	0.46	0.22
				80	0.09	0.00	0.41	0.15
				60	0.09	0.00	0.41	0.15
				40	0.05	0.00	0.41	0.15

6. Conclusion

The bilateral comparison has been conducted between TÜBİTAK UME and PTB. The voltage ratio ranges were from 30 to 1100/√3, at 50.2 Hz and 60 Hz. The uncertainties of TÜBİTAK UME are declared as 0.0020 % for ratio error measurements and 0.0020 crad for phase displacement measurements while the uncertainties of PTB are declared as 0.0010 % and 0.0010 crad respectively.

As traveling standard, two voltage transformers were used. They have low dependence on ambient parameters and very stable behavior. Both characteristics were very important because of the long time required for the comparison, due to hard difficulties in customs procedures.

The comparison results showed a good agreement between TÜBİTAK UME and PTB both for the ratio errors and phase displacements within the stated uncertainties. E_N values for each participant for all measurement points satisfy Equation (5).

TÜBİTAK UME’s new High Voltage Transformer Measuring System has been verified upon the completion of the comparison.

7. References

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

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

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[5] E. Mohns, J. Chunyang, H. Badura and P. Raether: "A Fundamental Step-Up Method for Standard Voltage Transformers Based on an Active Capacitive High-Voltage Divider," IEEE Trans. Instrum. Meas., vol. 68, no. 6, pp. 2121-2128, June 2019, DOI: 10.1109/TIM.2018.2880055

ANNEX A. Measurement methods for each participant

A.1. TÜBİTAK UME

Measurement circuits of TÜBİTAK UME are shown in Figure A 1. 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.

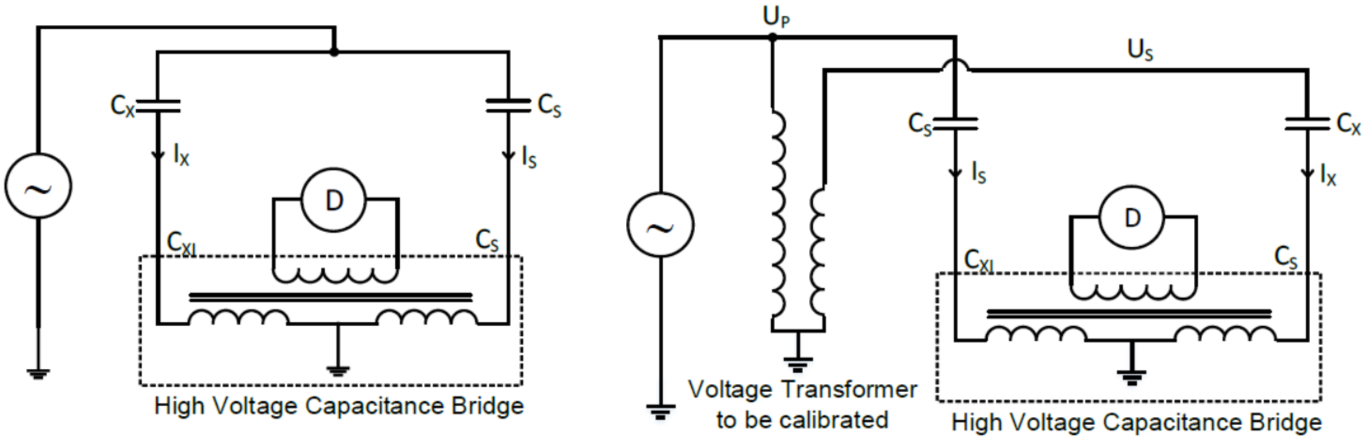

Figure A 1. Measurement circuit for Step 1 (a) and Step 2 (b)

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 an 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 their 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 the 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 the minimum up to highest test point, and then continuing by measuring the points in descending order.

A.2. PTB

The calibration was carried out by means of the ratio method, using a PTB standard voltage transformer as a reference. The principle of the ratio-based comparison method is shown in Figure A 2 [4, 5]. The transformer under test (X) and the VT (N) are connected to the high AC voltage U_p. Their secondary sides with the voltages U_X and U_N, which are usually on the order of 100 V, are connected to the ratio bridge (gray area, "ESM IV"). At the input of this bridge, two very accurate VTs, (A) and (B), together with an independent setting of their nominal divider ratio Dn, are used to scale U_X and U_N to the voltages U_B and U_A. The separate adjustment of VT (A) and (B) serves two purposes: (i) to prevent the inputs of the "HRPM" two-channel sampling system from overloading; and (ii) to bring the ratio of U_B and U_A close to one.

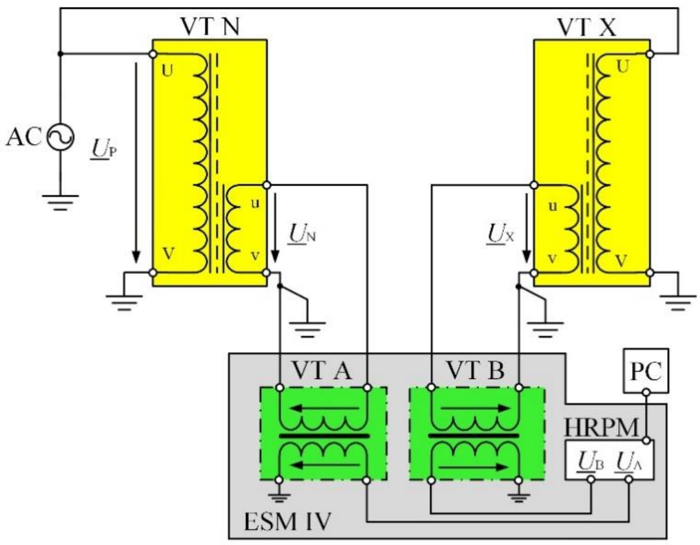

Figure A 2. Ratio-based calibration method for VTs.

Using the definitions for VT (N) and (X), as well as for VT (A) and (B), from the measured complex voltage ratio U_B / U_A, the ratio error ε_X and the phase error δ_X of VT (X) can be determined.

ANNEX B. Uncertainty budgets for each participant

B.1. TÜBİTAK UME

The uncertainty budgets of TÜBİTAK UME given in the Table B 1 and Table B 2 show the uncertainty contributions associated with the ratio error and phase displacement measurements of voltage transformers.

Table B 1. Uncertainty budget of TÜBİTAK UME for ratio error measurement

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 B 2. Uncertainty budget of TÜBİTAK UME for phase displacement measurement

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 [3].

B.2. PTB

The uncertainty budgets of PTB given in the Table B 3 and Table B 4show the uncertainty contributions associated with the ratio error and phase displacement measurements of voltage transformers.

Table B 3. Uncertainty Budget of PTB for ratio errors for calibrating voltage transformer with nominal primary voltages up to 120 kV / √3.

Quantity	Description	Unit
ε_X	Result: ratio error of the transformer (X)	µV / V
ε_N	Ratio error of the standard (N)	µV / V
ε_D	Indicated difference of the bridge for the ratio error X - N	µV / V
ε_{Bridge}	Uncertainty of the transformer measuring bridge	µV / V
ε_{LP}	Influence of the test point	µV / V
ε_B	Sensitivity of the transformer (X) due to a burden change	µV / V
ε_{Setup}	Influence of the setup	µV / V

model equation: $\varepsilon_x = \varepsilon_D + \varepsilon_N + \varepsilon_{Bridge} + \varepsilon_{LP} + \varepsilon_B + \varepsilon_{Setup}$

Quantity	Value	Standard uncertainty u	Distribution	Type	Sensitivity coefficient c	Variance $(c\ u)^2$	Index in %
ε_N	12,0 µV / V	1,5 µV / V	normal	B	1	2,1E+00	62,7
ε_D	-12,0 µV / V	0,4 µV / V	normal	A	1	1,6E-01	4,8
ε_{Bridge}	0,0 µV / V	0,2 µV / V	rectangular	B	1	4,0E-02	1,2
ε_{LP}	0,0 µV / V	0,2 µV / V	rectangular	B	1	4,0E-02	1,2
ε_B	0,0 µV / V	0,1 µV / V	rectangular	B	1	1,0E-02	0,3
ε_{Setup}	0,0 µV / V	1,0 µV / V	rectangular	B	1	1,0E+00	29,8
					Sum	3,4E+00	
ε_x	0 µV / V				U =	3,7	µV/V (k=2)

Table B 4. Uncertainty Budget of PTB for phase displacements for calibrating voltage transformer with nominal primary voltages up to 120 kV / √3.

Quantity	Description	Unit
δ_X	Result: phase displacement of the transformer (X)	µrad
δ_N	phase displacement of the standard (N)	µrad
δ_D	Indicated difference of the bridge for the phase displacement X - N	µrad
δ_{Bridge}	Uncertainty of the transformer measuring bridge	µrad
δ_{LP}	Influence of the test point	µrad
δ_B	Sensitivity of the transformer (X) due to burden change	µrad
δ_{Setup}	Influence of the setup	µrad

model equation: $\delta_x = \delta_D + \delta_N + \delta_{Bridge} + \delta_{LP} + \delta_B + \delta_{Setup}$

Quantity	Value	Standard uncertainty u	Distribution	Type	Sensitivity coefficient c	Variance $(c\ u)^2$	Index in %
δ_N	29,6 µrad	1,8 µrad	normal	B	1	3,1E+00	70,2
δ_D	-29,6 µrad	0,4 µrad	normal	A	1	1,6E-01	3,7
δ_{Bridge}	0,0 µrad	0,3 µrad	rectangular	B	1	9,0E-02	2,1
δ_{LP}	0,0 µrad	0,2 µrad	rectangular	B	1	4,0E-02	0,9
δ_B	0,0 µrad	0,1 µrad	rectangular	B	1	1,0E-02	0,2
δ_{Setup}	0,0 µrad	1,0 µrad	rectangular	B	1	1,0E+00	22,9
					Sum	4,4E+00	
δ_x	0,0 µrad				U =	4,2	µrad (k=2)

The uncertainty stated is the expanded measurement uncertainty obtained by multiplying the standard measurement uncertainty by the coverage factor k = 2. It has been determined in accordance with the “Guide to the Expression of Uncertainty in Measurement (GUM)”. The value of the measurand then normally lies, with a probability of approximately 95 %, within the attributed coverage interval.

The stated measurement uncertainty which is used in the comparison is:

Ratio error: $U(\varepsilon_u)$ = 10 µV/V

Phase displacement: $U(\delta_u)$ = 10 µrad

TECHNICAL PROTOCOL

Bilateral Comparison between the High Voltage Transformer Measuring Systems of TÜBİTAK UME and PTB

Pilot Lab:
Burak AYHAN
TÜBİTAK UME

Co-author:
Peter Raether
PTB

(Rev. 1)
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1. Introduction

Bilateral comparison was planned to verify TÜBİTAK UME's new High Voltage Transformer Measuring System. The measuring system was developed within in the frame of the project of "Design of Reference Voltage Transformer and Ensuring Traceability of High Voltage Ratio and Phase Measurements to National Standards".

UME is acting as the pilot institute. The travelling standards will be provided by TÜBİTAK UME. TÜBİTAK UME will be responsible to monitoring performance of travelling standards during the circulation and the evaluation and reporting of the comparison results.

The comparison will be carried out in accordance with the CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons [1].

2. Travelling Standards

2.1. Description of Travelling Standards

The travelling standards are:

- Voltage transformer NVRD 40

  Voltage transformer NVRD 40 is a multi-ratio voltage transformer with rated primary voltages from 3 kV to 33 kV, secondary voltages of 100 V, 110V, 120 V, 100 / √3 V, 110 / √3 V, 120 / √3 V, rated burden of 3 VA (PF=1). The nominal operating frequencies of the standard are 50 Hz and 60 Hz.

  Voltage transformer NVRD 40 with the serial number of 2/14/1189 was manufactured by EPRO.

  Voltage transformer NVRD 40 will be shipped in a custom built transportation case with dimensions 64 cm × 98 cm × 77 cm. The weight of the packed travelling standard in its case is 282 kg.

  Voltage transformer NVRD 40 and its transportation case are illustrated in Figure 1.

Figure 1. Travelling standard and transportation case of NVRD 40

- Voltage transformer TSVT-110

  The voltage transformer TSVT-110 is a two-stage voltage transformer with rated primary voltage 110 / √3 kV, secondary voltage of 100 V. The nominal operating frequencies of the standard are 50 Hz and 60 Hz.

  The voltage transformer TSVT-110 with the serial number of 2021010 was manufactured by CEPRI. **The voltage transformer TSVT-110 consists of SF6 gas (4 bar) for high voltage isolation.**

  The voltage transformer TSVT-110 will be shipped in a custom built transportation case with dimensions 92 cm × 95 cm × 150 cm. The weight of the packed travelling standard in its case is 352 kg.

  The voltage transformer TSVT-110 and its transportation case are illustrated in Figure 2.

Figure 2. Travelling standard and transportation case of TSVT-110

2.2. Quantities to be Measured

The quantities to be measured are the voltage error ε_u (preferably in %) and the phase displacement δ_u (preferably in crad) of the travelling standard for each of its rated transformation ratios and for a number of excitation voltages expressed as a percentage of rated primary voltage. The voltage error is defined as the error which a transformer introduces into the measurement of a voltage and which arises when the actual transformation ratio is not equal to the rated transformation ratio. The voltage error ε_u is given by the formula:

$$\varepsilon_u = \frac{K_n U_s - U_p}{U_p}$$

where U_p is the actual primary voltage, and U_s is the actual secondary voltage when U_p is applied under the conditions of measurement. The rated transformation ratio K_n is

$$K_n = \frac{U_{p,r}}{U_{s,r}}$$

where $U_{p,r}$ is the rated primary voltage, and $U_{s,r}$ is the rated secondary voltage.

The phase displacement δ_u is defined as the difference in phase between the primary voltage and the secondary voltage vectors, the direction of the vectors being chosen so 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.

2.3. Calculating the Reference Value

The reference value and associated uncertainty for each test point will be a weighted mean and weighted uncertainty, respectively, calculated from the results of two participating laboratories. The instrument transformer shall also be measured by TÜBİTAK UME prior to shipment to PTB and on its immediate return from PTB, and an additional component of uncertainty will be applied for the stability of the instrument transformer derived from the spread of those results.

3. Participant Laboratories

The pilot institute for this comparison is TÜBİTAK UME (Turkey). The contact details of the coordinator are given in the Table 1. The participating institutes and contact persons with their addresses are given in the Table 2.

Table 1. Pilot Institute

Pilot Institute :	TÜBİTAK Ulusal Metroloji Enstitüsü (UME)
Coordinator :	Burak AYHAN Tel: +90 262 679 50 00 Fax: +90 262 679 50 01 E-mail: burak.ayhan@tubitak.gov.tr

Table 2. Participants

Turkey	TÜBİTAK Ulusal Metroloji Enstitüsü	TÜBİTAK UME	TÜBİTAK Ulusal Metroloji Enstitüsü (UME) TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze-Kocaeli, TURKEY	Burak AYHAN burak.ayhan@tubitak.gov.tr Tel: +90 262 679 50 00
Germany	Physikalisch-Technische Bundesanstalt - PTB	PTB	Physikalisch-Technische Bundesanstalt - PTB Bundesallee 100 38116 Braunschweig - Germany	Peter Raether Tel: +49(531)-592-2339 Fax: +49(531)-592-69 2339 Email: Peter.Raether@ptb.de

4. Time Schedule

The time schedule for the comparison is given in the Table 3. The comparison will be organized in a single loop of two laboratories in order to allow close monitoring of the behaviour of the standards. Each laboratory will have 4 weeks to carry out the measurements and transportation. Any deviation in the agreed plan should be approved by the pilot institute.

Table 3. Circulation Time Schedule

Acronym of Institute	Country	Starting Date	Time for measurement and transportation
TÜBİTAK UME	Turkey	August, 2021	2 weeks
PTB	Germany	October-November, 2021	4 weeks
TÜBİTAK UME	Turkey	December, 2021	2 weeks

5. Transportation of Travelling Standards

The standard voltage transformers will be transported with an ATA Carnet for customs clearance. The participants are responsible for arranging transport and insurance from their institute to the next participant. The travelling standards will be shipped by highway. Extreme temperatures, pressure and humidity changes as well as violent impacts should be avoided.

After arrival in the participant’s laboratory, the standards should be allowed to stabilize in a temperature and possibly, humidity controlled room for at least one day before use.

Each institute will have two weeks available. This includes the measurements and the transportation of the standards to the next participant.

6. Failure of Travelling Standards

In case of any damage or malfunction of the travelling standards in any way during operation, TÜBİTAK UME must be notified immediately and then the comparison will be carried out after the travelling standards are repaired.

7. Financial aspects

Each participant institute is responsible for its own costs for the measurements as well as any damage that may occur within its country.

The overall costs for the organization of the comparison are covered by the pilot institute. The pilot institute has no insurance for any loss or damage of the travelling standards.

8. Measurement Quantities and Points

The quantities to be measured and the measurement points are given in the Table 4. Ambient temperature and relative humidity in the laboratory during the measurements must be recorded. No correction will be applied for the ambient temperature and relative humidity.

Table 4. Measurement Points

Nominal Primary Voltage	Nominal Secondary Voltage	Burden	Freq.	Percentage of Nominal Voltage	Ratio Error	Standard Uncertainty for Ratio Error	Phase Displacement	Standard Uncertainty for Phase Displacement
kV	V	Ω	Hz	%	(%)	(%)	(crad)	(crad)
3	100	3333	50	120				
				100				
				80				
				60				
				40				
			60	120				
				100				
				80				
				60				
				40				
6	100	3333	50	120				
				100				
				80				
				60				
				40				
			60	120				
				100				
				80				
				60				
				40				
10	100	3333	50	120				
				100				
				80				
				60				
				40				
			60	120				
				100				
				80				
				60				
				40				
30	100	3333	50	120				
				100				
				80				
				60				
				40				
			60	120				
				100				
				80				
				60				
				40				
110 / √3	100	13000	50	120				
				100				
				80				
				60				
				40				
			60	120				
				100				
				80				
				60				
				40				

9. Measurement Instructions

9.1. Tests before Measurements

Visual inspection for damage to the cast resin case of travelling standards, terminals and insulators that may have occurred in transport.

DC winding resistance checks should be performed to ensure the integrity of the internal connections and coils. Beware of the possible magnetisation of the magnetic core due to this test.

9.2. Measurements

The environmental conditions (temperature and humidity) during the measurements must be recorded. The recommended conditions are (20 to 23) °C ± 0.5 °C with a maximum of 65 % rh.

The terminals of voltage transformer NVRD 40 marked "B", "b" and "⊥" should be earthed to the measurement ground during the comparison measurements.

Voltage transformer TSVT-110 consists of SF6 gas for high voltage isolation. ***Please check whether there is 4 bar pressure on the pressure gauge before starting the comparison measurements.***

The supply frequencies are 50 Hz ± 0.5 Hz for 50 Hz measurements and 60 Hz ± 0.6 Hz for 60 Hz measurements with a sinusoidal waveform.

10. Measurement Uncertainty

The uncertainty of measurement must be calculated according to the JCGM 100 "Guide to the Expression of Uncertainty in Measurement" [2] for the coverage probability of approximately 95%.

All contributions to the measurement uncertainty should be listed in the report submitted by each participant. Even though the contributions to the uncertainty are specific to the measurement method used, it may be useful to consider the list of uncertainty sources given below.

1. Type A
2. Calibration of bridge and comparator
3. Error in the bridge
4. Error due to frequency setting
5. Error due to burden setting
6. Error due to temperature
7. Circuit configuration
8. Error due to voltage setting

This is not a complete list and should be extended with uncertainty contributions that are specific for the participant's measurement system.

11. Reporting of Results

The results should be communicated to the pilot institute within 30 days of completing the measurements.

The participant shall report their results using the standard certificate that they would normally issue to a customer. However, results shall also be reported in the pilot institute. The report must contain at least:

- Details of participating institute,
- The date and time of the measurements,
- A detailed description of the method used,
- The measurement standards used in the comparison measurements,
- Software used in the comparison measurements
- The environmental conditions during the measurements;
    - ambient temperature
    - relative humidity
- Results of measurement; The measurement results shall be provided according to Table .
- A statement of traceability,
- The Type A standard uncertainty;
- Detailed uncertainty budget with the different sources of uncertainty and their values, as;
- Expanded measurement uncertainty, estimated for the coverage probability of approximately 95%.

12. Final Report of the Comparison

The pilot institute is responsible for the preparation of a comparison report.

The draft version of the comparison report will be issued within two months after receiving the participant report by the pilot institute. Draft report will be sent to the PTB for discussion and approval. This draft will be confidential to the participants.

The participant will have one week to send their comments on Draft Report. After approval, Draft Report will become the Final Report. The Final Report will form the basis for the publication of results.

13. References

[1] CCEM Guidelines for Planning, Organizing, Conducting and Reporting Key, Supplementary and Pilot Comparisons, 2007 (available on the BIPM website: http://www.bipm.org/utils/common/pdf/CC/CCEM/ccem_guidelines.pdf)

[2] Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement (GUM), JCGM 100, First edition, September 2008 (available on the BIPM website: http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf)