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Original scientific paper

INFRASTRUCTURE DEVELOPMENT FOR EXTREME ELECTRICAL METROLOGY

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A b s t r a c t: In the paper analysis findings of the metrological infrastructure for testing and calibration in the area of extreme electrical quantities: very small and very high direct and alternating currents, very small and very high electrical resistances, very high frequencies of electrical signals, as well as electrical inductance and electrical capacitance, are presented. The analysis at the national, regional and international level is conducted within the framework of the scientific research project "Development and Upgrade of Laboratory Resources for Research and Introduction of New Analytical Methods in Electrical Metrology", financed by the Ministry of Education and Science of the Republic of North Macedonia. The needs for measurement, testing and calibration are identified, both for the economy and for enhancement of the laboratory research capacities. The identified gap in the technical readiness (equipment and facilities) of the national laboratories in relation to the international reference laboratories in the field of testing and calibration for extreme electrical quantities is bridged by enhancing the capacities of the Laboratory for Electrical Measurements (LEM) at the Ss. Cyril and Methodius University in Skopje, Faculty of Electrical Engineering and Information Technologies, accredited calibration laboratory in compliance with MKS EN ISO/IEC 17025:2018, with the objective of development and validation of new calibration and test methods, and expansion of the scope of LEM's accreditation in the areas of measurement, testing and calibration in the field of extreme electrical quantities.

Key words: electrical metrology; metrology infrastructure; calibration; extreme electrical quantities

РАЗВОЈ НА ИНФРАСТРУКТУРА ЗА ЕКСТРЕМНА ЕЛЕКТРИЧНА МЕТРОЛОГИЈА

А п с т р а к т: Во трудот се прикажани наодите од анализата на метролошката инфраструктура за тестирање и калибрација во областа на екстремни електрични големини: многу мали и многу високи еднонасочни и наизменични струи, многу мали и многу високи електрични отпорности, многу високи фреквенции на електрични сигнали, како и индуктивност и електрична капацитивност. Анализата е спроведена на национално, регионално и меѓународно ниво во рамките на научноистражувачкиот проект „Развој и надградба на лабораториски ресурси за истражување и воведување нови аналитички методи во електричната метрологија", финансиран од Министерството за образование и наука на Република Северна Македонија. Воочени се потребите од мерење, тестирање и калибрација, како за стопанството така и за зајакнување на истражувачките лабораториски капацитети. Идентификуваниот јаз во техничката подготвеност (опрема и капацитети) на националните лаборатории во однос на меѓународните референтни лаборатории за тестирање и калибрација на екстремни електрични големини е премостен со подобрување на капацитетите на Лабораторијата за електрични мерења (ЛЕМ) при Универзитетот „Св. Кирил и Методиј" во Скопје, Факултет за електротехника и информациски технологии, акредитирана за калибрација во согласност со МКС EN ISO/IEC 17025:2018, со цел развој и валидација на нови методи за калибрација и тестирање, како и проширување на опсегот на акредитацијата на ЛЕМ за мерење, тестирање и калибрација во областа на екстремни електрични големини.

Клучни зборови: електрична метрологија; метролошка инфраструктура; калибрации; екстремни електрични големини

1. INTRODUCTION

The metrological and laboratory infrastructure in the Republic of North Macedonia (RNM) is underdeveloped and represents an obstacle in the realization of scientific and R&D projects, which is also a condition for the development of the country's trade and economy [1]. One third of EU legislation relates to measurements and tests, e.g. for the safety of people, the environment, energy, etc., RNM has harmonized to a great extent the legislation in the regulated areas related to these fields, whereby several laws and by-laws were adopted. The existence of appropriately equipped scientific laboratories is fundamental for the quality of the results of measurements and tests, and for ensuring high-level scientific development of the research staff. The metrology of electrical quantities, as an area embedded in all industrial activities, represents a condition for more intensive involvement of Macedonia in industrial and technical cooperation, both at the regional and European level [2]. At the Faculty of Electrical Engineering and Information Technologies (FEEIT), at the Ss. Cyril and Methodius University in Skopje (UKIM), since its foundation, the metrology of electrical quantities has been nurtured. The Laboratory for Electrical Measurements (LEM), an identified independent unit of FEEIT, with implemented quality assurance system, was accredited on 22. 11. 2015 by the Institute of Accreditation of RN Macedonia (IARNM), and on 22. 11. 2019 it was re-accredited in compliance with the international standard MKS EN ISO/IEC 17025:2018, [3, 5], as a calibration laboratory of instruments for electrical quantities, electrical power and energy, with a Certificate for accreditation no. LC-012. The scope of LEM's accreditation covers calibration of instruments and generators for DC and AC voltages and currents, resistance, capacitance, frequency, phase angle, electrical power and energy. LEM is the primary and unique national calibration laboratory for electrical power and energy reference standards, thereby ensuring measurement traceability and uniformity of measurements in this very important area of scientific and legal metrology. The complete measurement and calibration capabilities of LEM are provided in the Annex to the Accreditation Certificate no. LC-012, (iarm.gov.mk) [16]. Since November 2015, the number of calibrations, as well as the type of instruments calibrated in LEM is constantly increasing (more than 400 calibration activities in 2021). LEM is closely related to scientific research conducted at the Institute for Electrical Measurements and Materials (IEMEM) at UKIM-FEEIT, in the field of metrology of electrical quantities. Hence, since 2015, new analytical methods for the calibration of electrical quantities instruments have been continuously introduced in LEM, which have been confirmed and validated on several occasions, through formal expansion of LEM accreditation scope by IARNM with improved the measurement and calibration capabilities (CMC). Calibration activities are carried out in LEM, for the local industry, international corporations operating in technological development zones, conformity assessment bodies (calibration and testing laboratories, inspection and certification bodies), but also for companies and laboratories from the region. One of the most significant activities of LEM is the successful participation in several international inter-laboratory comparisons and proficiency testing schemes, with which LEM successfully proves its top competence and quality in conducting calibrations of electrical quantities, through reports published in the KDBC key comparison database of the International Bureau of Weights and Measures (BIPM) in Paris, and relevant scientific publications [3, 4].

The ensuring of the development and introduction of new laboratory methods, as well as the maintenance of already introduced methods, requires continuous investment in laboratory resources, which is the main goal of the scientific research project financed by the Ministry of Education and Science of the RNM (MES) through the procurement of laboratory resources/reference standards for significant expansion of the LEM accreditation and CMC scope according to МКС EN ISO/IEC 17025: 2018, and for introduction of new calibration methods for instruments, for high direct and alternating currents, high frequencies of electrical signals, very high electrical resistances, very small electrical resistances and electrical inductance. The necessity of these laboratory resources have been identified through the most up-to-date scientific knowledge in electrical metrology, but also following the needs of the industry and other national and regional subjects for calibration services at higher metrology level. The metrology of electrical quantities is a very complex area, in which new scientific breakthroughs are constantly occurring, primarily in two directions:

- expansion of measurement capabilities – development of measurement procedures for new physical quantities, or for extreme values (very high or very small) of physical quantities outside the available measurement ranges, or

- improvement of the existing measurement capabilities – reduction of the measurement uncertainty budget through identification of new influential factors and their correction.

The contribution of the research includes the deepening and expansion of scientific knowledge through:

1. R&D and introduction of a new measurement laboratory procedure for the calibration of a quantity for which there are no traceable national measurement and calibration possibilities – electrical inductance,

2. research and introduction of new measurement laboratory procedures for calibration of very high direct and alternating currents (over 10 A DC and over 120 A AC), for very small resistances (under 100 mΩ), for very high resistances (over 100 MΩ), for high frequencies (above 1 MHz), and

3. reduction of the measurement uncertainties of the already introduced and accredited calibration methods, as well as achieving the lowest uncertainties through in-depth scientific evaluation of the contributions to the budgets of the measurement uncertainties in the newly introduced laboratory procedures, by applying complex mathematical, statistical and numerical methods.

2. ANALYSIS OF THE CURRENT-STATE-OF-THE-ART OF THE BEST MEASUREMENT AND CALIBRATION CAPABILITIES FOR EXTREME VALUES OF ELECTRICAL QUANTITIES

The state-of-the-art analysis of the best measurement and calibration capabilities for unrepresented (electrical inductance) or extreme electrical quantities (high frequencies, very small and very high values of electrical resistance, and very small and very high electrical currents) at the international level started from a survey of published measurement and calibration capabilities of the top national metrology institutes (NMIs) at international level (CMCs in KDBC base of BIPM) [6], but also at the regional level through published CMCs (Calibration and Measurement Capabilities) on the websites of national accreditation bodies for calibration laboratories. Bellow are some of the results of this extensive survey. The extended uncertainty is given with a coverage factor of $k = 2$, with a statistical probability of 95%.

2.1. *Comparison of the best measurement and calibration capabilities at the international and regional level for alternating voltage at high frequencies*

In Figures 1–3, the comparison of the values of the expanded measurement uncertainties of the national metrology institutes (NMIs) at the international and regional level when measuring alternating voltages up to 1 kV at very high frequencies of 500 kHz and 1 MHz, is given.

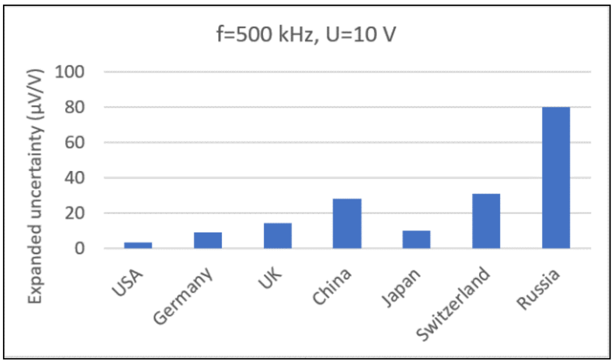

Fig. 1. Expanded measurement uncertainty at 10 V AC voltage at frequency of 500 kHz at the international NMIs level

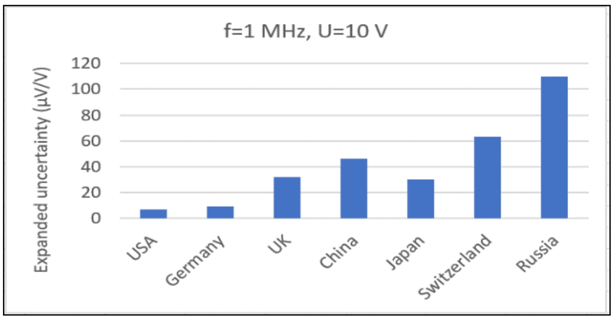

Fig. 2. Expanded measurement uncertainty at 10 V AC voltage at frequency of 1 MHz at the international NMIs level

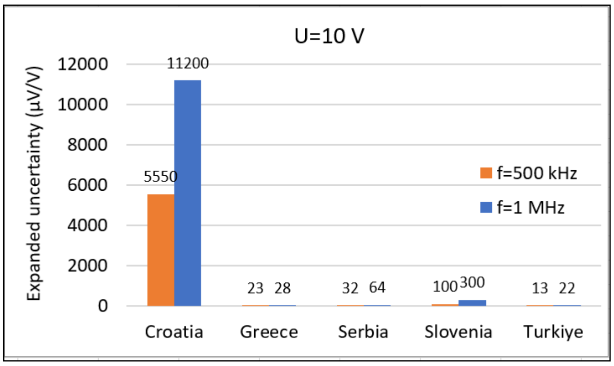

Fig. 3. Expanded measurement uncertainty at 10 V AC voltage at frequencies of 500 kHz and 1 MHz at the regional NMIs level

2.2. *Comparison of the best measurement and calibration capabilities at the international and regional level for high alternating currents*

In Figures 4 and 5, the comparison of the expanded measurement uncertainties of the national metrology institutes at the international and regional level for high alternating currents at high frequencies of 1 kHz and 10 kHz are given.

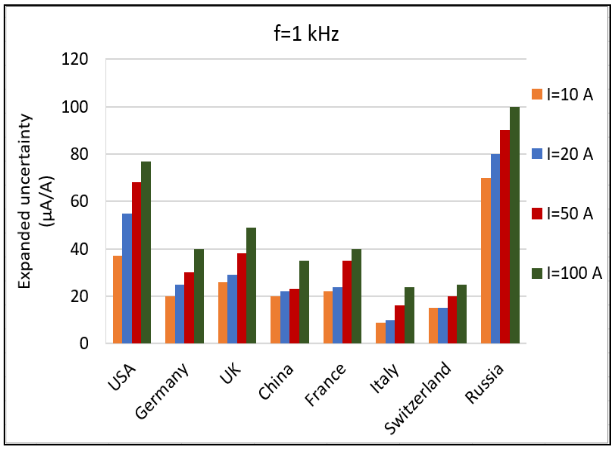

Fig. 4. Comparison of expanded measurement uncertainty of alternating current at frequency of 1 kHz at international NMIs level

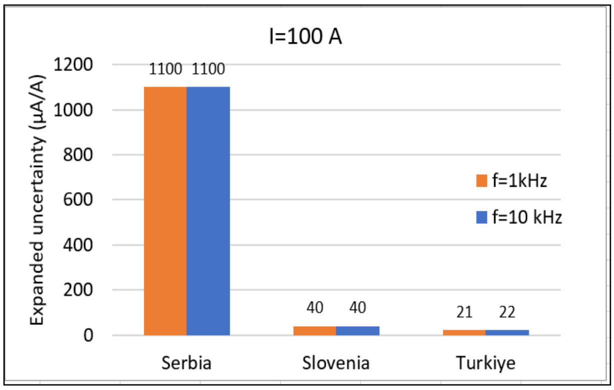

Fig. 5. Expanded measurement uncertainty at 100 A alternating current at 1 kHz and 10 kHz frequencies at the regional NMIs level

2.3. *Comparison of the best measurement and calibration capabilities at the international and regional level for electrical capacitance*

In Figures 6 and 7, the comparison of the expanded measurement uncertainties of the national metrology institutes at the international and regional level for electrical capacitance of 1 µF at high frequencies of 1 kHz are shown.

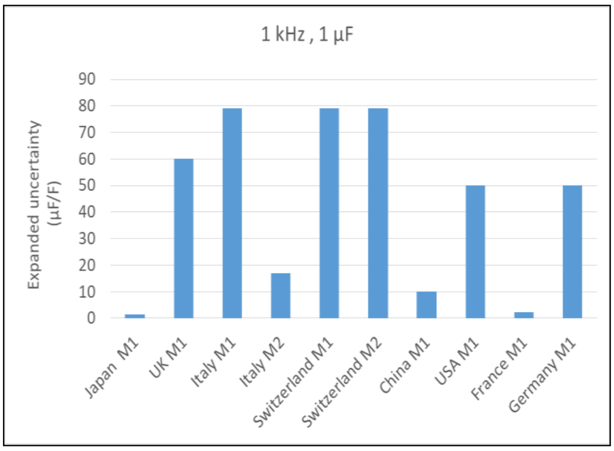

Fig. 6. Expanded measurement uncertainties of electrical capacitance of 1 µF at 1 kHz at the international NMIs level

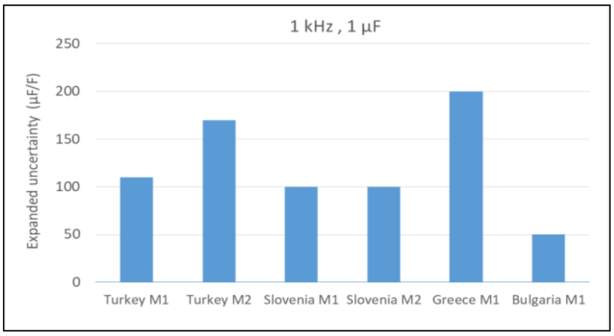

Fig. 7. Expanded measurement uncertainties of electrical capacitance of 1 µF at 1 kHz at the regional NMIs level

2.4. *Comparison of the best measurement and calibration capabilities at the international and regional level for electrical inductance*

In Figures 8 and 9, the comparison of the expanded measurement uncertainties of the national metrological institutes at the international and regional level when measuring electrical inductance of 10 mH at frequency of 1 kHz are displayed.

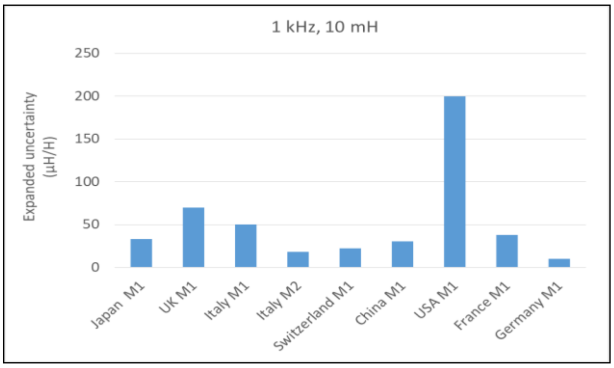

Fig. 8. Expanded measurement uncertainties of electrical inductance of 10 mH at 1 kHz at the international NMIs level

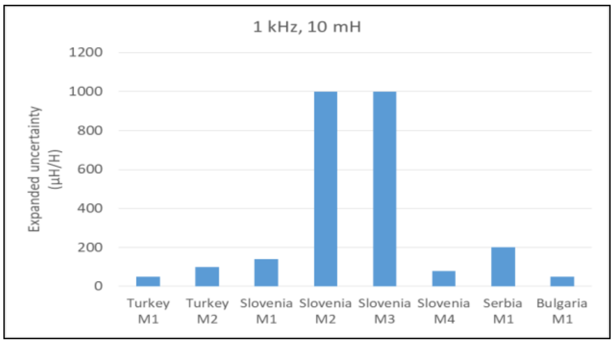

Fig. 9. Expanded measurement uncertainties of electrical inductance of 10 mH at 1 kHz at the regional NMIs level

2.5. *Comparison of the best measurement and calibration capabilities at the international and regional level for low electrical resistance*

In Figures 10 and 11, the comparison of the expanded measurement uncertainties of the national metrology institutes at the international and regional level when measuring a small electrical resistance of 1 mΩ are presented.

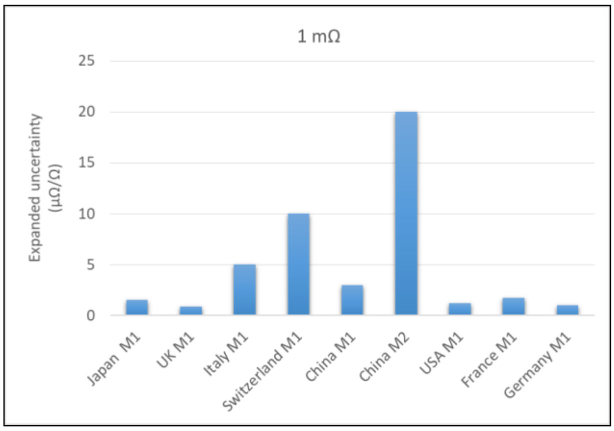

Fig. 10. Expanded measurement uncertainties of electrical resistance of 1 mΩ at the international NMIs level

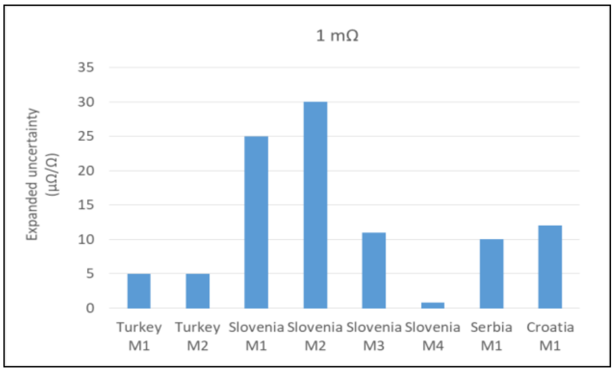

Fig. 11. Expanded measurement uncertainties of electrical resistance of 1 mΩ at the regional NMIs level

2.6. *Comparison of the best measurement and calibration capabilities at the international and regional level for high electrical resistance*

In Figures 12 and 13, the comparison of the expanded measurement uncertainties of the national metrology institutes at the international and regional level when measuring high electrical resistance of 1 GΩ are shown.

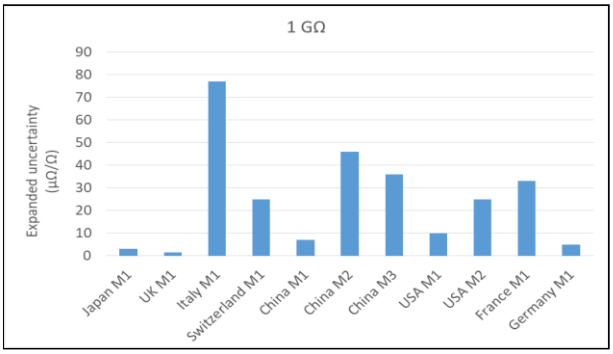

Fig. 12. Expanded measurement uncertainties of electrical resistance of 1 GΩ at the international NMIs level

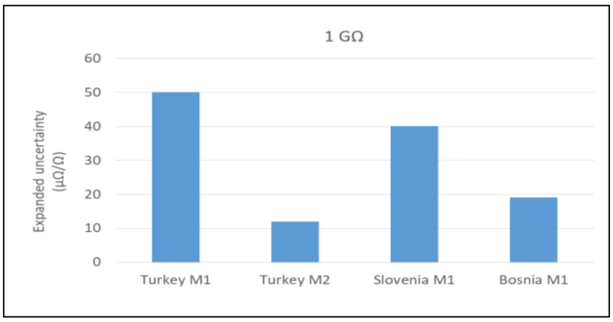

Fig. 13. Expanded measurement uncertainties of electrical resistance of 1 GΩ at the regional NMIs level

2.7. *Measurement and calibration capabilities of the Laboratory for Electrical Measurements at UKIM-FEIT*

In the RN Macedonia, the Laboratory for Electrical Measurements (LEM) at the Ss. Cyril and Methodius University in Skopje, Faculty of Electrical Engineering and Information Technologies, provides the current best measurement and calibration capabilities in the field of electrical quantities, published with the Annex to the accreditation certificate no. LC-012 issued by the IARNM on 26.12.2019.

The technical specifications of the primary and secondary LEM reference standards in Figure 14, as declared by the equipment manufacturers, are given in Table 1, while the published best measurement and calibration capabilities of the LEM are summarized in Table 2.

Fig. 14. The LEM primary and secondary reference standards for electrical quantities, Agilent 3458A and FLUKE 5500A

T a b l e 1

LEM reference standards uncertainties declared by the equipment manufacturers

Equipment	Measurement range	Uncertainty
DC voltage reference standard FLUKE 732A	10 V 1.018 V 1 V	±0.5 μV/V ±1.5 μV/V ±1.5 μV/V
8½ digit multimeter Agilent 3458A	DC voltage 0 mV up to 1000 V AC voltage 1 mV up to 1000 V, 1 Hz to 50 MHz, sinus DC current 100 nA up to ±1A, AC current 100 µA up to 1 A, 10 Hz up to 10 kHz, sinus Resistance 100 mΩ up to 1 GΩ, Phase angle 0 up to ± 179.99°, Frequency 1 Hz до 10 MHz,	±8 μV/V ±100 μV/V ±14 μA/A ±100 μA/A ±2.2 μΩ/Ω ±0.1 % ±0.1 %
Multifunctional calibrator FLUKE 5500 A	DC voltage 0 mV up to 1020 V AC voltage 1 mV up to 1020 V, 10 Hz up to 500 kHz, sinus DC current 0 up to ±11 A AC current 29 mA up to 11 A, 10 Hz up to 10 kHz, sinus Resistance 0 up to 329.999 MΩ Capacitance 0.33 nF up to 1.1 mF Phase angle 0 up to ± 179.99°, Frequency 0.01 Hz up to 2.0 MHz,	±50 μV/V ±30 μV/V ±10 μA/A ±60 μA/A ±9 μΩ/Ω ±25 μF/F ±0.15° ±25 μHz/Hz

T a b l e 2

Published LEM best measurement and calibration capabilities

Physical Quantity	Range	Uncertainty
DC voltage	10 mV "to 1020 V	22 µV/V
AC voltage	10 mV to 1020 V, 10 Hz to 1 MHz, sinus	35 µV/V
DC current	0 to ±11A	80 µA/A
AC current	50 µA to 11 A	170 µA/A
Resistance	0.1 Ω to 100 MΩ	20 µΩ/Ω
Capacitance	0.33 nF to 1.1 mF	25 µF/F
Active power Reactive power Apparent power	Up to 67.2 kW Up to 67.2 kVAr Up to 67.2 kVA	0.017 %
Electrical energy		0.018 %

3. BRIDGING THE METROLOGICAL GAP IN THE AREA OF EXTREME ELECTRICAL QUANTITIES BY ENHANCING THE CAPACITIES OF LEM

As a result of the perceived gap in measurement and calibration possibilities between top international laboratories, and taking into account the regional state of the metrological infrastructure in the area of electrical quantities, an analysis of the international supply of reference standards for electrical quantities that are not covered by the existing LEM reference standards has been carried out.

Based on the conducted analysis, LEM has defined a detailed technical specification for the procurement of reference standards, for significant expansion of the measurement and calibration capabilities of LEM.

Table 3 shows the detailed technical specifications of reference standards, acquired within the frame of the scientific research project "Development and Upgrade of Laboratory Resources for Research and Introduction of New Analytical Methods in Electrical Metrology", which is implemented within the program for financing scientific research projects of special and public interest for 2021 (support for the development of laboratory resources) by the Ministry of Education and Science of the Republic of North Macedonia.

Table 3

Detailed technical specifications of reference standards, acquired within the scientific project "Development and Upgrade of Laboratory Resources for Research and Introduction of New Analytical Methods in Electrical Metrology" for expansion of LEM's CMC for extreme electrical quanitites

Multifunctional calibrator Transmille 4015	
Technical specifications	
Measurement range	Best annual accuracy:
– DC voltage 0 – ±1025 V	±15 ppm
– DC current 0 – 30 A	±50 ppm
– AC voltage 20 mV – 1000 V, 10 Hz – 500 kHz	0.015%
– AC current 20 µA – 30 A, 10 Hz – 30 kHz	0.04%
– Electrical resistance (passive) 0 – 1 GΩ	40 ppm
– Electrical capacitance (passive) 1 nF – 10 µF	0.25%
– Frequency 1 Hz – 10 MHz	30 ppm
– Temperature (for thermocouples calibration) J / K / T / R / S / B / U / N / E / L / U / C / 10 µV°C	±0.09 °C
– Electrical resistance (simulated) 0 – 1 GΩ	100 ppm

Supplement to the multifunctional calibrator for calibration of oscilloscopes with frequency range up to 600 MHz Transmille sPC600	
Technical specifications	
Range	Resolution
2 mV/Div to 10 mV/Div	10 nV
20 mV/Div to 100 mV/Div	100 nV
200 mV/Div to 2 V/Div	1 µV
5 V/Div to 20 V/Div	10 µV
50 V/Div	100 µV
Range	Best annual accurac
DC voltage (2 mV to 50 V/Div)	0.01 %
AC volatge (2 mV to 50 V/Div)	0.1 %
Time base (2 ns/Div. to 5 s/Div.)	5 ppm
Frequency (reference frequency 50 kHz)	30 ppm
Rise time/fall	1 ns
Wave forms	Combined at least up to 100 ns

Supplement to the multifunctional calibrator for calibration of instruments for inductance (coils) with specifications for 1 kHz and accuracy of ± 50 µH Transmille IND			
Technical Specifications			
Electrical Inductance	Q-factor	Display resolution	Best annual accuracy
1 mH	1	100 nH	0.5 %
10 mH	2.8	1 µH	0.5 %
19 mH	3.8	1 µH	0.5 %
29 mH	4.7	1 µH	0.5 %
50 mH	6.1	1 µH	0.5 %
100 mH	8.6	10 µH	0.5 %
1 H	29	100 µH	0.5 %
10 H	110	1 mH	0.5 %

Supplement to the multifunctional calibrator for calibration of instruments for picoamp currents and adapter for high teraohm resistance Transmille EA008			
Technical specifications			
Measurement range	Resolution	Best annual accuracy in % of reading	Best annual accuracy in % of range
10 nA	1 pA	0.5	0.4
100 nA	10 pA	0.5	0.4
1 µA	100 pA	0.5	0.4
10 µA	1 nA	0.5	0.4
100 µA	10 nA	0.5	0.4

Supplement (high current coil) to the multifunctional calibrator for calibration of instruments for currents up to 1500 A (for frequencies from 0 to 60 Hz) Transmille EA002	
Technical specifications	
Measurement range	Best annual accuracy
Input 0 of 30 A Frequency from DC – 30 Hz to 60 Hz Effective output 0 to 60 A	0.35% + 0.008 A
Input 0 to 30 A Frequency from DC – 30 Hz to 60 Hz Effective output 0 to 300 A	0.41% + 0.01 A
Input 0 to 30 A Frequency from DC – 30 Hz to 60 Hz Effective output 0 to 1500A	0.24% + 0.04 A

Reference standard resistance decade from 1 mΩ to 1 Ω with resolution of 1 mΩ IET Labs 1433-01			
Technical specifications			
Resolution of change	Total resistance	Best stability (±ppm/year)	Accu-racy
1 mΩ	10 mΩ	50	±0.01%
10 mΩ	100 mΩ	50	±0.01%
100 mΩ	1 Ω	50	±0.01%

Reference standard resistance decade from 10 Ω to 1 TΩ for voltage of 5 kV IET Labs HRRSQ	
Technical specifications	
Characteristics	Value
Electrical resistance	from 10 Ω до 1 TΩ
Accuracy class	0.01%
Voltage level	5 kV
Temperature coefficient	5 ppm/°C
Voltage coefficient	0.2 ppm/V

All the acquired equipment is with calibration certificates insuring measurement traceability to SI units, from qualified and competent calibration laboratories (accredited by an accreditation body that is on the list of signatories of the MLA for the area of calibration EA-Mutual Recognition Agreement, or the Agreement on mutual recognition within the framework of ILAC-International Laboratory Accreditation Cooperation, or a national metrology institute signatory to the CIPM MRA- Agreement on mutual recognition of national standards and calibration and measurement certificates issued by national metrology institutes), which is in accordance with the Regulations for ensuring measurement traceability of RNM, published by IARNM.

4. DEVELOPMENT OF NEW CALIBRATION PROCEDURES AND MODIFICATION OF EXISTING PROCEDURES IN LEM FOR CALIBRATION OF INSTRUMENTS FOR EXTREME ELECTRICAL QUANTITIES WITH EXTENDED CMC

After the acquisition of the reference standards, a scientific approach will be taken to put the acquired equipment into research function, through the development of completely new laboratory procedures (calibration of inductance meters, calibration of high-frequency meters-oscilloscopes and function generators), as well as modification of the existing laboratory procedures for extreme values of electrical quantities and/or calibration of new types of meters (calibration of meters for high direct and alternating currents, calibration of meters for very small resistances-microohmmeters, calibration of meters for very high resistances – giga and teraohmeters).

The principles of best laboratory practice will be deployed in accordance with internationally standardized guidelines (BIPM, Euramet, ILAC, NIST, IEEE, IEC and EN guidelines/standards). In each of the measurement procedures, the measurement traceability chain continuity to national or internationally recognized primary standards will be ensured and scientific analysis of the influencing factors in the budget of measurement uncertainty will be conducted by applying advanced mathematical and statistical metrological methods, including non-conventional techniques from probability and statistics (Monte Carlo or Bayesian statistics), but also some numerical (method of least squares, finite element method) and stochastic methods.

Quality assurance and confidence in the results of newly introduced or modified calibration procedures will be achieved through internal and external quality measures (determining the degree of repeatability and reproducibility of the method, inter-laboratory comparisons and participation in proficiency testing schemes).

CONCLUSIONS

To achieve long-term sustainability of the laboratory facilities, after the full introduction of the new and modified laboratory procedures, their accreditation is planned, with the objective of expanding the measurement and calibration capabilities of LEM. The granting of an expanded scope of accreditation to LEM and its official publication on the IARNM website will enable further wider promotion and exploitation of the project results, i.e. provision of new calibration services for the research infrastructure and the industry in the country, but also widely in the region.

During the implementation of the project, young scientific personnel are directly trained and introduced to the new laboratory procedures, and the entire acquired equipment will be made available free of charge for research and education purposes.

REFERENCES

[1] Čundeva-Blajer, M., Dimčev, V,, Demerdžiev, K. et. al., *Development and Upgrade of Laboratory Resources for Research and Introduction of Novel Analitical Methods in Electrical Metrology*, Scientific project financed by the Ministry of Education and Science of RN Macedonia, Skopje, 2021–2023 (on-going).

[2] Arsov, L., Čundeva-Blajer, M. (2013): Establishing a metrological infrastructure and traceability of electrical power and energy in the R. Macedonia, *ACTA IMEKO*, December 2013, Vol. **2,** No. 2, pp. 86–90, www.imeko.org

[3] Demerdžiev, K., Čundeva-Blajer, M., Dimčev, V., Srbinovska, M., Kokolanski, Z. (2018): Improvement of the FEIT laboratory of electrical measurements best CMC through internationally traceable calibrations and inter-laboratory comparisons, *Conf. Proc. of Int. Conf. ETAI 2018, Struga, R. Macedonia, 20–22 September 2018* (ETAI 6-4).

[4] Velychko, O., Karpenko, S., Kazakova, E., Gubler, G., Gelovani, M., Abasbekova, E., Cayci, H., Sluciak, J., Čundeva-Blajer, M., Lei, W., Ariuntungalag, J., Bartolomew, J., Alorobaish, A. M., Halawa, M. (2019): Final Report on COOMET key comparison of power (COOMET.EM-K5), *Metrologia*, Vol. 56, No. 1A, 2019, pp. 01010, (https://iopscience.iop.org/article/10.1088/0026-1394/56/1A/01010)

[5] МКС EN ISO/IEC 17025 "General requirements for the competence of testing and calibration laboratories", *Cenelec*, Brussels, 2018.

[6] www.bipm.org (retrieved on: 03.06.2022).

[7] RU 7.2.01 *Working Instruction on Calibration of Multimeters*, LEM-FEIT, 2019.

[8] RU 7.2.02 *Working Instruction on Calibration of Electricity Reference Standards and Meters*, LEM-FEIT, 2019.

[9] RU 7.2.03 *Working Instruction on Calibration of Multifunctional Calibrators*, LEM-FEIT, 2019.

[10] RU 7.6.01 *Working Instruction on Expression of Measurement Uncertainty – General Procedure*, LEM-FEIT, 2019.

[11] EURAMET cg-15, *Guidelines on the Calibration of Digital Multimeters*, Ver. 3 02/2015.

[12] EURAMET cg-7, *Guidelines of Measuring Devices for Electrical Quantities, Calibration of Oscilloscopes*, Ver. 1.0, 06/2011.

[13] Čundeva-Blajer, M., Dimčev, V., Srbinovska, M., Kokolanski, Ž. (2016): A Contribution to the metrology infrastructure through accredited and traceable electrical measurements and calibrations, *Conf. Proc. of Int. Conf. ETAI, Skopje, R. Macedonia.*

[14] *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement* (GUM), JCGM 100 with member organizations (BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP and OIML), 2008.

[15] ISO/IEC 17043:2010 *Conformity Assessment – General Requirements for Poficiency Testing*, Geneve 2010

[16] www.iarm.gov.mk (retrieved on: 4.12.2022).