Review and Contribution to the Best Measurement and Calibration Capabilities in the Field of Electrical Energy and Power

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Abstract – **In this paper a review of the best measurement and calibration capabilities at international, regional and national level in the field of electrical energy and power will be made. The contribution of the Laboratory for Electrical Measurements at the Faculty of Electrical Engineering-Skopje to the enhancement of the national and regional electrical energy and power metrology infrastructure will be presented.**

Keywords – **electrical energy measurement, power measurement, metrology infrastructure, best measurement and calibration capability, measurement uncertainty.**

I. INTRODUCTION

The electrical energy and power measurements represent a very important segment in the trade of electrical energy, and they are in the scope of the legal metrology, [1, 2]. The insurance of measurement's accuracy is essential for safe and fair electrical energy delivery and trade. In R. Macedonia the coverage of this significant metrology segment is on a relatively basic level in comparison to the international state of the art, [2]. For the purpose of compliance to the international standards in this area, currently a procedure for establishment of national standard for electrical energy and power is in phase of implementation, [3, 4]. The national standard will enable calibration of secondary power and energy standards with accuracy up to class 0,01.

In this paper a comparison and review of the current state of the art at three levels, international, regional and national, of the best measurement and calibration capabilities will be conducted. This survey is necessary for further planning and development of the metrology infrastructure, especially at national and regional level, in the field of electrical energy and power as well as for an official proclamation of national standard for electrical energy and power, [4, 5]. The analysis can be conducted for different physical quantity ranges, but the main accent in this contribution will be on the best measurement and calibration capabilities of single phase active, reactive and apparent electrical power up to 400 Hz frequency range, [5]. The Laboratory of Electrical Measurements (LEM) at the Faculty of Electrical Engineering and Information Technologies (FEIT) at the Ss. Cyril and Methodius University in Skopje comprises the laboratory for calibration of electromagnetic quantities and owns a reference standard for electrical energy and power ZERA COM3003 with accuracy class 0,01. The LEM is an already accredited calibration laboratory for electromagnetic quantities, including a certain scope of electrical energy and power, according to the international standard ISO 17205:2005, [6], by the Institute of Accreditation of R. Macedonia (IARM).

In this paper the methodology for introduction of the ZERA COM3003 standard, [7], as potential national standard in R. Macedonia (the top of the metrology pyramid in the field of electrical energy and power), through the chain of hierarchy calibrations of secondary standards of energy and power will be elaborated. This will contribute to the development of the metrology infrastructure in the field of electrical energy and power at national as well as at regional level.

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II. SURVEY OF THE CURRENT STATE OF THE ART

The survey of the current state of the art in the field of metrology of electrical energy and power is conducted at three levels: national, regional (South-East Europe) and international. The main source is the official database of the International Bureau of Weights and Measures (BIPM) of the calibration and measurement capabilities (CMC) [5]. The coverage factor of the expanded measurement uncertainty is k=2 for level of confidence 95%.

A. Best Measurement and Calibration Capabilities-International Level

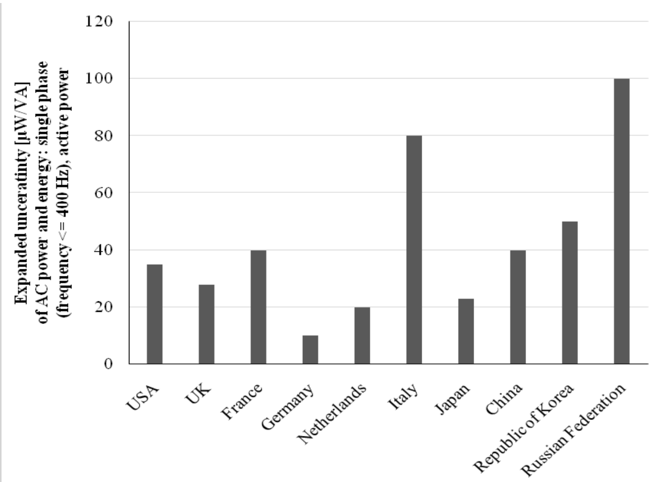

Fig. 1. Comparison of the best CMCs of the largest NMIs of active electrical power for frequencies up to 400 Hz.

TABLE I
COMPARISON OF THE BEST MEASUREMENT AND CALIBRATION CAPABILITIES FOR AC POWER AND ENERGY: SINGLE PHASE (FREQUENCY <= 400 HZ), ACTIVE POWER OF THE NATIONAL METROLOGY INSTITUTES AT INTERNATIONAL LEVEL

	Measurand Level or Range				Measurement Conditions/Independent Variable		Expanded Uncertainty			
	Method of Measurement	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence
USA NIST (National Institute of Standards and Technology	Comparison	0	60	kW	Voltage	60 V to 600 V	35	µW/VA	2	95%
					Current	0.1 A to 100				
					Phase shift	all				
					Frequency	50 Hz to 400				
UK NPL (National Physical Laboratory)	Digital sampling	0	130	kW	Voltage	1 V to 1000 V	28-40	µW/VA	2	95%
					Current	2 mA to 100				
					Phase shift	1 to 0, inductive or capacitive				
					Frequency	50 Hz to 400				
France LNE (Laboratoire national de métrologie et d'essais)	Direct comparison	0	60	kW	Voltage	60 V to 600 V	40 to 70	µW/VA	2	95%
					Current	0.05 A to 100				
					Phase shift	1 to 0, inductive or capacitive				
					Frequency	45 Hz to 65				
Germany PTB (Physikalisch-Technische Bundesanstalt)	Direct comparison	0	76,8	kW	Voltage	30 V to 480 V	10 to 140	µW/VA	2	95%
					Current	0.005 A to 160				
					Phase shift	-180 to 180				
					Frequency	16.7 Hz to 400				
Netherlands VSL	Direct comparison	0	1,2	kW	Voltage	120 V and 240 V	20	µW/VA	2	95%
					Current	1 A and 5 A				
					Phase shift	1 to 0, inductive or capacitive				
					Frequency	45 Hz to 65 Hz				
Italy INRIM (Istituto Nazionale di Ricerca Metrologica)	Comparison with reference standard	0	30	kW	Voltage	1 V to 600 V	80	µW/VA	2	95%
					Current	0.05 A to 50 A				
					Phase shift	1 to 0, inductive or capacitive				
					Frequency	50 Hz, 60 Hz				
Japan NMIJ (National Metrology Institute of Japan) and JEMIC	Direct comparison	0	0,6	kW	Voltage	100 V, 110 V, 120 V	23 to 28	µW/VA	2	95%
					Current	5 A				
					Phase shift	1 to 0 L/C				
					Frequency	50 Hz, 60 Hz				
China NIM (National Institute of metrology)	Direct comparison	0	40	kW	Voltage	50 V to 400 V	40	µW/VA	2	95%
					Current	0.5 A to 100 A				
					Phase shift	0.0 lead and lag, 0.5 lead and lag, 0.866 lead and lag, 1.0				
					Frequency	45 Hz to 65 Hz				
South Korea KRISS (Korea Research Institute of Standards and Science	Direct comparison	1,5	12	kW	Voltage	60 V to 240 V	50 to 100	µW/VA	2	95%
					Current	/				
					Phase shift	0.25 to 1				
					Frequency	45 Hz to 65				
Russian Federation VNIIM (D.I. Mendeleyev Institute for Metrology, Rosstandard)	Direct comparison	0,25	20	kW	Voltage	50 V to 400 V	100	µW/VA	2	95%
					Current	0.01 A to 50				
					Phase shift	1.0 i/c to 0.5 i/c				
					Frequency	45 Hz to 55 Hz				

A comparison of the best measurement and calibration capabilities of the largest national metrology institutes (NMIs) in the field of single phase electrical power up to 400 Hz frequency is made, [5]. The voltage ranges are from 0 to 200 kV, electrical current from 0 to 2000 A, the power factor cosφ is from 0 to 1 capacitive and inductive load. The comparison is displayed in Table 1.

The lowest measurement uncertainty of ±10 μW/VA of active electrical power at cosφ=1 is declared by PTB-Germany. However, the highest uncertainty among the largest NMIs is of ±100 μW/VA, as displayed in Figure 1.

Additionally, the lowest measurement uncertainty of ±20 μW/VA of electrical power at cosφ=0 (reactive power) is declared by VSL-Netherlands.

B. Best Measurement and Calibration Capabilities-Regional Level in South-East Europe

In some of the countries in South-East Europe (SEE) the measurements and calibrations in the field of electrical energy and power are present, [5], because they a significant pillar in the legal metrology system.

The metrology infrastructure, in the field of energy and power, demands allocation of high and expensive resources (facilities, equipment, development of measurement methods and personnel training), [2, 4, 6]. Therefore, the investments and the development plans in this field must be optimized according to the national as well as regional needs of the economy.

TABLE II

COMPARISON OF THE BEST MEASUREMENT AND CALIBRATION CAPABILITIES FOR AC POWER AND ENERGY: SINGLE PHASE (FREQUENCY <= 400 HZ), ACTIVE POWER OF THE NATIONAL METROLOGY INSTITUTES IN SOUTH-EAST EUROPE

	Measurand Level or Range				Measurement Conditions/Independent Variable		Expanded Uncertainty			
	Method of Measurement	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence
Slovenia MIRS/SIQ/ Metrology (MIRS/Slovenian Institute of Quality and Metrology)	Direct voltage sampling	0	35	kW	Voltage	0.1 V to 700 V	25 to 800	μW/VA	2	95%
					Current	1 mA to 50 A				
					Phase shift	1 to 0, inductive or capacitive				
					Frequency	45 Hz to 65 Hz				
Serbia DMDM (Directorate of Measures and Precious Metals)	Direct comparison or sampling method	0	48	kW	Voltage	4 V to 700 V	30 to 129	μW/VA	2	95%
					Current	0.05 A to 100 A				
					Phase shift	1 to 0, inductive or capacitive				
					Frequency	16 Hz to 400 Hz				
Turkey UME (TÜBİTAK Ulusal Metroloji Enstitüsü)	Direct comparison	0	60	kW	Voltage	30 V to 500 V	100	μW/VA	2	95%
					Current	0.01 A to 120				
					Phase shift	1 to 0, inductive or capacitive				
					Frequency	45 Hz to 65				
Bulgaria BIM (Bulgarian Institute of Metrology)	Direct comparison	0	48	kW	Voltage	10 V to 480 V	16 to 150	μW/VA	2	95%
					Current	0.002 A to 100 A				
					Phase shift	1 to 0, inductive or capacitive				
					Frequency	46 Hz to 65				
Greece EIM (Hellenic Institute of Metrology)	Direct comparison	0,075	1,2	kW	Voltage	60 V to 240 V	150	μW/VA	2	95%
					Current	5 mA to 5 A				
					Phase shift	1 to 0.25, inductive or capacitive				
					Frequency	53 Hz				
Romania INM (National Institute of Metrology)	Direct comparison	0,15	57,6	kW	Voltage	60 V to 480 V	100 to 380	μW/VA	2	95%
					Current	0.005 A to 120 A				
					Phase shift	0.5 i to 1 to 0.5 c				
					Frequency	50 Hz				

So, for the purposes of creation of proper and optimal development strategy, a survey of the current state of the art in the area of measurements and calibrations of electrical energy and power in most of the SEE countries, is conducted, [5]. A comparison of the best CMCs of the SEE national metrology institutes (NMIs) in the field of single phase electrical power up to 400 Hz frequency is made, [5]. The voltage ranges are from 0 to 700 V, electrical current from 0 to 120 A, the power factor cosφ is from 0 до 1 capacitive and inductive load. The comparison is shown in Table 2. The lowest measurement uncertainty of ±16 µW/VA of active electrical power at cosφ=1, is declared by BIM-Bulgaria. The highest uncertainty among the SEE NMIs is ±150 µW/VA, as shown in Figure 2.

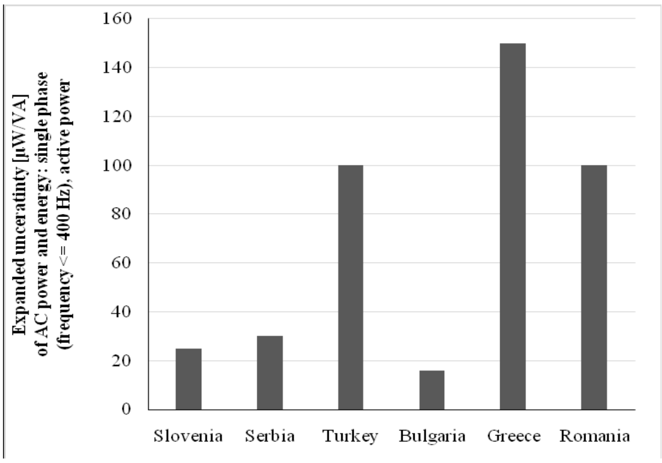

Fig. 2. Comparison of the best CMCs of the SEE NMIs of active electrical power for frequencies up to 400 Hz.

The other countries in the South-East Europe (Croatia, Bosnia and Herzegovina, Montenegro, Macedonia and Albania) have no CMC in the BIPM database in the field of AC electrical power and energy, [5]. It can be concluded that in the region of South-East Europe there are opportunities for further development of the metrology infrastructure in the field of electrical energy and power. However, this development must be planned and well adjusted to the regional and national measurement and calibration needs.

III. Contribution to the Development of National Metrology System for Electrical Energy and Power in R. Macedonia

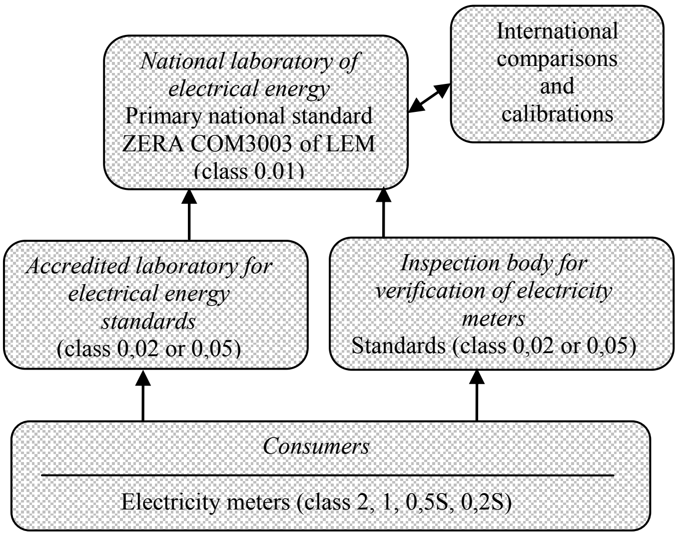

Fig. 3. Proposal-scheme of national metrology infrastructure in electrical energy and power in R. Macedonia.

The current state and the importance of the measurements of electrical energy for billing and other purposes requires measures for upgrading of the Macedonian system of legal and industrial metrology for electrical energy. The procedure for establishment of a national standard of electrical energy and national laboratory for electrical energy, as well as traceability of the electrical energy measurements has already started. Namely, the Laboratory for Electrical Measurements (LEM) at FEIT has accomplished the accreditation in compliance to the international standard ISO 17025, [6] according to the legal conditions, of [3, 4]. The proposed scheme for practicing the legal metrology and establishing of the traceability chain in the measurements of electrical energy in R. Macedonia is given in Figure 3. The LEM owns a reference standard for electrical energy and power ZERA COM3003 with accuracy class 0,01, [7]. LEM is accredited with a scope in electrical energy and power as in Table III.

Table III
Scope of Accreditation of LEM in Electrical Energy and Power

	Ranges	Rel. exp. uncertainty at k=2, P=95%
AC Power	Voltage: 70, 140, 280, 560 V	±0,2%
	Current: 0,5, 6, 20, 120 A	±0,2%
	Power	±0,4%
AC Energy	Voltage: 70, 140, 280, 560 V	±0,2%
	Current: 0,5, 6, 20, 120 A,	±0,2%
	Time	±0,05%
	Energy	±0,4%

IV. Conclusion

In this paper a survey of the current state of the art in the field of metrology of electrical energy and power at international, regional and national level is made as a basis for metrology infrastructure development planning. The proclamation of the LEM's ZERA COM3003 electrical energy comparator as a national standard will significantly fill the gap in the electrical energy/power legal metrology system and will upgrade the regional metrology landscape as well.

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