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Interlaboratory comparisons of laboratories for calibration of active electrical energy meters

O. Velychko[1], Yu. Kulish[1], D. Nikitenko[1], A. Verkevicius[2]

[1] *State Enterprise "UKRMETRTESTSTANDARD", Metrologichna Str., 4, 03143, Kyiv, Ukraine*
velychko@ukrcsm.kiev.ua; yulika.ua@gmail.com; nikitenko@ukrcsm.kiev.ua
[2] *ELGAMA-ELEKTRONIKA Ltd., 2, Visorių Str., LT-08300, Vilnius, Lithuania*
andrius.verkevicius@elgama.eu

Abstract

Electrical energy meters are designed for measuring, recording, and monitoring of the consumption of electrical energy in residential, commercial, and industrial premises. Working measurement standards of the unit of active electrical energy are used for verification of energy meters, which are in turn subject to regular calibration. Working measurement standards are calibrated by calibration laboratories (CLs). Interlaboratory comparisons (ILCs) for calibration of measuring instruments are essential to ensure the accuracy, reliability, and reproducibility of measurement results across laboratories. The results of these comparisons in terms of a specific calibration constitute important evidence for national accreditation bodies.

Two CLs participated in an ILC for calibration of the active energy meter: SE "UKRMETRTESTSTANDARD" – UMTS, Ukraine, and ELGAMA-ELEKTRONIKA, Lithuania. The participating laboratories performed measurements of active electrical energy at an alternating current of 230 V at a frequency of 50 Hz at calibration points from 0.05 to 10 A at power factors of ±1 and ±0.5 Lag. The energy measurements of both CLs can be traced back to CLs in Germany. The results of the ILC of energy measurement standards demonstrated a satisfactory consistency of the obtained calibration results. The laboratories meet the established requirements for the E_n value (UMTS – from 0.02 to 0.20; ELGAMA – from 0.02 to 0.19) and have confirmed their technical competence.

The UMTS is accredited by the National Accreditation Agency of Ukraine (NAAU), and the ELGAMA is accredited by the National Accreditation Bureau of Lithuania (LNAB). Both NAAU and LNAB are among the participants of the ILAC Mutual Recognition Arrangement (ILAC MRA). Both CLs meet the requirements of the international standard ISO/IEC 17025. All this contributes to the recognition of calibration results of the laboratories in their scope of accreditation, both at the national and international levels.

Keywords: electrical energy; interlaboratory comparisons; calibration; electrical energy meter; measurement standard; measurement uncertainty.

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Introduction

Electrical energy meters are designed for measuring, recording, and monitoring of the consumption of electrical energy in residential, commercial, and industrial premises. They provide accurate data for the analysis of electricity consumption, which enables energy companies to effectively plan the supply of energy resources and their management. Working measurement standards of the unit of active electrical energy are used for verification of energy meters, which are in turn subject to regular calibration.

Electrical energy measurement standards are calibrated by accredited laboratories. Calibration laboratories (CLs) carry out calibrations of working measurement standards, linking their readings to reference values of the measurand values. This allows minimizing the measurement error of a measurement standard being calibrated. Interlaboratory calibrations (ILCs) for calibration of measuring instruments are essential to ensure the accuracy, reliability, and reproducibility of measurement results across laboratories. The analysis of results of such comparisons contributes to the improvement of calibration procedures, increasing their accuracy and efficiency.

The results of ILCs in terms of a specific calibration constitute important evidence for national accreditation bodies. This contributes to the recognition of calibration results, both at the national and international levels. Positive results of ILCs confirm a high level of competence of a CL in carrying out

the calibration of measuring instruments and working measurement standards according to certain types of measurements by a specific specialist using specific measuring equipment. Unsatisfactory results of ILCs may be related not only to insufficient competence of the specialist, but also to malfunctions of the measuring equipment available in the laboratory.

Programmes for carrying out ILCs and processing of their results shall be developed accounting for the requirements of such international standards as ISO/IEC 17025 [1], ISO/IEC 17043 [2], and ISO 13528 [3]. Issues of the organization of ILCs and methods of processing of received primary data from laboratories in specific types of calibration are discussed in [4–10]. The improvement of methods for measurement and evaluation of the measurement uncertainty in laboratories for various types of measurements is considered in [4–7]. The assessment of laboratory results for various types of measurements is considered in [8–11].

The algorithm for assessing the measurement and calibration capabilities of a CL is presented in [12], and the influence of the instability of a calibration object (CO) on ILC results is considered in [13]. A Brazilian applied programme for ILCs in terms of electrical energy is generally described in [14]. This is the one and only work in which the ILC results are specifically considered for calibration of electrical power measuring instruments. Therefore, ILCs of calibrations of active electrical energy meters are relevant.

The authors of the paper aimed to highlight the results of the conducted ILCs of calibration of electrical energy measuring instruments, given the practical absence of such scientific publications. In addition, it is important to verify the results of ILCs of calibration laboratories accredited in various national accreditation systems, selected by statistical methods. Positive results of such ILCs can confirm the possibility to recognize the results of their calibrations in their scope of accreditation, both at the national and international levels.

Participants of the interlaboratory comparison for calibration of active electrical energy meters

The ILC for calibration of active electrical energy meters (UMTS-ILC-E2) was conducted from October to November 2024. In the comparison, two laboratories took part: State Enterprise "UKRMETRTESTSTANDARD" – UMTS, Ukraine, and ELGAMA-ELEKTRONIKA Ltd. – ELGAMA, Lithuania.

The UMTS is accredited by the National Accreditation Agency of Ukraine (NAAU). The ELGAMA-ELEKTRONIKA Calibration and Verification Lab is accredited by the Lithuanian National Accreditation Bureau (LNAB). Both NAAU and LNAB are among the participants of the ILAC Mutual Recognition Arrangement (ILAC MRA). The participating laboratories carried out their measurements of active electrical energy at an alternating current (AC) voltage of 230 V at a frequency of 50 Hz. The UMTS measurement results are traceable to the National Metrology Institute of Germany – PTB. The ELGAMA measurement results are traceable to the EMH Energie-Messtechnik GmbH (Germany).

The UMTS was also a pilot laboratory of a regional key comparison of electrical power (COOMET.EM-K5) [15] and a regional supplementary comparison of electrical energy (GULFMET.EM-S5) [16].

Calibration object for the ILC and measurement conditions

SATEC EM133-XM(SE) 5A (EM133-XM) is an active energy meter (serial no. 40004123) which was selected as a calibration object for the ILC. EM133-XM is an electrical energy meter with direct and indirect (operated by a transformer) measuring connection. The meter has a 5A nominal measured current/10A max current intended for transformer-operated applications (connection to high voltage power lines) [17].

Main characteristics of EM133-XM (Fig. 1):

- measured voltage/supply voltage 57/100-277/480 V;
- measurement frequency range for voltage 25–400 Hz;

Fig. 1. General view of EM133-XM

- direct current rating up to 10 A;
- current load for 10A < 0.4 V·A;
- total voltage load 5 V·A;
- measurement frequency range 50/60 Hz.

Main measurements for the ILC shall be performed with input signals and ambient conditions as follows:

- AC voltage 230 V ± 1%;
- AC current from 0.05 to 10 A ± 1%;
- power factor (PF) ±1.0, ±0.5 Lag;
- operating frequency 50 Hz ± 0.3%;
- ambient temperature (23 ± 2) °C;
- relative humidity <75%;
- supply voltage 230 ± 10% V;
- frequency of the supply voltage (50 ± 1) Hz.

Calibration results for laboratories and assigned values with uncertainties

Each laboratory's calibration report for the object of calibration included a description of the applied measurement method, traceability to the SI units, results, and associated measurement uncertainties.

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

$$X_{AV} = \left(x_{\text{UMTS}} + x_{\text{ELGAMA}}\right)/2 \qquad (1)$$

with expanded standard measurement uncertainties

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

where x_{UMTS} and x_{ELGAMA} are calibration errors for the UMTS and ELGAMA CL accordingly, $u(x_{\text{UMTS}})$ and $u(x_{\text{ELGAMA}})$ are combined standard measurement uncertainties for the UMTS and ELGAMA CL accordingly.

The calibration errors x_i with expanded measurement uncertainties $U(x_i)$ for laboratories and AVs with expanded standard measurement uncertainties are given in Table 1 for AC voltage of 230 V at frequencies of 50 Hz.

Degrees of equivalence and consistency of results for the laboratories

Degrees of equivalence (DoE) for each of the participating laboratories of the ILC are established for an AC voltage of 230 V at a frequency of 50 Hz for all current and PF calibration points. The laboratory DoE with a corresponding expanded measurement uncertainty, accounting for an AV and its measurement uncertainty, is estimated as:

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

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

To establish the consistency of the obtained calibration results for the laboratories of the ILC, the E_n value is applied, which is calculated according to the following expression and should not exceed the value of 1.0:

$$E_{n\ lab\ i} = 2\left|D_{lab\ i}\right|\Big/U\left(D_{lab\ i}\right) \le 1.0. \qquad (5)$$

DoE with extended measurement uncertainty and the E_n value for each of the participating laboratories of the ILC are given in Table 2 for an AC voltage of 230 V at a frequency of 50 Hz at all current and PF calibration points. The laboratories demonstrate a satisfactory consistency of the obtained results of the ILC according to the established requirements regarding the value of E_n.

Table 1

Calibration results for laboratories and AVs and their expanded uncertainties

Current, A	PF	Calibration error x_i, %		Uncertainty $U(x_i)$, %		AV X_{AV}, %	Uncertainty $U(X_{AV})$, %
		UMTS	ELGAMA	UMTS	ELGAMA		
0.05	1	–0.042	–0.044	0.049	0.045	–0.043	0.033
0.5		–0.024	–0.031	0.047	0.045	–0.027	0.033
5		–0.022	–0.033	0.046	0.045	–0.028	0.032
10		–0.045	–0.046	0.046	0.045	–0.046	0.032
0.5	0.5 Lag	0.071	0.064	0.044	0.045	0.067	0.032
5		–0.028	–0.034	0.045	0.045	–0.031	0.032
10		–0.099	–0.105	0.044	0.045	–0.102	0.032
5	–1	–0.019	–0.025	0.046	0.045	–0.022	0.032
10		–0.044	–0.047	0.045	0.045	–0.045	0.032
5	–0.5 Lag	–0.040	–0.042	0.044	0.045	–0.041	0.032
10		–0.100	–0.101	0.045	0.045	–0.101	0.032

Table 2

DoE with expanded uncertainties for laboratories and the E_n value

Current, A	PF	DoE $D_{lab\ i}$, %		Uncertainty of DoE $U(D_{lab\ i})$, %		E_n for UMTS	E_n for ELGAMA
		UMTS	ELGAMA	UMTS	ELGAMA		
0.05	1	0.000	–0.001	0.0592	0.0559	0.03	0.03
0.5		0.003	–0.003	0.0571	0.0555	0.12	0.11
5		0.006	–0.005	0.0561	0.0553	0.20	0.19
10		0.001	–0.001	0.0561	0.0553	0.02	0.02
0.5	0.5 Lag	0.004	–0.004	0.0541	0.0549	0.13	0.14
5		0.003	–0.003	0.0551	0.0551	0.10	0.10
10		0.003	–0.003	0.0541	0.0549	0.11	0.11
5	–1	0.003	–0.003	0.0561	0.0553	0.11	0.11
10		0.001	–0.001	0.0551	0.0551	0.05	0.05
5	–0.5 Lag	0.001	–0.001	0.0541	0.0549	0.04	0.04
10		0.001	–0.001	0.0551	0.0551	0.02	0.02

Conclusion

The results of the ILC of active energy measurement standards with a nominal value of 230 V at an industrial frequency of 50 Hz for AC current from 0.05 to 10 A and PF ±1, ±0.5 Lag between CLs from Ukraine and Lithuania showed a satisfactory consistency of the obtained calibration results. The laboratories meet the established requirements for the E_n values (UMTS – from 0.02 to 0.20; ELGAMA – from 0.02 to 0.19) and have demonstrated their technical competence during the calibration.

The UMTS is accredited by the NAAU, the ELGAMA is accredited by the LNAB, and these national accreditation bodies are the participants of the ILAC MRA. Both laboratories meet the requirements of the international standard ISO/IEC 17025 and have confirmed their technical competence according to the results of the ILC. All this contributes to the recognition of the calibration results of the laboratories in their accreditation scope, both at the national and international levels.

Міжлабораторні звірення лабораторій з калібрування лічильника активної електричної енергії

О.М. Величко[1], Ю.М. Куліш[1], Д.В. Нікітенко[1], А. Веркявичюс[2]

[1] *Державне підприємство "УКРМЕТРТЕСТСТАНДАРТ", вул. Метрологічна, 4, 03143, Київ, Україна*
velychko@ukrcsm.kiev.ua; yulika.ua@gmail.com; nikitenko@ukrcsm.kiev.ua
[2] *ТОВ "ЕЛЬГАМА-ЕЛЕКТРОНІКА", вул. Візори, 2, LT-08300, Вільнюс, Литва*
andrius.verkevicius@elgama.eu

Анотація

Лічильники електричної енергії призначені для вимірювання, реєстрації та контролю споживання електричної енергії в житлових, комерційних і промислових приміщеннях. Робочі еталони одиниці активної електричної енергії використовуються для повірки електролічильників, які підлягають регулярному калібруванню. Калібрувальні лабораторії (КЛ) здійснюють калібрування робочих еталонів. Міжлабораторні звірення (МЗ) для калібрування засобів вимірювання мають важливе значення для забезпечення точності, надійності та відтворюваності результатів вимірювань у лабораторіях. Результати МЗ щодо конкретного калібрування є важливим доказом для національних органів з акредитації лабораторій.

У МЗ для калібрування лічильника активної енергії взяли участь дві КЛ: ДП "УКРМЕТРТЕСТСТАНДАРТ" – UMTS, Україна та ELGAMA-ELEKTRONIKA, Литва. Лабораторії-учасники МЗ проводили вимірювання активної електричної енергії при змінному струмі напругою 230 В на частоті 50 Гц у точках калібрування від 0,05 до 10 А

при коефіцієнтах потужності ±1 і ±0,5 Lag. Вимірювання енергії обох КЛ можна простежити до КЛ Німеччини. Результати проведеного МЗ еталонів енергії показали хорошу узгодженість отриманих результатів калібрування. Лабораторії відповідають встановленим вимогам щодо показника E_n (UMTS – від 0,02 до 0,20; ELGAMA – від 0,02 до 0,19) і підтверджують свою технічну компетентність.

КЛ UMTS акредитована Національним агентством з акредитації України (НААУ), а КЛ ELGAMA – Національним бюро акредитації Литви (LNAB). НААУ та LNAB є одними з учасників Угоди про взаємне визнання результатів калібрування Міжнародної співпраці з акредитації лабораторій (ILAC). Обидві КЛ задовольняють вимоги міжнародного стандарту ISO/IEC 17025. Усе це сприяє визнанню результатів калібрування лабораторій за їхньою сферою акредитації як на національному, так і на міжнародному рівнях.

Ключові слова: електрична енергія; міжлабораторні звірення; калібрування; лічильник електроенергії; еталон вимірювання; невизначеність вимірювання.

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