

# Linking results of key and supplementary comparisons of AC/DC voltage transfer references

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Received: 25 January 2017 / Accepted: 11 February 2018

**Abstract.** A regional key comparison (KC) COOMET.EM-K6.a and a supplementary comparison (SC) COOMET.EM-S1 of AC/DC voltage transfer references were conducted between participating laboratories from the Eurasian region. Measurements were made over the period 2004–2014. The results showed good agreement between all but one of the participating laboratories. The proposed procedure of linking results of key and SCs of regional metrology organization of AC/DC voltage transfer references is presented. Linking results is realized for COOMET.EM-K6.a and CCEM-K6.a KCs, and for COOMET.EM-K6.a KC and COOMET.EM-S1 SC.

**Keywords:** comparison / key comparison / supplementary comparison / linking / regional metrological organization / degrees of equivalence

## 1 Introduction

Mutual recognition arrangement (MRA) of International Committee for Weights and Measures (CIPM) for national measurement standards and for calibration and measurement certificates issued by national metrology institutes (NMIs) is a response to a growing need for an open, transparent and comprehensive scheme to give users reliable quantitative information on the comparability of national metrology services and to provide the technical basis for wider agreements negotiated for international trade, commerce and regulatory affairs.

A regional metrology organization (RMO) key comparison (KC) is executed in the framework of a RMO. The link to the KC reference value (RV) for a KC carried out by a RMO is obtained by reference to the results from those NMIs which taken part in the CIPM KC also. The degree of equivalence relative to the KC RV of a measurement standard or a measurement result is the degree which the measured value is consistent with the KC RV [1,2].

To allow the participation in KC of all the NMIs of an RMO, the RMOs may organize their own KC. The RMO KC must be linked to the corresponding CIPM KC by means of joint NMIs (linking NMIs). This is mandatory to demonstrate global equivalence. Instead of the method to determine of RV, the RMO KC protocol must include the way which the results will be linked to the corresponding CIPM KCRV.

A supplementary comparison (SC) is a comparison, usually carried out by an RMO to meet specific needs not covered by KC (e.g. regional needs), for instance measurements of specific artefacts, or measurements of parameters not within the “normal” scope of the Consultative Committees (CC) of CIPM, and for supporting confidence in calibration and measurement certificates of NMIs [1,3].

SCs are normally organized by the RMOs to cover areas or techniques not covered by KCs. Rules for the participation in CIPM and RMO KCs apply to CIPM and RMO SCs also. The differences are next: approval is given by the corresponding RMO committee; degrees of equivalence relative to a SC RV may be computed, but this is not mandatory.

The proposed procedures linking of results of KCs CC of electric and magnetism (CCEM) and RMO of AC/DC voltage transfer references (COOMET.EM-K6.a [4] to CCEM-K6.a [5]), and key and SCs of RMOs of AC/DC voltage transfer references (COOMET.EM-S1 [6] to COOMET.EM-K6.a) was realized with using results of linking NMI (VNIIM, Russia).

## 2 Travelling standards for comparisons

The COOMET.EM-K6.a is the KC of national AC/DC voltage transfer references between the countries – participants of the RMO COOMET. In this comparison took part five NMIs: State Enterprise “Ukrmetrteststandard” (UMTS, Ukraine); VNIIM (Russia); SMS (Azerbaijan); BelGIM (Belarus); INM (Romania). UMTS (Ukraine) was the pilot laboratory in COOMET.EM-K6.a KC which

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would be responsible for providing the travelling standard, coordinating the schedule, collecting and analyzing the comparison data, and preparing of draft reports.

Traveling AC-DC-transfer standard is the Single Junction Thermal Converter type ПНТЭ-6А serial No 1848 (thereinafter – the traveling standard ПНТЭ-6А). The traveling standard ПНТЭ-6А have manufactured as three-dimensional construction, in which used the thermocouple type ТББ-2 (vacuum contact-free thermocouple, design 2).

The coaxial connector for input voltage of the traveling standard ПНТЭ-6А is completed by detachable adapter in order to provide adaptation to usual connector N-type (female) [4].

The COOMET.EM-S1 SC is the comparison of national AC/DC voltage transfer references between the countries – participants of the RMO COOMET. In this comparison took part two NMIs: VNIIM (Russia) and UMTS (Ukraine). The VNIIM was pilot laboratory which is responsible for providing travelling standard, coordinating the schedule, collecting and analyzing the comparison data, and preparing of draft reports.

The AC/DC Thin-film Planar Multi-junction Thermal Converter (PMJTC) was used as the traveling standard. This PMJTC marked as 256 [6].

The input signals for COOMET.EM-K6.a and COOMET.EM-S1 comparisons are shown in Table 1.

### 3 Proposed linking key comparisons procedure

Proposed to link the results from COOMET.EM-K6.a [4] to the CCEM-K6.a [5] which carried out between 1993 and 1999. VNIIM (Russia) is linking NMI as far as they participated in CCEM-K6.a. The procedure used for RMO KC data evaluation is intended to provide linking to CIPM KC data with low uncertainty [7,8].

Results COOMET.EM-K6.a to be linked to CCEM-K6.a at 1 kHz, 20 kHz, 100 kHz, and 1 MHz with using a method similar to that used to linking EUROMET.EM-K6.a to CCEM-K6.a, SIM.EM-K6.a to CCEM-K6.a, and APMP.EM-K6.a to CCEM-K6.a, SIM.EM-K6.1 to CCEM-K6.a [9–12].

The degrees of equivalence of  $i$ th NMI with respect to linking to CCEM-K6.a is estimated as

$$d_i = x_i + \Delta - x_{\text{refK6a}}, \quad (1)$$

where  $x_i$  is result from COOMET.EM-K6.a for NMI participant in COOMET.EM-K6.a only;  $d_i$  is best estimate of result from NMI  $i$  to linking to CCEM-K6.a;  $x_{\text{refK6.a}}$  – KCRV of COOMET.EM-K6.a KC

$$x_{\text{refK6.a}} = \frac{\sum_{i=1}^N x_i}{\sum_{i=1}^N u_c^2(x_i)} / \frac{\sum_{i=1}^N 1}{\sum_{i=1}^N u_c^2(x_i)}, \quad (2)$$

with combine standard uncertainties

$$u_c^2(x_{\text{ref}}) = 1 / \sum_{i=1}^N \frac{1}{u_c^2(x_i)}, \quad (3)$$

**Table 1.** Input and output signals of travelling standards for comparisons.

Comparison	COOMET.EM-K6.a	COOMET.EM-S1
Quantity	ПНТЭ-6А	PMJTC
Input voltage	3 V	1.5 V
Output voltage	5 mV	90 mV
Input resistance	1000 $\Omega$	180 $\Omega$
Output resistance	20 $\Omega$	10 k $\Omega$

where  $u_c(x_i)$  is uncertainty of results from COOMET.EM-K6.a for NMI participant in COOMET.EM-K6.a.

Measurements from the linking NMIs provide estimates

$$\Delta_{iLINK} = d_{iLINK} - D_{iLINK}, \text{ for the correction } \Delta, \quad (4)$$

where  $d_{iLINK}$  is result from CCEM-K6.a for a linking NMI;  $D_{iLINK}$  is result from COOMET.EM-K6.a for a linking NMI.

The linking NMI is VNIIM (Russia). No significant changes to the method of measurement used in CCEM-K6.a and COOMET.EM-K6.a were made by VNIIM.

Table 2 lists the values of the quantities used in the calculation.

The best estimate of the result from NMI  $i$  had it participated in CCEM-K6.a is calculated using (1). The standard uncertainty is calculated as:

$$\begin{aligned} u^2(d_i) &= u^2(D_i) + u^2(\Delta) \\ &= u^2(D_i) + s^2(\Delta) + u^2(m_{\text{ref}}), \end{aligned} \quad (5)$$

where  $u(m_{\text{ref}}) = 0.018$  is the uncertainty in  $u(m_{\text{ref}})$ , the CCEM-K6.a KCRV. The expanded uncertainty is  $U(d_i) = k_{d_i} u(d_i)$ , where is chosen  $k_{d_i} = 2$  to give 95% coverage.

The calculated degrees of equivalence with respect to CCEM-K6.a KCRV are tabulated in  $d_i$  Table 3 (Azerbaijan is not significant of CIPM MRA in 2014).

The declared uncertainties are judged as confirmed if the following equation is satisfied

$$|d_i| < 2u_c(d_i). \quad (6)$$

Degrees of equivalence  $D_i$  with respect to the CCEM-K6.a KCRV for CCEM-K6.a (red diamonds), EUROMET.EM-K6.a (green triangle), SIM.EM-K6.a (blue circles), APMP.EM-K6.a (orange squares), SIM.EM-K6.1 (pink triangle), and COOMET.EM-K6.a (brown squares) are shown on Figures 1–4 for frequencies 1 kHz; 20 kHz; 100 kHz; 1 MHz [13].

### 4 Proposed linking key and supplementary comparisons procedure

The RMO SCs are carried out with the purpose of confirming calibration and measurement capabilities (CMC) of the corresponding NMI. During the evaluation of the SCs data

**Table 2.** CCEM-K6.a and COOMET.EM-K6.a comparison results and expanded uncertainties for linking NMI, ( $10^{-6}$ ).

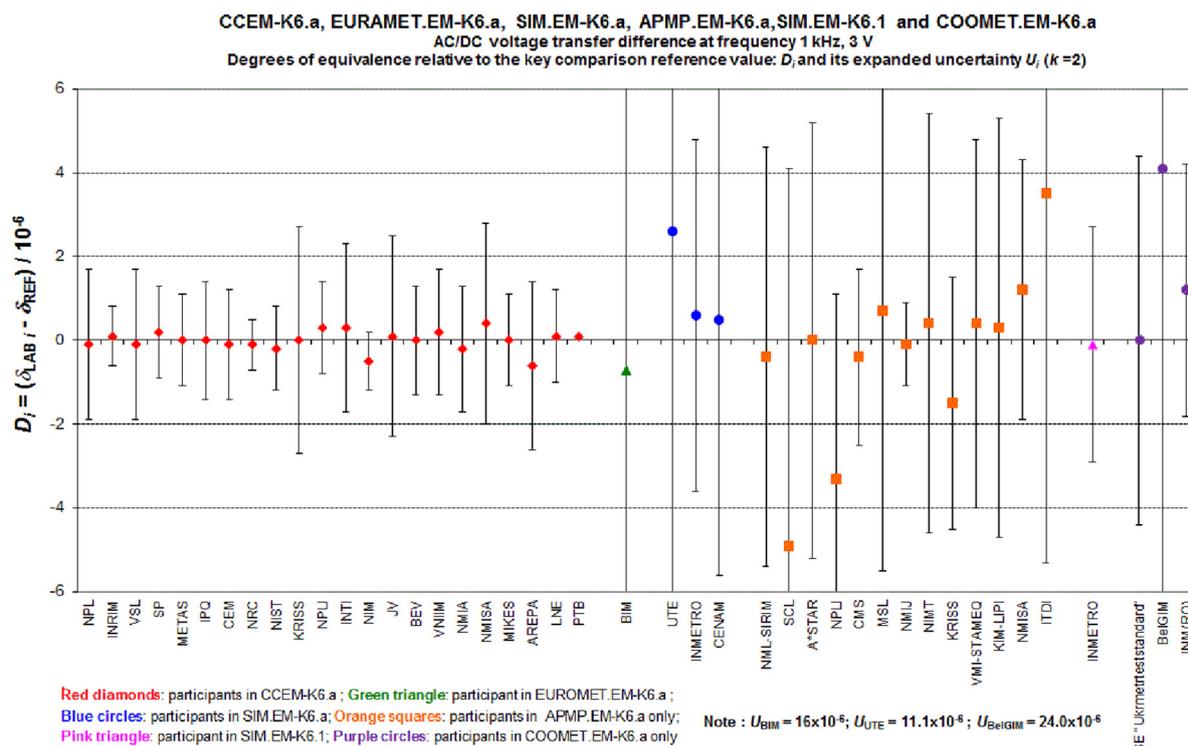
Linking NMI	$d_{iLINK}$	$D_{iLINK}$	$\Delta_{iLINK}$	$u(\Delta_{iLINK})$	$x_{TrefK6a}$
1 kHz	0.2	-0.8	1.0	0.3	0.0
20 kHz	1.0	-1.5	2.5	1.3	0.9
100 kHz	4.2	-5.0	9.2	2.1	7.2
1 MHz	103.0	-57.0	160.0	6.8	121.0

**Table 3.** Proposed degrees of equivalence for NMI participants of COOMET.EM-K6.a comparison relative to CCEM-K6.a KCRV, ( $10^{-6}$ ).

NMI	1 kHz		20 kHz		100 kHz		1 MHz	
	$d_i$	$U(d_i)$	$d_i$	$U(d_i)$	$d_i$	$U(d_i)$	$d_i$	$U(d_i)$
UMTS	1.3	4.0	0.0	4.0	-8.0	7.8	-32.0	37.3
BelGIM	5.4	23.9	11.6	28.9	21.0	139.0	-	-
INM	2.5	2.4	-1.5	2.5	10.8	11.5	18.0	16.7

**Table 4.** RVs and its uncertainties for COOMET.EM-K6.a and COOMET.EM-S1 comparisons,  $10^{-6}$ .

Frequency	Reference value (RV)		Uncertainties of RV $U(RV), k=2$	
	1	2	1	2
1 kHz	0.3	1.5	1.7	4.4
20 kHz	-2.0	0.3	1.9	4.5
100 kHz	-6.8	1.2	3.4	6.5
1 MHz	-40.4	14.1	15.9	47.5



**Fig. 1.** Degrees of equivalence  $D_i$  with respect to the CCEM-K6.a KCRV at 1 kHz.

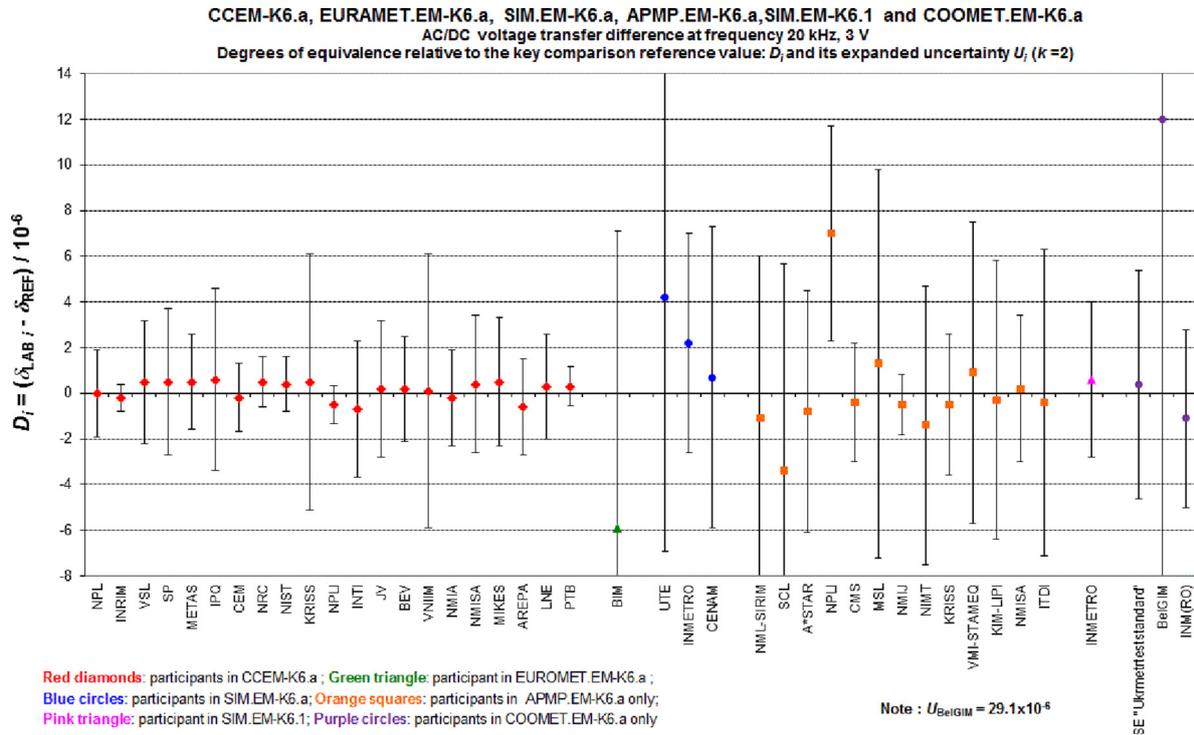


Fig. 2. Degrees of equivalence  $D_i$  with respect to the CCEM-K6.a KCRV at 20 kHz.

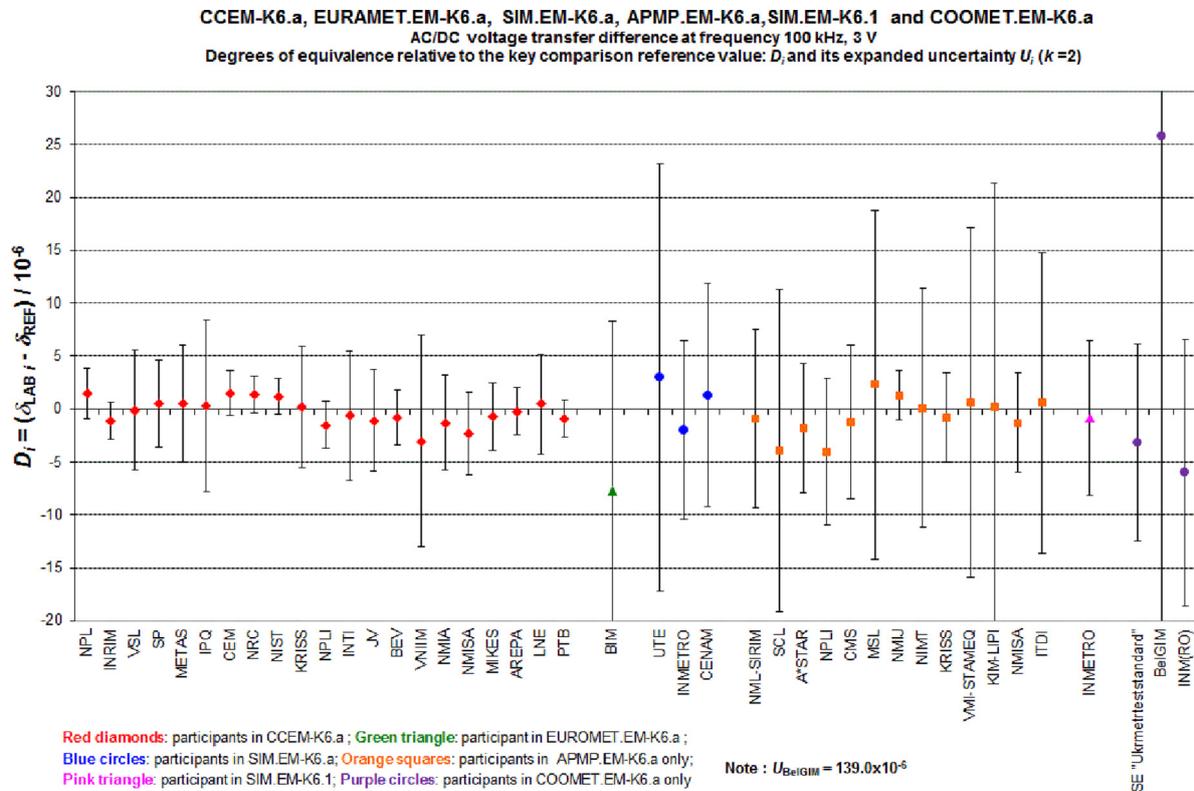


Fig. 3. Degrees of equivalence  $D_i$  with respect to the CCEM-K6.a KCRV at 100 kHz.

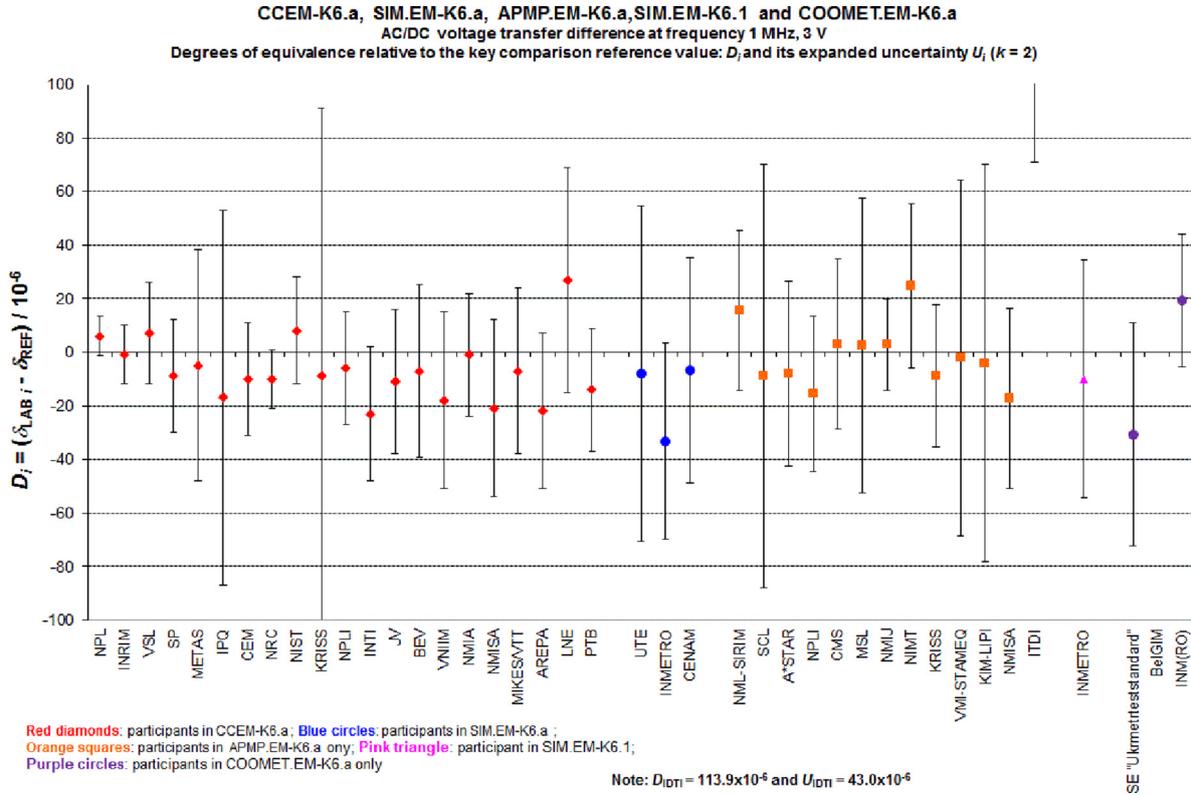


Fig. 4. Degrees of equivalence  $D_i$  with respect to the CCEM-K6.a KCRV at 1 MHz.

Table 5. Degrees of equivalence and its uncertainties for COOMET.EM-K6.a and COOMET.EM-S1 comparisons,  $10^{-6}$ .

NMI	1 kHz		20 kHz*		100 kHz		1 MHz	
	$D_i$	$U(D_i)$	$D_i$	$U(D_i)$	$D_i$	$U(D_i)$	$D_i$	$U(D_i)$
COOMET.EM-K6.a								
VNIIM	-1.1	1.8	0.5	2.1	1.8	2.1	-16.6	23.3
UMTS	0.0	4.0	0.4	4.0	-3.2	7.7	-30.6	36.7
BelGIM	4.1	23.9	12.0	28.9	25.8	139.0	-	-
INM	1.2	2.4	-1.1	2.4	-6.0	11.5	19.4	15.2
COOMET.EM-S1								
VNIIM	-0.5	1.5	-1.2	1.5	-3.8	3.0	1.9	24.0
UMTS	-2.0	4.1	-1.5	4.2	-5.0	5.8	16.0	41.0

the measurement uncertainties claimed by the participants of comparisons are confirmed that, essentially, is the confirmation of corresponding measurement CMC [8,9].

Results of COOMET.EM-S1 SC(2) to be linked to COOMET.EM-K6.a KC(1) (SC to the KC). VNIIM (Russia) is linking NMI as far as they participated in CCEM-K6.a. RVs and its uncertainties are given in Table 4.

The degree of equivalence  $D_i$  of AC/DC voltage transfer references and its expanded uncertainty  $U(D_i)$  that participated in COOMET.EM-K6.a [4] and COOMET.EM-S1 [6] comparisons are shown in Table 5 for frequencies 1 kHz; 20 kHz; 100 kHz; 1 MHz.

For each of the joint participants in both comparisons was calculated degree of equivalence and its uncertainty with used next formula [14]:

$$D_i = x_i - RV_j, \tag{7}$$

$$u(D_i) = \sqrt{u^2(x_i) + u^2(RV_j) - 2r_i u(x_i)u(RV_j)}, \tag{8}$$

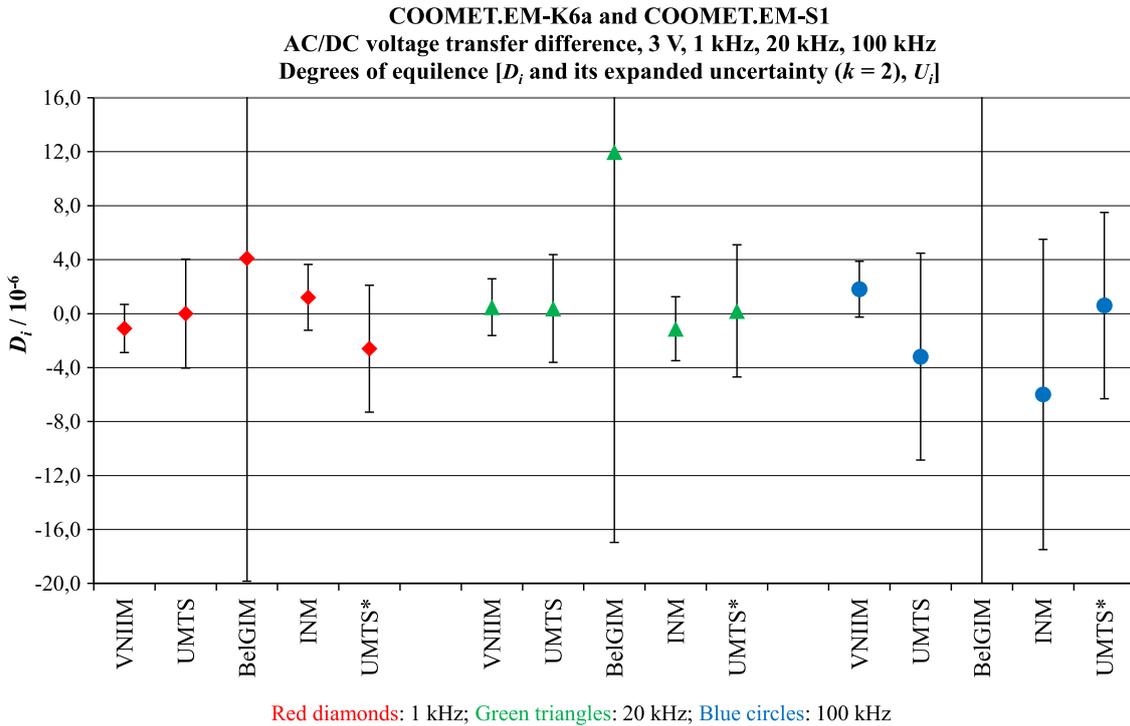
where  $x_i$  is measured value for participant;  $RV_j$  is reference value of comparison (for frequencies for frequencies 1 kHz; 20 kHz; 100 kHz; 1 MHz);  $r_i$  is correlation between the results from the participant and the  $RV_j$ ;  $u(x_i)$  is combined

**Table 6.** Proposed correction factor and its uncertainties for COOMET.EM-S1,  $10^{-6}$ .

Frequency	$d$	$U(d)$
1 kHz	-0.6	2.3
20 kHz	1.7	2.6
100 kHz	5.6	3.7
1 MHz	14.7	33.4

**Table 7.** Degrees of equivalence of UMTS and its uncertainties for COOMET.EM-S1 in terms RV COOMET.EM-K6.a,  $10^{-6}$ .

NMI	1 kHz		10 kHz		100 kHz		1 MHz	
	$D_i$	$U(D_i)$	$D_i$	$U(D_i)$	$D_i$	$U(D_i)$	$D_i$	$U(D_i)$
UMTS*	-2.6	4.7	0.2	4.9	0.6	6.9	30.7	52.9



**Fig. 5.** Degrees of equivalence of COOMET.EM-K6.a and corrected degrees of equivalence of COOMET.EM-S1 for NMIs in terms of  $RV_{K6a}$  (1, 20, 100 kHz).

standard uncertainty of measured value for NMI;  $u(RV_j)$  is combined standard uncertainty of  $RV_j$ .

If correlations have been ignored ( $r_i = 0$ )

$$u(D_i) = \sqrt{u^2(x_i) + u^2(RV_j)}. \tag{9}$$

The results of the COOMET.EM-S1 comparison are to be expressed in relation to the COOMET.EM-K6.a  $RV - RV_{K6a}$ . For this purpose the degrees of equivalence of COOMET.EM-S1 comparison (indicated  $D_{S1}$ ), will be corrected by a correction  $d$ , which is determined from the results of the participant linking NMI (VNIIM):

$$d = D_{K6aVNIIM} - D_{S1VNIIM}, \tag{10}$$

where  $D_{K6aVNIIM}$  is degree of equivalence of national standard VNIIM in COOMET.EM-K6.a KC;  $D_{S1VNIIM}$  is degree of equivalence of national standard VNIIM in COOMET.EM-S1 comparison with the uncertainty:

$$u(d) = \sqrt{u^2(D_{K6aVNIIM}) + u^2(D_{S1VNIIM})}. \tag{11}$$

VNIIM correction  $d$  and its uncertainties are shown in Table 6.

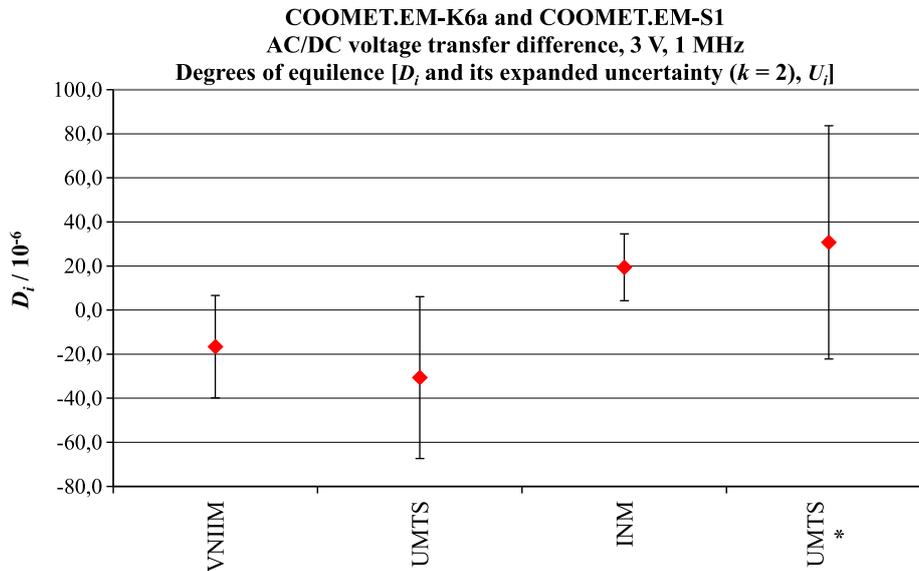
The corrected degrees of equivalence for the participants in COOMET.EM-S1 in terms of  $RV_{K6a}$  are then given by:

$$D'_{S1i} = D_{S1i} + d, \tag{12}$$

with the uncertainty:

$$u'(D_{S1i}) = \sqrt{u^2(D_{S1i}) + u^2(d)}. \tag{13}$$

The corrected degrees of equivalence for UMTS as participant of COOMET.EM-S1 in terms of  $RV_{K6a}$  and its expanded uncertainty are shown on Table 7 and Figure 5 (COOMET.EM-K6.a; \*COOMET.EM-S1, 1 kHz, 10 kHz, 100 kHz) and Figure 6 (COOMET.EM-K6.a; \*COOMET.EM-S1, 1 MHz). Result of UMTS is linked to the COOMET.EM-K6.a comparison with using proposed procedure.



**Fig. 6.** Degrees of equivalence of COOMET.EM-K6.a and corrected degrees of equivalence of COOMET.EM-S1 for NMIs in terms of  $RV_{K6a}$  (1 MHz).

## 5 Conclusion

The results of a regional KC COOMET.EM-K6.a and SC COOMET.EM-S1 of AC/DC voltage transfer references showed good agreement between all but one of the participating laboratories.

The results of RMO SCs for confirming CMCs NMIs are used. For each of the joint participants in key and SCs for equal nominal of electrical quantity can be calculated degrees of equivalence national standards and its uncertainty in term KC RV.

The procedure of practical linking the results of KCs CCEM and RMO of AC/DC voltage transfer references, and key and SCs of RMOs of AC/DC voltage transfer references are proposed.

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**Cite this article as:** Oleh Velychko, Linking results of key and supplementary comparisons of AC/DC voltage transfer references, *Int. J. Metrol. Qual. Eng.* **9**, 4 (2018)