Alternative Method for Evaluation of Reference Value on COOMET Key Comparison for Power

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Abstract – **Particular interest is the question of the development and practical application of alternative methods for processing data of international comparisons. The paper is considered the alternative method for processing of international comparison results, which based on preference aggregation method. Processing of COOMET.EM-K5 key comparison data for power by the preferences aggregation method is presented. The results are compared with the traditional approach and the considered alternative method.**

I.   INTRODUCTION

In a frame of Consultative Committees (CCs) and Regional Metrology Organizations (RMOs) special comparisons for National Metrology Institutes (NMIs) and Designated Institutes (DIs) are Key Comparisons (KC), which are executed within the framework of the International Committee for Weights and Measures (CIPM) of Mutual Recognition Arrangement (MRA) [1,2].

The main goal of KC is to determine the equivalence between different NMIs/DIs. It should be mention that according to the CIPM MRA the degree of equivalence (DoE) of each NMI/DI is obtained as the deviation of measurement result from the key comparison reference value (KC RV), together with the expanded uncertainty associated with this deviation [3].

In general the CIPM MRA describes how to evaluate KC RV data. Nevertheless it does not provide enough specifics to define an unambiguous analysis. Since the CIPM MRA was signed many different approaches and methodologies for analyzing KC data and ways of evaluating KC RV data have been suggested [4-7].

The present paper deals with alternative method (AM) for evaluation of KC RV which is applied to COOMET.EM-K5 KC of power.

II.   GENERAL REVIEW OF KEY COMPARISONS OF POWER

The CC for Electricity and Magnetism (CCEM) organized international KC of 50/60 Hz for electric power (EP) (CCEM-K5) in 1995. The NIST (USA) was the pilot laboratory in this KC [8].

EURAMET.EM-K5.1 KC was started in 2003, where the UME (Turkey) was a PL [9]. Furthermore, some participated NMIs/DIs in the KC improved their capabilities for EP measurement results and their expanded uncertainties. The SE "Ukrmetrteststandard" (UMTS, Ukraine) took part as the participant in EURAMET.EM-K5.1 KC.

In 2008 UMTS as a PL organized and coordinated COOMET.EM-S2 Supplementary Comparison (SC) [10]. It was decided to perform the comparison at 120 V, 5 A, frequencies 50 Hz and 53 Hz, power factors 1.0, 0.5 Lead/Lag with the main aim to be in order with requirements of EURAMET.EM-K5.1 KC.

In 2016 UMTS (Ukraine) as a PL organized and coordinated COOMET.EM-K5 KC of Power [11]. The main goal of which was to compare national standards of EP of low-frequency 50/60 Hz and to link with the CCEM-K5 KC.

This KC was carried out between 13 NMIs/DIs which are the member of 5 RMOs: COOMET, EURAMET, APMP, GULFMET and AFRIMET. Low-frequency travelling standard (TS) of 50/60 Hz power was compared at: UMTS (Ukraine), BelGIM (Belarus), VNIIM (Russia), GeoSTM (Georgia), CMS (Kyrgyzstan), UME (Turkey), SMU (Slovakia), LEM-FEIT (R. Macedonia), NIM (China), MASM (Mongolia), QCC EMI (UAE), SASO-NMCC (Saudi Arabia), and NIS (Egypt). NIM (China) and VNIIM (Russia) were linking NMIs for the linking process between CCEM-K5 KC and COOMET.EM-K5 KC through participating in CCEM-K5.

KC RVs x_{ref} for COOMET.EM-K5 KC were calculated of traditional method (TM) [12-14] as the mean of NMI/DI results and were given by [11]. Linked results of EURAMET.EM-K5.1 and COOMET.EM-K5 KCs were presented [15].

III.   ALTERNATIVE METHOD FOR EVALUATION OF KEY COMPARISON REFERENCE VALUES

The AM, called preference aggregation method, has been claimed in [16, 17] intended for determination RV

for processing comparison data. This way based on the preference aggregation that allows determining the KC RV x_{ref} in the procedure of KC.

AM also provides the ability to generate the largest consistent subset where outliers are excluded. The main stages of processing KCs data using the AM has been detailed described in [18] and consists:

forming a range of actual values;

constructing the preference profile;

forming the profile matrix;

finding the consensus ranking according to the Kemeny rule;

determining a unique consensus ranking;

obtaining a RV;

forming the largest consistent subset; finding the uncertainty for the KC RV.

The AM consists in converting the uncertainty provided by NMIs/DIs during comparison, in ranking of the measured value. The obtained rankings, which constitute the initial preference profile, then serve as initial data for finding the consensus ranking according to the Kemeny rule. It is allowed to obtain KC RV x_{ref} of the measured value and to estimate the ability of the NMI/DI to provide reliable results.

In this case, the range of actual values is determined, as the algebraic union of the uncertainties obtained by each m NMI/DI participants. Then this range is divided into $n - 1$ equal interval. The boundaries of the intervals correspond to n values of the measured quantity $A = \{a_1, a_2, ..., a_n\}$. The preference profile Λ is involved of m rankings describing the uncertainties of the NMIs/DIs. Ranking is a combination of binary relations strict order "$\succ$" and equivalence "$\sim$" and has the following properties:

$$a_i \succ a_j \text{ if } a_i \in u(x_k) \wedge a_j \notin u(x_k);$$
$$a_i \sim a_j \text{ if } a_i, a_j \in u(x_k) \vee a_i, a_j \notin u(x_k); \quad (1)$$
$$a_i \prec a_j \text{ if } a_i \notin u(x_k) \wedge a_j \in u(x_k).$$

The purpose of the AM is to determine a single preference relation β, i.e. to aggregate m rankings and to determine the best compromise between them. Such a ranking β is called consensus ranking (CR) [19]. To determine the CR, the Kemeny median is used, for searching of which an algorithm based on the branch and bound method has been developed and described in works [18, 19].

The value that takes the first place in the CR β is taken as KC RV x_{ref} of the measured value. The uncertainty of obtained KCRV is defined as the smaller of two values: the maximum lower bound and the minimum upper bound of the uncertainties, which were declared by the participated NMIs.

The data of COOMET.EM-K5 were processed, using AM. Consider the application of this method by example of finding the KC RV for measurement point 120 V, 5 A,

power factor 1.0 at frequency 50 Hz.

The range of actual values is from -97.1 to 103.4, which was divided into five equal intervals. The boundaries of the intervals corresponded to seven values of the measured quantity: $a_1 = -97.1$, $a_2 = -63.7$, $a_3 = -30.3$, $a_4 = 3.2$, $a_5 = 36.5$, $a_6 = 70.0$, $a_7 = 103.4$.

Ranking for the NMIs/DIs had a form:

λ_1: $a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6 \sim a_7$;
λ_2: $a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6 \sim a_7$;
λ_3: $a_4 \sim a_3 \succ a_1 \sim a_2 \sim a_5 \sim a_6 \sim a_7$;
λ_4: $a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6 \sim a_7$;
λ_5: $a_5 \sim a_4 \sim a_3 \succ a_1 \sim a_2 \sim a_6 \sim a_7$;
λ_6: $a_6 \sim a_5 \succ a_1 \sim a_2 \sim a_3 \sim a_4 \sim a_7$;
λ_7: $a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6 \sim a_7$;
λ_8: $a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6 \sim a_7$;
λ_9: $a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6 \sim a_7$;
λ_{10}: $a_7 \sim a_6 \sim a_5 \sim a_4 \sim a_3 \succ a_1 \sim a_2$;
λ_{11}: $a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6 \sim a_7$;
λ_{12}: $a_4 \sim a_3 \sim a_2 \sim a_1 \succ a_5 \sim a_6 \sim a_7$;
λ_{13}: $a_4 \succ a_1 \sim a_2 \sim a_3 \sim a_5 \sim a_6 \sim a_7$.

The consensus ranking found by the Kemeny rule has the form $\beta = \{a_4 \succ a_3 \succ a_5 \succ a_6 \succ a_1 \sim a_2 \sim a_7\}$. The first place in it is occupied by the value a_4, so it was chosen as the KC RV $x_{AM} = 3.2$ µW/(VA) with a corresponding expanded uncertainty $U_{AM} = 2.3$ µW/(VA).

Evaluated KC RV x_{ref} and theirs expanded uncertainties U_{ref} by a TM are presented in 1 and 2 columns of Table 1. KC RV x_{AM} and theirs expanded uncertainties U_{AM} obtained by an AM are presented in 3 and 4 columns of Table 1. The difference between methods for all measurement points (power factors 1.0, 0.5 Lag, 0.5 Lead, 0.0 Lag, 0.0 Lead, frequencies of 50 Hz and 53 Hz) are presented in 5 and 6 columns of Table 1.

The difference of the estimation KC RV x_{ref} which was obtained using of the TM and the AM at frequency of 50 Hz and 53 Hz is evaluated by:

$$\Delta_D = \left| X_{ref} - X_{AM} \right|, \quad (2)$$

$$\Delta_{U_D} = \left| U_{ref} - U_{AM} \right|. \quad (3)$$

As an example, the results of processing NMI/DI data of COOMET.EM-K5 KC using of AM for measurement point 120 V, 5 A, power factor 1.0 at frequency 50 Hz are shown in Figure 1. The solid green line is indicated KC RV x_{AM} obtained by AM, and the dashed green lines are its expanded uncertainty boundary U_{AM}.

Results of COOMET.EM-K5 KC was evaluated of traditional method [11] and are given on Figure 2 for measurement point 120 V, 5 A, power factor 1.0 at frequency 50 Hz. Brief analyze of Figures 1 and 2 shows that the measurement results of one NMI/DI participant of COOMET.EM-K5 KC (SMU) is outlier for AM.

Table 1. Key comparison reference values and expanded uncertainties, µW/(VA).

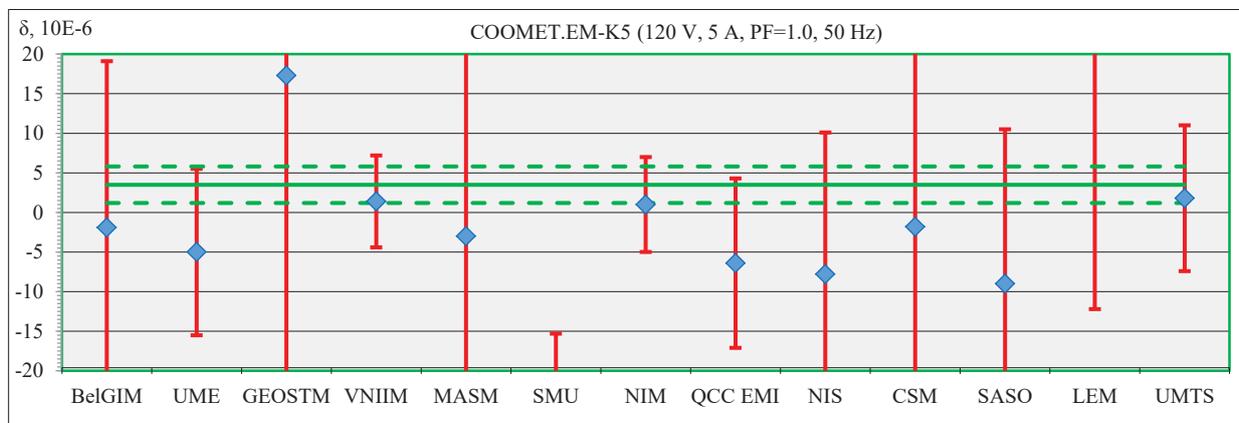| Frequency	Power factor	x_{ref}	U_{ref}	x_{AM}	U_{AM}	Δ_D	Δ_{U_D}
50 Hz	1.0	-0.8	6.4	3.2	2.3	4.3	4.1
	0.5 Lag	5.8	6.5	3.0	3.4	2.8	3.1
	0.5 Lead	-5.6	6.4	-5.2	4.4	0.4	2.0
	0.0 Lag	4.2	5.7	2.6	9.1	1.7	3.4
	0.0 Lead	-7.1	5.7	-13.1	3.9	5.9	1.8
53 Hz	1.0	-2.1	5.8	-2.6	3.1	0.5	2.7
	0.5 Lag	8.0	5.5	8.7	2.1	0.7	3.4
	0.5 Lead	-9.7	5.5	-9.6	1.5	0.1	4.0
	0.0 Lag	6.4	5.2	7.1	14.8	0.7	9.6
	0.0 Lead	-10.2	5.2	-11.9	3.0	1.7	2.2

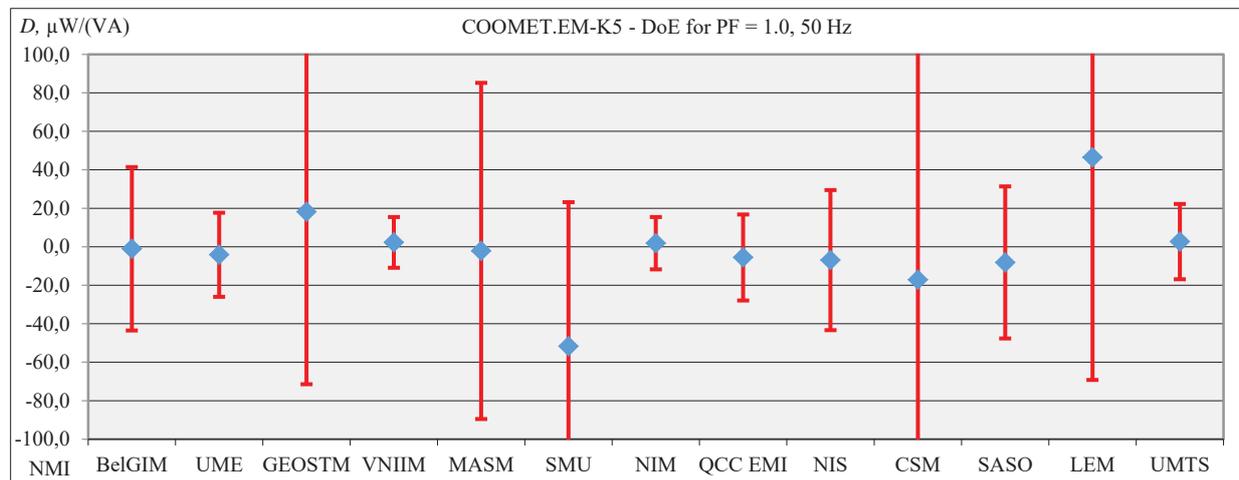Figure 1 Results of processing COOMET.EM-K5 key comparison data using of alternative method

Figure 2 Results of processing COOMET.EM-K5 key comparison data using of traditional method

It is advisable to check the results of SMU using E_n and z scores. The value of E_n score for SMU is 1.4 (indicates unsatisfactory performance), and the value of z score is 2.5 (indicates a dubious performance characteristic and requires precautionary measures). This confirms for SMU the result obtained using AM.

Estimation comparison results by using AM and TM show a difference from 0.1 to 5.9 for Δ_D and from 1.8 to 9.6 for Δ_{U_D}. Good level of coincidence results of both evaluation of KC RV has been achieved.

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IV. EVALUATION OF PERSONAL COMPETENCE OF NMI/DI LABORATORIES

In framework of the COOMET.EM-K5 KC, a special questionnaire was sent by PL to all NMI/DI participants with questions regarding the competence of laboratory personnel. This questionnaire was not a mandatory part of the comparisons, but only an initiative of the PL to study additional factors influencing the results of comparisons. All NMI/DI participants of the comparison completed the questionnaire and sent it to the PL except for two participants.

The data obtained from the NMI laboratories were processed by the PL using the methodology described in [20]. For the realization of this methodology, the following criteria of the personal competence evaluation are applied:

education and scientific level in the field of metrology; overall experience;

experience in the field of metrology;

experience as expert in the field of metrology (participation in comparisons);

work status.

The obtained results of evaluation of the competence of laboratory personnel were ranked in order to increase the uncertainty of the results and are shown on Figure 3.
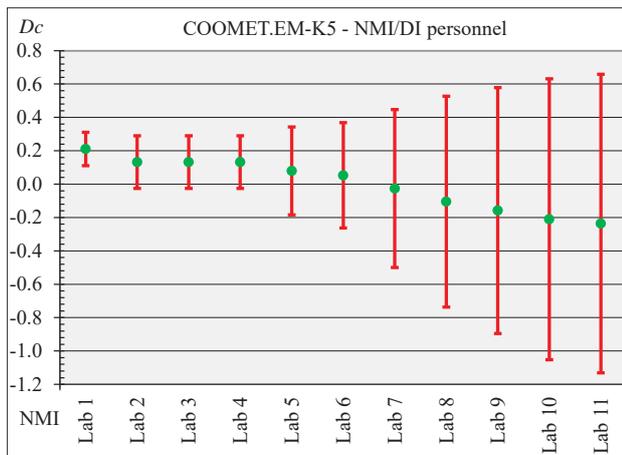

Figure 3 Results of processing of COOMET.EM-K5 KC personal data of NMI/DI participant-labs.

In Figure 3, all NMI/DI laboratories received the designation from Lab 1 to Lab 11 in the order of their ranking. The values of D_c for each NMI/DI laboratory are obtained as a deviation from the average value for all NMI/DI laboratories.

In evaluation of the personal competence of NMI/DI laboratories, the requirements of the international standard ISO/IEC 17043 [21] were used. The identity of participants in a competency evaluation shall be confidential (ISO/IEC 17043, 4.10 [21]) and known only to persons NMI/DI involved in the competency evaluation. The PL of COOMET.EM-K5 comparison

sent the appropriate NMI/DI Lab identification (Lab$_i$) to the competency evaluation participants.

In order to be able to compare the obtained results of the comparison of standards and the results of evaluation of the personnel competence, it was proposed to compare them according to the obtained values of the E_n score for each NMI/DI laboratory for COOMET.EM-K5 KC.

Results of comparing E_n score (ΔE_n) are shown on Figure 4. In author's opinion, the result should be positive when the absolute value of ΔE_n score is less than 0.5. From Lab 4 to Lab 11 (72 % of all Labs) meet this condition.
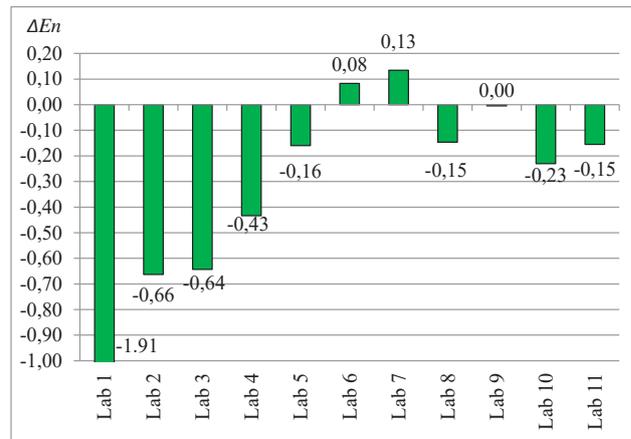

Figure 4 Results of comparing E_n score for COOMET.EM-K5 KC.

V. CONCLUSION

The AM can be applied for processing KC data of national standards in addition to the TM. The AM implements the transformation of the uncertainties provided by NMI/DI participants into rankings of measured values.

The data of COOMET.EM-K5 KC for power were processed using the AM. Using of this method showed that the KC RV determined by AM and the associated uncertainties are very close to the values obtained by traditional method.

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