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Original scientific paper

INTERLABORATORY COMPARISONS OF THE CALIBRATION RESULTS OF ENERGY METERS

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A b s t r a c t: The article is devoted to the analysis of the results of the interlaboratory comparison (ILC) of the electric energy meter, which were carried out in 2024. ILC results of calibration of the energy meter at the points of alternating voltage 230 V, currents from 0.05 A to 10 A, power factors from ±1.0 to ±0.5 at a frequency of 50 Hz are presented. The deviations of the results obtained by each laboratory were determined, and the consistency of the obtained results was assessed, taking into account the uncertainty of the measurements using the criterion of functioning statistics. In general, laboratories have received satisfactory accuracy and there is good agreement between participants for this quantity. Laboratories meet the established requirements and confirms their qualification (technical competence) during the calibration in accordance with the requirements of the standard ISO/IEC 17025. It is expected that this ILC will be able to provide support for participants' calibration capabilities.

Key words; calibration; energy meter; interlaboratory comparison; uncertainty

МЕЃУЛАБОРАТОРИСКА СПОРЕДБА НА РЕЗУЛТАТИ ОД КАЛИБРАЦИЈА НА БРОИЛА ЗА ЕЛЕКТРИЧНА ЕНЕРГИЈА

А п с т р а к т: Трудот е посветен на анализата на резултатите од меѓулабораториската споредба (ILC) на броилата за електрична енергија, која беше направена во 2024 година. Прикажани се резултатите од споредбата за напон од 230 V, струи од 0,05 A до 10 A, факторите на моќност од ±1,0 до ±0,5, при фреквенција од 50 Hz. Утврдени се отстапувања на резултатите добиени од секоја лабораторија и оценета е конзистентноста на добиените резултати, земајќи ја предвид мерната неодреденост. Генерално, лабораториите добија задоволителна точност и постои добро совпаѓање на добиените резултати. Лабораториите ги исполнуваат утврдените барања и ја потврдуваат нивната квалификација (техничка компетентност) за калибрацијата во согласност со барањата на стандардот ISO/IEC 17025. Се очекува дека меѓулабораториската споредба ќе придонесе за развојот на калибрациските капацитети на двете лаборатории.

Клучни зборови: калибрација; броило за електрична енергија; меѓулабораториска споредба; мерна неодреденост

1. INTRODUCTION

Electrical energy measurement is important for a variety of purposes, including: calculating electricity consumption; consumption management; diagnostics and network support; research and development, etc. For commercial and residential users, energy measurement allows one to accurately calculate the cost of used electricity. For industrial enterprises or power supply networks, it is important to measure energy for effective consumption management, resource planning and optimization of production processes. Monitoring power consumption helps to detect anomalies that may indicate network problems, such as overloads or faults. Energy measurement is also used in scientific research and development of new technologies to improve energy efficiency and create new energy sources.

Interlaboratory comparisons (ILCs) are the process of comparing the results of measurements made in different laboratories in order to assess and confirm the accuracy, reliability and reproducibility of measurements. They have several important meanings: validation of measurement methods; evaluation of measurement standards and measuring instruments; confirmation of mutual acceptability of results; increasing confidence in measurement results; data quality assurance, etc. Comparing results between different laboratories helps to determine the effectiveness and reproducibility of used standards and measuring instruments. ILCs contribute to the improvement of the data quality control system and help to identify possible sources of error or discrepancies in measurements. The ILC results can contribute to increasing confidence in the data obtained in measuring laboratories and provide greater objectivity and reliability of measurements.

Confirmation of the competence of laboratories is an important process for ensuring the quality and reliability of measurement results. The main stages of this process include: accreditation as the first step in confirming competence; participation in ILCs; laboratory quality system; periodic inspection and calibration of measurement equipment to ensure the required accuracy of measurements; assessment of personnel qualifications; internal and external audits, etc. Together, these steps ensure a high level of competence of the laboratories in the performance of their functions and ensure the reliability and objectivity of the results of their activities.

ILC is one of the forms of experimental verification of the activity of laboratories with the aim of determining technical competence in a certain type of activity. A laboratory can participate in ILC programs, where its measurement results are compared with the results of other laboratories. This helps to assess the accuracy and reliability of its measurement methods. Successful ILC results for the laboratory are confirmation of competence in carrying out certain types of measurements by a specific specialist on specific equipment. National agencies for the accreditation of laboratories have established strict requirements for participation in the relevant ILCs, in particular for calibration laboratories (CL) for each type of measurement and each type of measurement value, which are included in the scope of laboratory accreditation.

2. RELATED PAPERS

Publications devoted to issues of organization of ILCs and methods of processing the received data in specific types of measurement or test are of considerable interest. The ILC program is developed taking into account the requirements of international standards ISO/IEC 17025 [2], ISO/IEC 17043 [1], ISO 13528 [3]. Improvement of the methods of processing ILC results is necessary to obtain reliable ILC results. Unsatisfactory ILC results can be associated not only with a deviation from the normal state of competence of the laboratory, but also with malfunctions of the equipment available in the laboratory or insufficient competence of the specialist who worked with it.

Scientific publications deal with a number of important issues regarding conducting ILC for CL, which mainly relate to the specifics of calibration for certain types of measurements. Algorithms and results of ILCs are given in works [4–8] for the purpose of evaluating the measuring capabilities of laboratories and obtaining highly accurate and precise data. Approaches for improvement of measurement methods and uncertainty assessment of ILC participating laboratories for various types of measurements (pressure, water flow, active power, temperature) are considered in [9–12]. Evaluation of the results of laboratories that participated in ILCs on specific types of measurements (reactive power, length, pressure) are presented in [13–15].

3. PROBLEM STATEMENT

The purpose of the carried-out research was to process the data received from ILC participating laboratories and compare them.

To achieve the set goal, it is necessary to solve the following problems:

– to research the calibration item for the ILC of energy meters, determine the assigned value and its extended uncertainty of this ILC;

– to calculate the degree of equivalence for each of the ILC participating laboratories and their expanded uncertainties;

– to evaluate the results of the calibration by participating laboratories of the ILC, taking into account the criteria of functioning statistics.

4. OVERVIEW OF THE INTERLABORATORY COMPARISON RESULTS

ILC for calibration of energy meter (UMTS-ILC-E:2024) was conducted from February to April 2024. In this ILC two laboratories carried out: State Enterprise "All-Ukrainian State Research and Production Center for Standardization, Metrology, Certification and Consumers Rights Protection" (SE "Ukrmetrteststandard" – UMTS, Ukraine), and SATEC Calibration Lab. (Israel). UMTS is accredited of the National Accreditation Agency of Ukraine (NAAU), Calibration No. 40004. SATEC Calibration Lab. is accredited of the Israel Laboratory Accreditation Authority (ISRAC), Calibration No. 357. NAAU and ISRAC are one of the signatories of the International Accreditation Cooperation (ILAC) arrangement for the mutual recognition of calibration results.

UMTS was selected as the referent laboratory (RL). Dr. Oleh Velychko was the ILC coordinator. The RL is responsible for providing the calibration item (CI) for ILC, coordinating the schedule, collecting and analyzing the comparison data, preparing the draft of report, etc. The ILC program was developed taking into account the requirements of international standards ISO/IEC 17025 [2], ISO/IEC 17043 [1] and ISO 13528 [3]. ILC was carried out in accordance with ISO/IEC 17025 standard to confirm the competence of accredited calibration laboratories.

Selected CI is SATEC EM133-XM(SE) 5A, an self-energized version of EM133 energy meter, serial number 40004123. SATEC EM133 is an energy meter family, ideal for a wide range of applications such as revenue active/reactive multi-tariff energy metering (Time of Use tariff system), industrial power monitoring and for interfacing SCADA in utility substations – with direct & indirect (transformer operated) measuring connection. Based the SATEC PM13X family functionality, it is a version designed as DIN-rail mount, equipped with built-in communication ports, digital I/Os and antitamper enclosures. The family comprises of meters with direct connection (up to 63 A) and transformer operated application (up to 10 A); self-energized (SE) and auxiliary power supply versions. More information of the EM133 is available at [16].

Meter chosen for comparison has 5A nominal measured current/10A max current is intended for transformer-operated applications (connection to High Voltage power lines).

Main characteristics of EM133-XM(SE)-5A (self-energized version, powered from measured voltages):

– measured voltage/supply voltage 57/100-277/480 V (L-L/L-N);
– measurement frequency range for voltage 25–400 Hz;
– current rating direct up to 10 A;
– current burden for 10 A < 0.4 VA;
– voltage burden (total) 5 VA;
– frequency range measurement 50/60 Hz;
– operational range of temperature –25°C to 60°C;
– dimensions 125 × 90 × 75 mm.

Appearance of EM133-XM(SE)-5A is shown on Figure 1.

Fig. 1. Appearance of EM133-XM (SE)-5A

Main measurements should be performed with the input signals and environmental conditions:

– AC voltage 230 V ± 0.05 %;
– current from 0.05 to 10 A ± 0.05 %;
– power factor (PF) 1.0, ±0.5;
– frequency 50 ± 0.01 Hz;
– ambient temperature 22 ± 3 °C;
– relative humidity 40 ± 3 %.

UMTS as a basis for the AC power standard uses National AC Power Measurement Standard of Ukraine (NDETU EM-08-2023), which consists of a reference standard COM 3003 ZERA AC energy and a Highly Stable Power Source. This measurement setup is usually for calibration service. A block diagram of the measurement setup of the UMTS AC energy measurement is shown in Figure 2.

The operating principle is based on comparing the measured energy values of the reference standard COM 3003 ZERA and the device under test (DUT) SATEC EM133 electric energy meter. Using a reference generator, the highly stable voltage and current signals were applied to the reference standard and the electric energy meter with the setting of the corresponding phase shifts between them. Voltage and current connection scheme is three-phase, star (WYE).

With the help of the measuring head, which is connected to the reference standard, the numbers of pulses of the electric energy meter, which are proportional to the corresponding measured value of electric energy for a certain period of time, were scanned. These pulses were compared with the reference pulses, which are proportional to the measured value of electrical energy using the reference standard. The errors and standard deviation of the electrical energy readings were calculated with the help of software of NDETU EM-08-2023.

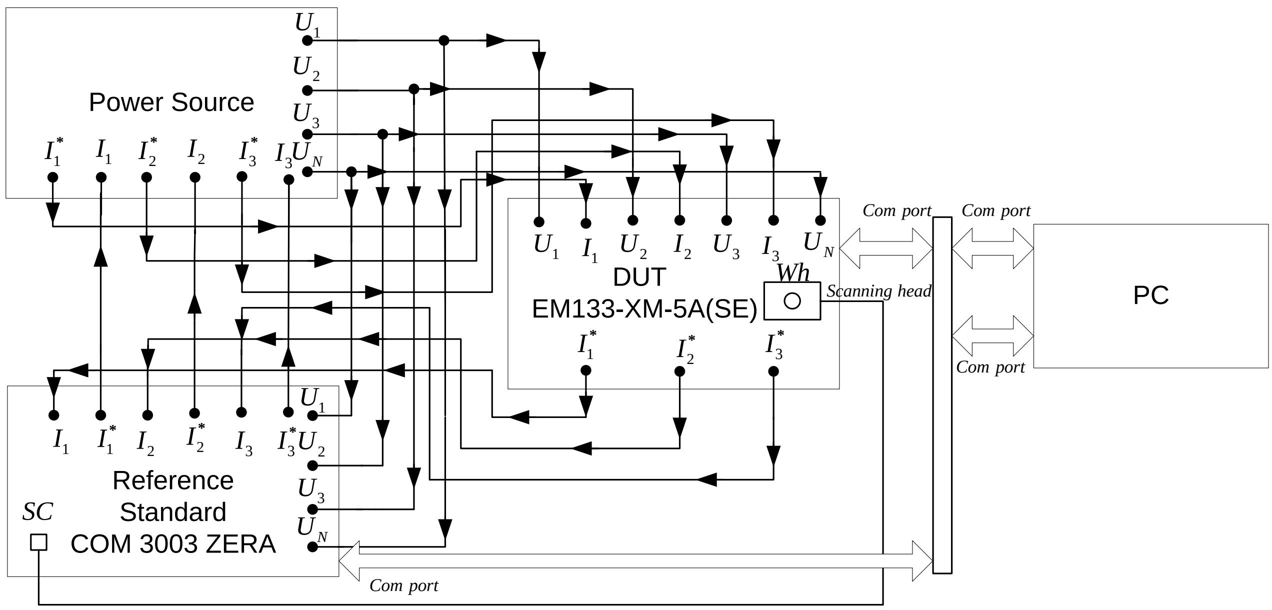

Fig. 2. Simplified schematic diagram of the measurement setup of the UMTS

The full measurement report of UMTS and SATEC contained all relevant data and uncertainty estimates. The reports included a description of the measurement method, the traceability to the SI, and the results and associated uncertainties. The calibration errors x_i and their expanded uncertainties $U(x_i)$ reported by the laboratories are given in Table 1 for AC voltage 230 V at frequencies of 50 Hz.

Table 1

Calibration results of measurement of electric energy for laboratories

Current A	PF	Flow positive/negative	Calibration error x_i %		Uncertainty $U(x_i)$ %	
			UMTS	SATEC	UMTS	SATEC
0.05	1.0	Positive	–0.06	–0.055	0.049	0.049
0.5			–0.02	–0.029	0.047	0.036
5			–0.021	–0.031	0.046	0.036
10			–0.044	–0.054	0.046	0.036
0.5	0.5	Positive	0.077	0.092	0.044	0.05
5			–0.03	–0.033	0.045	0.05
10			–0.108	–0.067	0.044	0.05
5	1.0	Negative	–0.023	–0.032	0.046	0.036
10			–0.045	–0.056	0.045	0.036
5	0.5	Negative	–0.033	–0.041	0.044	0.05
10			–0.115	–0.101	0.045	0.05

5. RESULTS OF THE ANALYSIS

UMTS was a pilot laboratory of COOMET key comparison of power (COOMET. EM-K5) [18], and GULFMET supplementary comparison of AC energy (GULFMET. EM-S5) [19], responsible for providing the travelling standard, coordinating the schedule, collecting and analyzing the comparison data, and preparing the draft report.

The uncertainty was calculated following the GUM [17]: standard uncertainties, degrees of freedom, correlations, scheme for the uncertainty evaluation. All contributions to the uncertainty of measurement were listed separately in the report and identified as either Type A or Type B uncertainties. The overall uncertainty, as calculated from the individual uncertainties, was stated.

Uncertainties were evaluated at the level of one standard uncertainty. The main uncertainty components were expected: experimental standard uncertainty of the mean of N independent measurements; uncertainty in the primary standard or working standard against which the CI is measured; uncertainty due to leads correction. Participants included additional sources of uncertainty also.

The uncertainty budget for the UMTS reference for PF = 1.0, AC current of 0.05 A, AC voltage of 230 V at frequency of 50 Hz is presented in Table 2.

The ILC assigned values (AV) X_{AV} are calculated as the mean of participant data:

$$X_{AV} = \frac{(x_{\text{UMTS}} + x_{\text{SATEC}})}{2} \qquad (1)$$

$$U(X_{AV}) = 2\sqrt{\frac{1}{\left(\frac{1}{u^2(x_{\text{UMTS}})} + \frac{1}{u^2(x_{\text{SATEC}})}\right)}}, \qquad (2)$$

where x_{UMTS} and x_{SATEC} are measurement error for UMTS and SATEC, accordingly, $u(x_{\text{UMTS}})$ and $u(x_{\text{SATEC}})$ are combined standard uncertainty for UMTS and SATEC, accordingly.

Assigned values with expanded standard uncertainties is given for AC voltage of 230 V and frequency of 50 Hz in Table 3. Only one value is reported for laboratories. Degrees of equivalence (DoE) of the laboratories are reported for AC voltage of 230 V at frequencies of 50 Hz.

The DoE of i-th laboratory with expanded uncertainties with respect to the AV is estimated as

$$D_{lab\ i} = x_{lab\ i} - X_{AV}, \qquad (3)$$

$$U(D_{lab\ i}) = \sqrt{U^2(x_{lab\ i}) + U^2(X_{AV})}. \qquad (4)$$

DoE with expanded uncertainties for laboratories for AC voltage 230 V at frequencies of 50 Hz are given in Table 4.

T a b l e 2

The uncertainty budget for the UMTS for PF = 1.0, AC current of 0.05 A, AC voltage of 230 V at frequencies of 50 Hz

i	Quantity (unit)	Distribution	x_i	$u(x_i)$, %	ν_i	c_i	$u_i(y)$, %
1	Standard deviation of the relative mean value of the observation of the differences between the value energy meter and the reference standard	normal	–0.059	0.010	4	1	0.010
2	Correction due to the accuracy of reproduction of the voltage by the power source	rectangular	0	0.014	∞	1	0.014
3	Correction due to the accuracy of reproduction of the current strength by the power source (PS)	rectangular	0	0.014	∞	1	0.014
4	Correction due to the accuracy of the electrical energy measurement by the reference standard COM 3003 ZERA	normal	0	0.005	∞	1	0.005
5	Correction due to the accuracy of the frequency internal generator of impulse signals of the COM 3003 ZERA for energy comparison	normal	0	$5\cdot10^{-5}$	∞	1	$5\cdot10^{-5}$
6	Correction determined by the stability of voltage reproduction by the PS	normal	0	0.005	∞	1	0.005
7	Correction determined by the stability of current reproduction by the PS	normal	0	0.005	∞	1	0.005
8	Drift of the reference standard COM 3003 since the last calibration	normal	–0.0017	0	∞	1	0
y	Combined standard uncertainty, %						0.024
	Expanded uncertainty (95 %, k = 2), %						0.049

Table 3

AV and expanded uncertainties of AV for AC voltage of 230 V at frequencies of 50 Hz

Current A	PF	Flow positive/negative	AV X_{AV} %	Uncertainty $U(X_{AV})$ %
0.05	1.0	Positive	–0.058	0.0346
0.5			–0.026	0.0286
5			–0.027	0.0284
10			–0.050	0.0284
0.5	0.5		0.084	0.0330
5			–0.031	0.0334
10			–0.090	0.0330
5	1.0	Negative	–0.029	0.0284
10			–0.052	0.0281
5	0.5		–0.036	0.0330
10			–0.109	0.0334

Table 4

DoE with expanded uncertainties for laboratories

Current A	PF	Flow positive/negative	DoE $D_{\text{tab i}}$ %		Uncertainty of DoE $U(D_{\text{lab i}})$ %	
			UMTS	SATEC	UMTS	SATEC
0.05	1.0	Positive	0.000	0.003	0.0600	0.0600
0.5			0.006	–0.003	0.0550	0.0460
5			0.006	–0.004	0.0540	0.0458
10			0.006	–0.004	0.0540	0.0458
0.5	0.5	Positive	–0.007	0.008	0.0550	0.0599
5			0.001	–0.002	0.0561	0.0602
10			–0.018	0.023	0.0550	0.0599
5	1.0	Negative	0.006	–0.003	0.0540	0.0458
10			0.007	–0.004	0.0531	0.0457
5	0.5		0.003	–0.005	0.0550	0.0599
10			–0.006	0.008	0.0561	0.0602

6. RESULTS OF THE ANALYSIS

The criterion of functioning statistics – the E_n number is chosen for the analysis of the obtained results of the ILC and the formation of conclusions about the laboratories.

Additionally, the performance E_n number is calculated as:

$$E_{n\ lab\ i} = 2\frac{|D_{lab\ i}|}{U(D_{lab\ i})} \leq 1.0. \qquad (5)$$

E_n number for laboratories for AC voltage of 230 V at frequencies of 50 Hz are given in Table 5. Laboratories meet the established requirements for E_n number ($|E_n| \leq 1.0$): UMTS – from 0.00 to 0.33; SATEC – from 0.04 to 0.39.

Table 5

DoE with expanded uncertainties for laboratories

Current A	PF	Flow positive/negative	E_n for UMTS	E_n for SATEC
0.05	1.0	Positive	0.00	0.04
0.5			0.10	0.07
5			0.11	0.08
10			0.11	0.08
0.5	0.5		0.12	0.14
5			0.02	0.03
10			0.33	0.39
5	1.0	Negative	0.10	0.07
10			0.13	0.09
5	0.5		0.06	0.08
10			0.11	0.13

7. CONCLUSION

A ILC of active and reactive energy meter at the points of alternating voltage of 230 V, currents from 0.05 A to 10 A, power factors from ±1.0 to ±0.5 at a frequency of 50 Hz has been conducted between participating calibration laboratories from Ukraine and Israel. In general, laboratories have received satisfactory accuracy and there is good agreement between participants for this quantity. Laboratories meet the established requirements for E_n number ($|E_n| \leq 1.0$) and confirms the its qualification (technical competence) during the calibration in accordance with the requirements of the standard ISO/IEC 17025. It is expected that this ILC will be able to provide support for participants' calibration capabilities.

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