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Main results of supplementary comparisons of high voltage and current measuring systems

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Abstract

High voltages of alternative current (AC) are important because they are needed for numerous applications in physics and engineering. High AC voltages are also used to test insulating materials for their dielectric properties. Calibrations of instruments for high-voltage measurements should provide metrological traceability to national standards. This applies to the requirements for both voltage measuring instruments and current measuring instruments. The transformer for high-voltage measurements is used to reduce the values of currents and voltages during measurements in high-voltage electrical networks.

Voltage transformers (VTs) are used to accurately measure high AC voltages. Current transformers (CTs) are used to convert line currents in power systems to levels that are acceptable for other measuring instruments, which are necessary to trip protective devices. There are measuring installations that are well known for accurate measurements of the CT coefficient for large primary currents, and systems for determining the behaviour of the industrial current and VT under distorted waveforms, etc. The calibration of a high voltage measuring system must be traceable to national or international measurement standards. Mutual comparisons of calibration results of CT and VT standards are carried out with the participation of several national laboratories.

The results of high voltage transformer measuring systems (GULFMET.EM-S6) and high current transformer measuring systems (GULFMET.EM-S7) supplementary comparisons are described. The comparisons were carried out between national laboratories from three Regional Metrology Organizations. In general, the participants of both comparisons have demonstrated a good agreement of the results in the ratio error and phase displacement for high voltage and current. The comparison results may be used to improve the participants' existing calibration and measurement capabilities entries in the Key Comparison Database (KCDB) of the International Bureau of Weights and Measures (BIPM).

Keywords: AC high-voltage; AC high-current; standard; measurement; uncertainty of measurement.

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Introduction

High voltages of alternative current (AC) are important because they are needed for numerous applications in physics and engineering. High AC voltages are also used to test insulating materials for their dielectric properties. Calibrations of instruments for high-voltage measurements should provide metrological traceability to national standards. This applies to the requirements for both voltage measuring instruments and current measuring instruments [1].

Direct measurements of high AC voltages is possible up to about 200 kV. Several types of voltmeters can be directly connected across the test circuit. Step-down transformers and voltage dividers are also used for high AC voltage measurements. The transformer for high-voltage measurements is used to reduce the values of currents and voltages during measurements in high-voltage electrical networks. Voltage transformers (VTs) are used to accurately measure high AC voltages. The voltage on the secondary windings of VTs is closely proportional in the amplitude and almost in the phase to the voltage on the primary windings [2].

Large power transmission systems use high AC voltage measurements for many applications. Current transformers (CTs) are used to convert line currents in power systems to levels that are acceptable for other measuring instruments, which are necessary to trip protective devices. In this case, the primary winding of the CT is connected in series with the high-voltage circuit, and the secondary winding is connected to the indicated measuring instruments [3].

A measurement setup is described in [4], which was developed for accurate ratio measurements of AC by CTs for primary currents up to 5 kA. Secondary current sampling digitizers, together with step-down transformers, are also used in high-voltage power systems. In such systems, it is necessary to measure the harmonic content in the low-voltage measuring part. A measuring system, which uses a digitizer to characterize industrial current and voltage transformers with the harmonic signal distortion, is described in [5].

The PTB (Germany) carried out an intercomparison of the calibration of a CT standard and a VT standard in cooperation with the SMU (Slovakia), GUM (Poland), UkrCSM (Ukraine) and VNIIMS (Russia) [6]. In addition, the PTB (Germany) and the NRC (Canada) carried out bilateral comparisons of calibration systems for high-voltage transformers. For the comparisons, a portable calibration system for VTs of the NRC based on a current comparator was used. At the frequencies of 50 Hz and 60 Hz with a resistive burden and voltages of 20% up to 120% of the rated voltage, the results of two different methods at all ratios were found to differ by no more than 15×10^{-6} for the voltage ratio and 30 rad for the phase displacement [7].

The problem statement, purpose and objectives of the study

The purpose of the paper is to highlight the results of supplementary comparisons of high AC voltage measuring systems for VTs and CTs, in particular:

- analysis of the stability of transmission standards and the consistency of the results obtained by the participants of the comparisons;
- analysis of the possibility of improving the calibration and measurement capabilities of the participants of the comparisons.

Travelling standards for supplementary comparisons

The GULFMET supplementary comparisons of high voltage transformer measuring systems (GULFMET.EM-S6) and high current transformer measuring systems (GULFMET.EM-S7) were conducted from November 2020 to December 2021 [8, 9]. Three national laboratories took part in the comparisons: SE “Ukrmetrteststandard” (UMTS, Ukraine – pilot laboratory), SASO-NMCC (Saudi Arabia) and UME (Turkey) from the following Regional Metrology Organizations (RMO): GULFMET, COOMET, and EURAMET.

The National primary standard of units of the AC electric voltage in the range from 1 to $1.2\times330/\sqrt{3}$ kV and with the coefficient of the scale transformation of the electric voltage at the frequency of 50 Hz (DETU 08-05-99) took part in the GULFMET.EM-S6 comparison from UMTS. The National primary standard of the unit of the coefficient of the scale transformation of the AC current at the industrial frequency (NDETU EM-03-2020) took part in the GULFMET.EM-S7 comparison from UMTS.

Voltage transformers ПЭТН-6/10 and НЛЛ-35 were selected as travelling standards for the GULFMET.EM-S6 comparison. The travelling standard ПЭТН-6/10 is characterised by primary rated voltages of 6 kV and 10 kV and secondary rated voltages of 100 V. The travelling standard НЛЛ-35 is characterised by primary rated voltages of 22 kV and 35 kV and secondary rated voltages of 100 V. For both travelling standards, the operating frequencies were 50 Hz and 60 Hz at the load of 0 VA (for an open circuit, the load must be more than 100 kΩ).

The current transformer CA535/2 was selected as travelling standard for the GULFMET.EM-S7 comparison. Main characteristics of the travelling standard are: the primary rated current from 0.5 A to 5000 A; the secondary rated current 5 A; load not more than 0.05 Ω.

The comparison of measuring systems was provided by measuring the ratio error ε_u and phase displacement δ_u of the travelling standards for the GULFMET.EM-S6 and GULFMET.EM-S7 comparisons. For the GULFMET.EM-S6 comparison, the measurements were performed at the values of 40, 80, 100 and 120% of each primary nominal voltage. For the GULFMET.EM-S7 comparison, the measurements were performed at the values of 5, 20, 100 and 120% of each primary nominal. The operating frequencies were 50 Hz and 60 Hz for both comparisons.

As the pilot laboratory, the UMTS performed repeated measurements on all travelling standards during the GULFMET.EM-S6 and GULFMET.EM-S7 comparisons. All travelling standards provide extreme linearity coupled with extreme stability. The standard deviation σ of the travelling standards at the frequency of 50 Hz for the GULFMET.EM-S6 comparison varied for the ratio error from 0.0002% to 0.0006% and for the phase displacement from 0.0002 crad to 0.0033 crad [8]. The standard deviation σ of the travelling standard at the frequency of 50 Hz for the GULFMET.EM-S7 comparison varied for the ratio error from 0.0001% to 0.0002% and for the phase displacement from 0.0001 crad to 0.0004 crad [9].

Main results of the supplementary comparisons

The preparation of the RMO supplementary comparison reports should follow the same process as for key comparisons [10]. The difference in the preparation of a report on supplementary comparisons is that the degree of equivalence (DoE) with respect to the reference value (RV) of such a comparison can be calculated, but this is not mandatory, and the final report must be published in the Key Comparison Database (KCDB) [11] of the International Bureau of Weights and Measures (BIPM) to underpin the calibration and measurement capabilities (CMCs) [12].

RVs with expanded uncertainties and DoEs with expanded uncertainties of all the participants for the frequencies of 50 Hz and 60 Hz and all measurements for the GULFMET.EM-S6 and GULFMET.EM-S7 comparisons were calculated [8, 9]. Measurement results of the SASO-NMCC for VTs and CTs were presented at the frequency of 60 Hz only.

E_n values of the GULFMET.EM-S6 comparison participants for the ratio error and phase displacement at the frequency of 50 Hz are given in Table 1. E_n values for all participants at all measurement points are satisfactory and varied from 0.00 to 0.71 [8].

E_n values of the GULFMET.EM-S7 comparison participants for the ratio error and phase displacement at the frequency of 50 Hz are given in Table 2. E_n values for all participants at all measurement points are satisfactory and varied from 0.00 to 0.50 [9].

Table 1

E_n values of the GULFMET.EM-S6 comparison participants for the ratio error and phase displacement at the frequency of 50 Hz

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	UME	UMTS	UME
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

Table 2

E_n values of the GULFMET.EM-S7 comparison participants for the ratio error and phase displacement at the frequency of 50 Hz

Nominal primary current, A	Percentage of nominal primary current, %	E_n values for ratio error ε_I		E_n values for phase displacement δ_I	
		UMTS	UME	UMTS	UME
5	5	0.43	0.14	0.50	0.00
	20	0.33	0.00	0.35	0.00
	100	0.24	0.00	0.35	0.00
	120	0.24	0.00	0.35	0.00
50	5	0.08	0.13	0.45	0.19
	20	0.04	0.00	0.43	0.19
	100	0.00	0.00	0.34	0.15
	120	0.00	0.04	0.30	0.11
200	5	0.08	0.08	0.18	0.07
	20	0.17	0.21	0.18	0.07
	100	0.17	0.21	0.14	0.04
	120	0.17	0.21	0.09	0.04
400	5	0.17	0.17	0.20	0.07
	20	0.13	0.17	0.18	0.07
	100	0.08	0.13	0.27	0.11
	120	0.08	0.13	0.23	0.11
800	5	0.21	0.17	0.02	0.00
	20	0.13	0.13	0.02	0.00
	100	0.08	0.04	0.00	0.00
	120	0.00	0.04	0.02	0.00
1500	5	0.04	0.04	0.09	0.04
	20	0.08	0.04	0.16	0.07
	100	0.08	0.04	0.14	0.04
	120	0.13	0.17	0.02	0.00
2000	5	0.17	0.13	0.05	0.04
	20	0.04	0.00	0.02	0.00
	100	0.13	0.13	0.05	0.04
	120	0.13	0.13	0.05	0.04
4000	5	0.29	0.25	0.41	0.15
	20	0.21	0.21	0.14	0.07
	100	0.08	0.13	0.02	0.00
	120	0.04	0.08	0.11	0.04

Calibration and measurement capabilities of the participants of the supplementary comparisons

The results of the participants of the GULFMET.EM-S6 and GULFMET.EM-S7 comparisons may be used to underpin their CMC entries [12].

The new measurement capabilities of the UME for high voltage VTs are underpinned by the results of the GULFMET.EM-S6 comparison. The UME plans to revise its existing CMC entries in the KCDB of the BIPM, as given in Table 3. The GULFMET.EM-S6 comparison results may be used to improve the UME existing CMC entries in the KCDB of the BIPM for expanded uncertainties with the ratio error from 5.0×10^{-5} to 2.0×10^{-5} (2.5 times) and phase displacement from 0.0050 crad to 0.0020 crad (2.5 times).

The new measurement capabilities of the UMTS for high voltage VTs and CTs are underpinned by the results of the GULFMET.EM-S6 and GULFMET.EM-S7 comparisons, respectively. The UMTS plans to revise its existing CMC entries, as given in Table 4 and 5.

The GULFMET.EM-S6 comparison results may be used to improve the existing CMC entries of the UMTS with expanded uncertainties at the frequencies of 50 Hz and 60 Hz and the primary voltage range from 6 kV to 36 kV for the ratio error from 6.0×10^{-4} to 2.4×10^{-5} (25 times) and phase displacement from 0.0170 crad to 0.0030 crad (5.7 times). The GULFMET.EM-S7 comparison results may be used to improve the existing CMC

Table 3

Existing and to be revised CMC entries of the UME for high voltage VTs

CMC entries	Primary voltage range	Expanded uncertainty	
		Ratio error	Phase displacement, crad
Existing CMCs	30 V to 800 V	1.0×10^{-5}	0.001
	800 V to 36 kV	5.0×10^{-5}	0.005
To be revised	800 V to 230 kV	2.0×10^{-5}	0.002

Table 4

Existing and to be revised CMC entries of the UMTS for high voltage VTs

CMC entries	Frequency	Primary voltage range	Expanded uncertainty	
			Ratio error	Phase displacement, crad
Existing CMCs	50 Hz	1 kV to 220 kV	6.0×10^{-4}	0.017 to 0.075
To be revised	50 Hz and 60 Hz	1 kV to 220 kV	6.0×10^{-4}	0.017 to 0.075
	50 Hz and 60 Hz	6 kV to 36 kV	2.4×10^{-5}	0.003

Table 5

Existing and to be revised CMC entries of the UMTS for high voltage CTs

CMC entries	Frequency	Current ranges	Expanded uncertainty	
			Ratio error	Phase displacement, crad
Existing CMCs	50 Hz	Primary current: 0.5 A to 10000 A Secondary current: 0.5 A, 1 A, 2 A, 2.5 A, 5 A	6.0×10^{-5} to 8.0×10^{-5}	0.010 to 0.100
To be revised	50 Hz and 60 Hz	Primary current: 0.5 A to 10000 A Secondary current: 0.5 A, 1 A, 2 A, 2.5 A, 5 A	6.0×10^{-5} to 8.0×10^{-5}	0.010 to 0.100
	50 Hz and 60 Hz	Primary current: 5 A to 4000 A Secondary current: 5 A	2.0×10^{-5}	0.004

entries of the UMTS with expanded uncertainties at the frequencies of 50 Hz and 60 Hz, the primary current from 5 A to 4000 A, and the secondary current of 5 A for the ratio error from 6.0×10^{-5} to 2.0×10^{-5} (3.0 times) and phase displacement from 0.010 crad to 0.004 crad (2.5 times).

Summary

The supplementary comparisons of high voltage transformer measuring systems (GULFMET.EM-S6) and high current transformer measuring systems (GULFMET.EM-S7) were conducted between national laboratories from three RMOs (GULFMET, COOMET, and EURAMET). In general, the participants of both comparisons have demonstrated a good agreement of the results in the ratio error and phase displacement for high voltages and currents. The results of these comparisons may be used to improve the participants' existing CMC entries in the KCDB of the BIPM.

Основні результати додаткових звірень вимірювальних систем високої напруги та струму

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Анотація

Високі напруги змінного струму (АС) важливі, оскільки вони необхідні для багатьох застосувань у фізиці та техніці. Вимірювання високої напруги змінного струму використовується в системах масового передавання електроенергії для керування та захисту, моніторингу та вимірювання. Високі напруги змінного струму вимірюються шляхом зниження напруги за допомогою трансформаторів і подільників напруги. Вимірювальний високовольтний трансформатор використовується для зниження значень струму та напруги при вимірювальних роботах в електричних мережах високої напруги.

Трансформатори напруги (ТН) використовуються для точного вимірювання високої напруги змінного струму. Напруга на вторинній стороні ТН близько пропорційна за амплітудою до напруги на первинній стороні та майже в фазі. Трансформатори струму (ТС) перетворюють мережевий струм у значення, придатні для засобів вимірювання, лічильників, захисних реле та інших подібних пристроїв. Первинна обмотка ТС з'єднана послідовно з ланцюгом, по якому проходить лінійний струм, який потрібно виміряти, а вторинна обмотка з'єднана з приладами або захисними пристроями.

Добре відомі вимірювальні установки для точного вимірювання коефіцієнта ТС для великих первинних струмів, системи для визначення поведінки промислового струму і ТН за спотворених форм сигналу тощо. Калібрування вимірювальної системи високої напруги має бути простежено до національних або міжнародних еталонів. Взаємні звірення калібрування еталонів ТН і ТС проводяться за участю ряду національних лабораторій.

Описано результати додаткових звірень систем вимірювання високовольтних ТН (GULFMET.EM-S6) і систем вимірювання високовольтних ТС (GULFMET.EM-S7). Ці звірення проводилися між національними лабораторіями трьох регіональних метрологічних організацій. Загалом між учасниками обох звірень є хороша узгодженість результатів щодо похибки співвідношення і зсуву фаз для високої напруги та струму. Проведені звірення покращують для учасників наявні рядки калібрувальних та вимірювальних можливостей в Базі даних ключових звірень Міжнародного бюро з мір та ваг.

Ключові слова: змінний струм високої напруги; змінний струм сильного струму; еталон; вимірювання; невизначеність вимірювання.

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