

# Investigation of Metrological Characteristics of National Standard of Electric Power and Power Factor Units

O. Velychko<sup>1</sup>, S. Karpenko<sup>2</sup>

<sup>1</sup>State Enterprise "All-ukrainian research and production center for standardization, metrology, certification and consumers rights protection" (SE"Ukrmetrteststandard"), Kyiv, Ukraine  
e-mail: [velychko@ukrcsm.kiev.ua](mailto:velychko@ukrcsm.kiev.ua)<sup>1</sup>, [s.r.karpenko86@gmail.com](mailto:s.r.karpenko86@gmail.com)<sup>2</sup>  
phone+38 044 526 55 68

**Abstract** – Results of the investigation of metrological characteristics of the National standard of electric power and power factor units are presented. The methods and principles of assessment of the metrological characteristics of the National standard of electric power and power factor units were described. The comparative analysis of the estimated metrological characteristics over time was done.

**Keywords** – electric power, standard, metrological characteristics, uncertainty.

## I. INTRODUCTION

National standard of electric power (EP) and power factor (PF) units is stored and operated since 2002 in State Enterprise "Ukrmetrteststandard" (Kyiv, Ukraine) for metrological assurance of high-precision measurements of EP and PF units [1-2]. It was modernized in 2016 [3]. Also, the special national standard DSTU 4116 was developed, which establishes the procedure for transferring the size of EP and PF units from the National standard of EP and PF units using Secondary standard of EP and PF units working standards.

National standard of EP and PF units was designed for reproduction and storage of EP unit from 0.01 to 72000 W (in single-phase mode) in the frequency range from 40 to 70 Hz. It was developed on the basis of highly stable multichannel current and voltage generators, a reference EP and PF comparator, apparatus for reproducing and storing EP and PF units, group of standard voltage-current-voltage converters, precision reference measures of EP and PF units and auxiliary equipment. National standard of EP and PF units is shown on Fig. 1 [3-4]. International comparisons of National standards of EP of National Metrological Institutes (NMIs) all over the world are held every 5-10 years.

In order to ensure traceability and unity of measurements of the EP and PF units in Ukraine is

always necessary continuous research of the metrological characteristics (MC) of the National standard of EP and PF units [4-5].



Fig. 1. National standard of electric power and power factor units of Ukraine

## II. GENERAL QUESTIONS OF EVALUATION METROLOGICAL CHARACTERISTICS OF STANDARDS

Taking into account the national standard of Ukraine DSTU GOST 8.381, it can be concluded that the main MC, which will characterize the National standard of EP and PF units, is the non-excluded systematic error (NESE), standard deviation (SD) of the results of reproduction of EP and PF units, instability, and measurement uncertainty [3].

The method of reproduction of EP unit is based on the method of simultaneous comparison of the voltage formed at the output of thermoelectric converters, alternately connected to a circuit of constant and alternating sinusoidal currents [6].

The reproducible size of EP unit can be described as follows:

$$P_{V_{\infty}} = \frac{U_{=TC+} + U_{=TC-}}{2} \cdot \frac{U_{=PR+}/R_n + U_{=PR-}/R_n}{2} \cdot \cos\varphi \quad (1)$$

where:  $P_{V\approx}$  –reproducible value of EP unit in circuits of alternating sinusoidal current;  $U_{=TC+}$  –measured value of DC voltage at the input of the thermo-electrical converter by means of a precision voltmeter;  $U_{=TC-}$  – measured value of DC voltage at the input of the thermo-electrical converter by means of a precision voltmeter, with a change in polarity;  $U_{=PR+}$  –measured value of DC voltage at the input of a thermo-electric with the precision resistor and precision voltmeter;  $U_{=PR-}$  –measured value of DC voltage at the input of thermo-electric with the precision resistor and precision voltmeter, with a change in polarity;  $\varphi$  –phase shift angle (PSA) between voltage and current;  $R_n$  –resistance nominal value of the precision resistor.

### III. EVALUATION OF THE METROLOGICAL CHARACTERISTICS OF THE NATIONAL STANDARD OF ELECTRIC POWER AND POWER FACTOR UNITS

#### A. Non-excluded systematic error

Table 1. Investigation of components of non-excluded systematic error.

Year	The value of the investigated component					
	$\delta_{TC}$	$\delta_U$	$\delta_R$	$\delta_\varphi$	$\delta_t$	$\delta_{NESE}$
2010	0.000025	0.000005	0.000005	0.000005	0.000003	0.000053
2011	0.000029	0.000006	0.000005	0.000005	0.000004	0.000061
2012	0.000021	0.000003	0.000002	0.000006	0.000001	0.000044
2013	0.000022	0.000002	0.000001	0.000003	0.000003	0.000045
2014	0.000020	0.000002	0.000001	0.000002	0.000004	0.000041
2015	0.000021	0.000002	0.000002	0.000002	0.000003	0.000043
2016	0.000017	0.000002	0.000001	0.000002	0.000001	0.000034
2017	0.000016	0.000002	0.000001	0.000001	0.000001	0.000032

According to the passport data the value of NESE must be in the range from 0.00004 W to 0.00007 W. Hence it can be concluded that the investigated values of NESE do not go beyond the prescribed passport limits in 2010-2015. However, during the modernization period 2016-2017 of the National standard of EP and PF units, the values of NESE were improved (Fig. 2).

Due to illustration it is possible to make general

An expression for evaluation NESE of reproduction of EP unit, taking into account that there is no correlation between the components, has the next form:

$$\delta_{NESE} = k \cdot \sqrt{2(\delta_{TC}^2 + \delta_U^2 + \delta_R^2 + \delta_\varphi^2 + \delta_t^2)}, \quad (2)$$

where:  $\delta_{NESE}$  –NESE of reproduction EP unit in the circuits of an alternating sinusoidal current;  $k$  –coefficient equal to 1.4 with confidence probability  $p = 0.99$ ;  $\delta_{TC}$  – error of the thermo-electrical converter in the transition from an AC voltage to DC voltage;  $\delta_U$  –measurement error of DC voltage;  $\delta_R$  –error caused by the deviation of the resistance of the precision resistor from the nominal value;  $\delta_\varphi$  –error caused by the deviation of the PSA between voltage and current from the value equal to  $0^\circ$ ;  $\delta_t$  –error caused by temperature instability during measurement.

The values of NESE during reproduction of EP unit in the circuits of an alternating sinusoidal current at the National standard of EP and PF units in 2010-2017 were analyzed. All values of NESE are reduced to a generalized Table 1.

conclusion that the values of has a linear dependence, which is due to: firstly, the high stability of the National standard of electric power EP and PF units, and secondly, the perfection of the reproduction method of the EP unit of the of the National standard of electric power EP and PF units.

B. Standard deviation of the results of reproduction of EP and PF units

The SD of the results of reproduction of EP and PF units is calculated according to the expression:

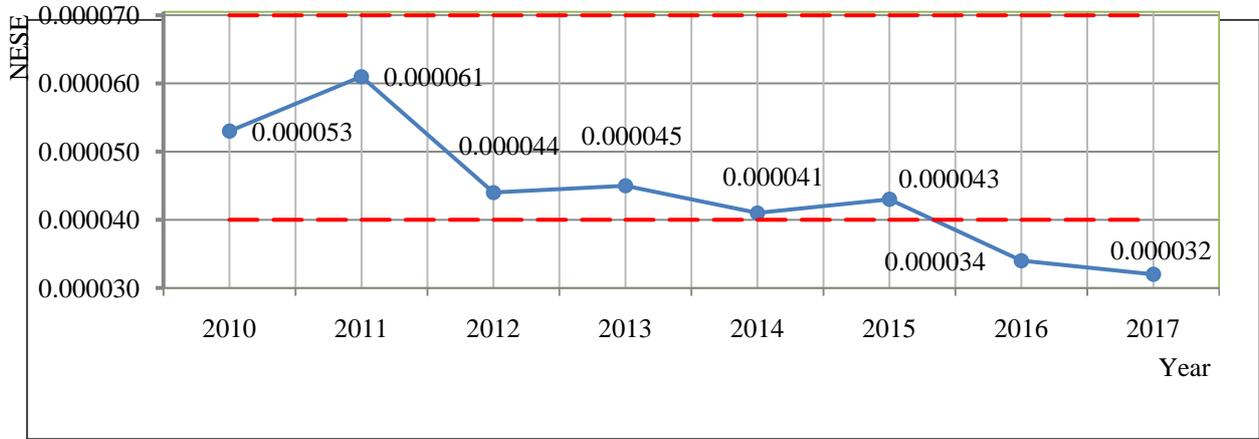


Fig. 2. Investigation of non-excluded systematic error of National standard of electric power and power factor units of Ukraine.

$$SD = \left( \sqrt{\left( I_{in} \cdot \cos\left(\frac{\varphi \cdot \pi}{180}\right) \right)^2 \cdot S^2(\bar{U}) + \left( U_{in} \cdot \cos\left(\frac{\varphi \cdot \pi}{180}\right) \right)^2 \cdot S^2(\bar{I})} \right) / \left( U_{in} \cdot I_{in} \cdot \cos\left(\frac{\varphi \cdot \pi}{180}\right) \right) \cdot 100\%, \quad (3)$$

where:  $I_{in} \cdot \cos\left(\frac{\varphi \cdot \pi}{180}\right)$  – coefficient of influence of alternating sinusoidal voltage;  $U_{in} \cdot \cos\left(\frac{\varphi \cdot \pi}{180}\right)$  – coefficient of influence of alternating sinusoidal current;  $U_{in} \cdot I_{in} \cdot \cos\left(\frac{\varphi \cdot \pi}{180}\right)$  – measured EP unit.

The generalized Table 2 is presented SD of the results of reproduction of EP and PF units as an example, only at points: voltage 120 V, current 5 A, KM 0.5 L, 1.0, 0.5 C. This array of points was chosen not by accident. At

such points, all international comparisons in which National standard of EP and PF units of Ukraine took place.

According to the passport data the value of SD of the results of reproduction of EP and PF units must be in the range from 0.00003 W to 0.00006 W. Hence it can be concluded that the investigated values of SD in 2010-2015 don't go beyond the prescribed passport limits. However, during the modernization period 2016-2017 of the National standard of EP and PF units, the values of SD were also improved (Fig. 3).

Table 2. Investigation of standard deviation of the results of reproduction of electric power and power factor units.

Year	The group of precision reference measures RM-15-04								
	№ 4418			№ 503536			№ 503537		
	PF (x10 <sup>-3</sup> )								
	0.5 L	1.0	0.5 C	0.5 L	1.0	0.5 C	0.5 L	1.0	0.5 C
2013	0.005	0.002	0.005	0.010	0.005	0.011	-0.008	-0.003	-0.009
2014	0.006	0.001	0.004	0.009	0.004	0.008	-0.009	-0.004	-0.009
2015	0.004	0.002	0.004	0.009	0.004	0.009	-0.006	-0.006	-0.007
2016	0.006	0.003	0.006	0.011	0.003	0.010	-0.007	-0.002	-0.007
2017	0.004	0.001	0.005	0.009	0.003	0.011	-0.006	-0.004	-0.009

C. Instability

According to the passport data the value of instability the National standard of EP and PF units must no bigger 0.00003 W per year (4 times). Hence it can be

concluded that the investigated values of instability do not go beyond the prescribed passport limits in 2010-2017 (Fig. 4).

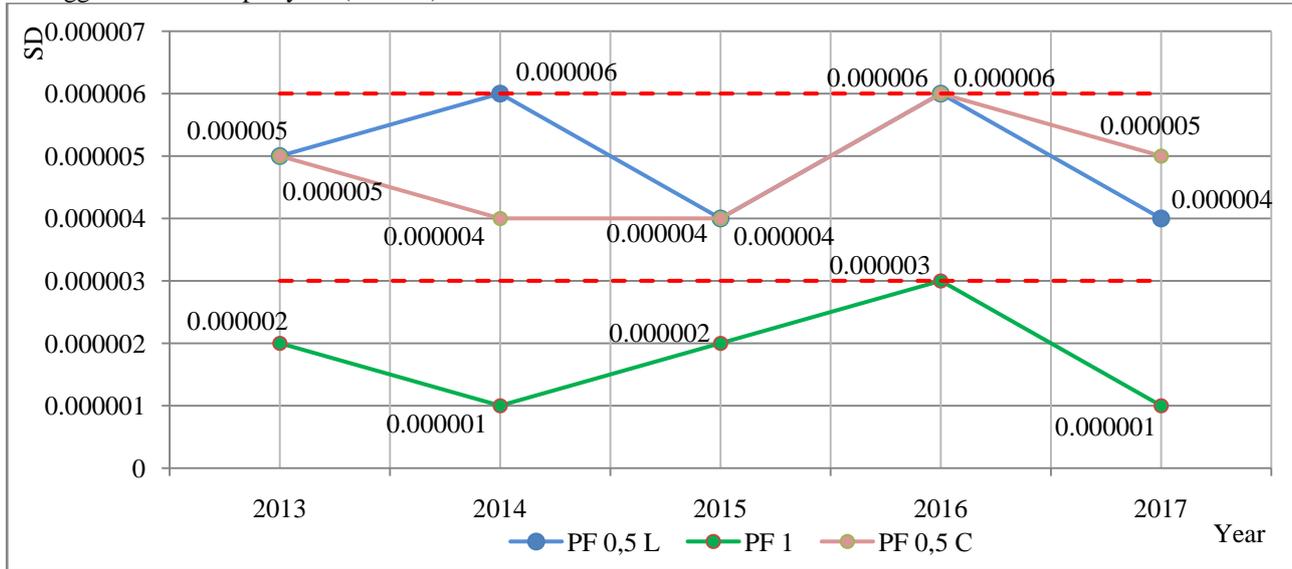


Fig. 3. Investigation of standard deviation of the results of reproduction of electric power and power factors units.

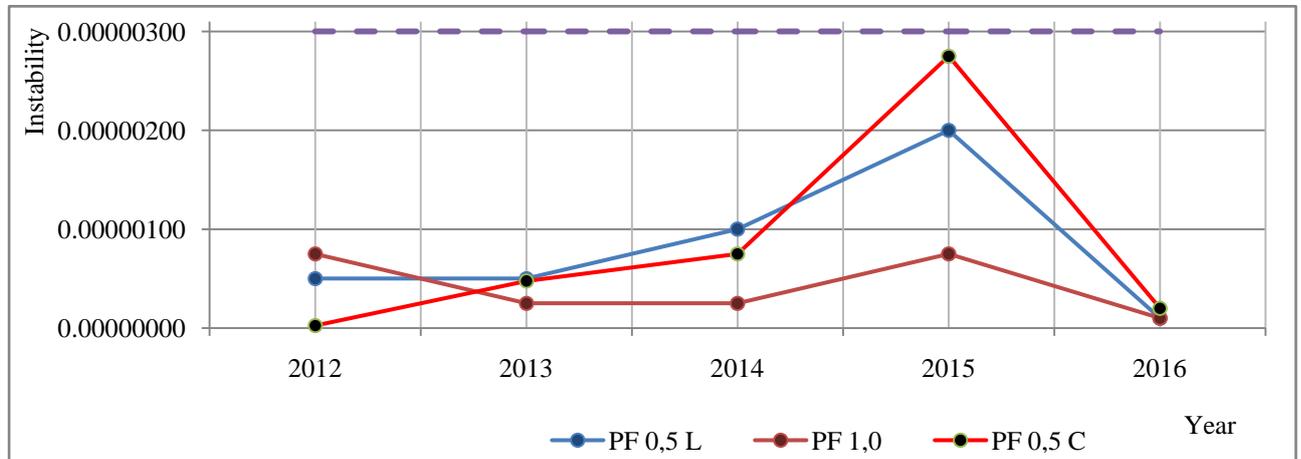


Fig. 4. Investigation of instability of National standard of electric power and power factor units of Ukraine.

D. Measurement traceability and uncertainty

To confirm the calibration and measurement capabilities (CMC), which are published on the website of the International Bureau of Weights and Measures in Key Comparisons Database, SE "Ukrmetrteststandard" as NMI of Ukraine and of determining the equivalence of national standards with national standards stored in other NMIs participated in two international comparison of power: key comparison EURAMET.EM-K5.1 in 2005-2008 as a participant and supplementary comparison

COOMET.EM-S2 in 2008-2013 as a pilot laboratory [7-8].

By the results of the evaluation of the combined standard uncertainty of the measurement result electric power is composed uncertainty budget, which is given in Table 3.

The uncertainty is from 0.000003 W to 0.000005 W [9].

To support the CMCs declared by members of COOMET in the framework of the CIPM-MRA, SE "Ukrmetrteststandard" (UMTS, Ukraine) organized in

2015 COOMET key comparison of EP unit for electrical standards of low-frequency 50/60 Hz power [10].

UMTS was proposed to be the pilot laboratory, which would be responsible for providing the travelling standard, coordinating the schedule, collecting and

analysing the comparison data, and preparing the draft report.

By the results of key comparison COOMET.EM-K5 SE "Ukrmetrteststandard" is going to improved CMC [10].

Table 3. The budget of components of standard uncertainty of measurements of electric power.

	The input value $x_i$	The evaluation of the input value	The total standard uncertainty, $u(x_i)$	The law of distribution	The sensitivity coefficient, $\frac{\partial \Delta}{\partial x_i}$	The contribution of the relative uncertainty
1	$\delta_{CKBr}$	$\delta_{CKBr}$	$u_A(P) = \delta_{CKBr} / \sqrt{n}$	uniform	1.0	$u_A(P)$
2	$\delta_{TC}$	0.000016	0.000009	uniform	1.0	0.000009
3	$\delta_U$	0.000002	0.000001	normal	1.0	0.000001
4	$\delta_R$	0.000001	0.000001	normal	1.3	0.000001
5	$\delta_\phi$	0.000001	0.000001	normal	1.0	0.000001
6	$\delta_t$	0.000001	0.000001	normal	1.0	0.000001
7	$u_c(P)$					$u_c(P)$

#### IV. CONCLUSIONS

In order to ensure traceability and unity of measurements of the EP and PF units in Ukraine were continuous researched the MC of the National standard of EP and PF units. The comparative analysis of the estimated metrological characteristics over time was done. We can make the general conclusion about the investigated MC. In the period of 2016-2017 all the MC were improved.

SE "Ukrmetrteststandard" can ensure traceability of measurements of electrical power and energy and also calibrates the working standards of active electric power except for the working standards of the bases have to Ukraine and the other countries all over the world.

Also SE "Ukrmetrteststandard" is going to improved CMC by the results of key comparison COOMET.EM-K5.

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