

Evaluation of the uncertainty of calibration of the three phase high precision comparator of the electrical power

O. Velychko, S. Karpenko, V. Gachok

State Enterprise "Ukrmetrteststandard"

4, Metrologichna Str., 03680, Kyiv, Ukraine, Tel./Fax: +38 044 526 0335, e-mail: velychko@ukrcsm.kiev.ua

Abstract – The paper describes the evaluation of the uncertainty and calibration results three phase high precision comparator of the electrical power which is one of the main parts of the Secondary Standard of Ukraine of the unit of the electrical power with using of the State Standard of Ukraine of the unit of the electrical power.

I. Power measurements and traceability

The Ukraine is a manufactured and powerful exporter of electrical energy. The calibration of working standards of electrical power is very relevant and appropriate for national economic.

Such kind of three phase high precision comparator is common used in national metrological institutes (NMIs) but also official test laboratories as primary standard. Power utilities and meters manufactures use this kind of high accurate instruments to perform their traceability to national standards. It acts as a reference instrument for testing ammeter and voltmeter as well as single and multiphase power and energy meters.

In Ukrainian NMI – SE "Ukrmetrteststandard" (UMTS) three phase high precision comparator is one of the main parts of the Secondary Standard of Ukraine of the unit of the electrical power (VETU 08-08-01-08). To ensure that VETU 08-08-01-08 need traceability to State Standard of Ukraine of the unit of the electrical power (DETU 08-08-02) it must be calibrated with using of the DETU 08-08-02 (Figure 1).



Figure 1. Calibration of the three phase high precision comparator

The metrological characteristics of DETU 08-08-02 (keeping in UMTS) are confirmed by the results of international comparison of national standards of the unit of the electrical power of according to the project EURAMET.EM-K5.1 [1, 2]. The results of EURAMET.EM-K5.1 comparison was linked to international comparison CCEM-K5 (Figure 2 for 120 V, 5A, power factor – PF = 1.0) [3]. Appropriate UMTS calibration and measurement capabilities (CMC) were published in BIPM Key Comparison Database (KCDB) [4] (Table 1).

UMTS CMC's of the active electrical power for voltage values in range from 10 to 600 V, current values in range from 0.1 to 10 A, power factors (PF = 1.0; 0.5 Lead; 0.5 Lag) and frequencies from 40 to 70 Hz (single and three phases) are shown in Table 1.

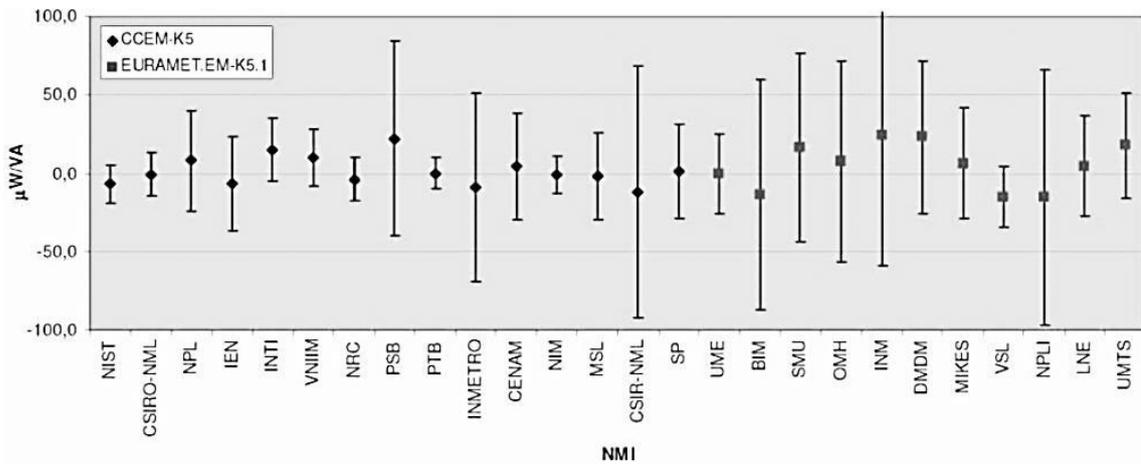


Figure 2. Linked results of EURAMET.EM-K5.1 comparison to CCEM-K5 comparison (PF = 1.0)

Table 1 – UMTS CMC's for active electrical power

Calibration and measurement services	Measurand level or range, W	Measurement conditions	Relative expanded uncertainty*
AC active power (single phase)	1...600	Voltage: 10... 600 V Current: 0.1... 10 A	PF = 1.0: 30 μW/W PF = 0.5: 50 μW/W
AC active power (three phase)	1...10392	Frequency: 40... 70 Hz Power factor: 1.0, 0.5 Lag, 0.5 Lead	PF = 1.0: 30 μW/W PF = 0.5: 50 μW/W
* Level of confidence: 95 %, coverage factor: $k = 2$.			

II. Evaluation of the calibration uncertainty

The calibration of three phase high precision comparator is performed in accordance with the scheme of measurements shown in Figure 3.

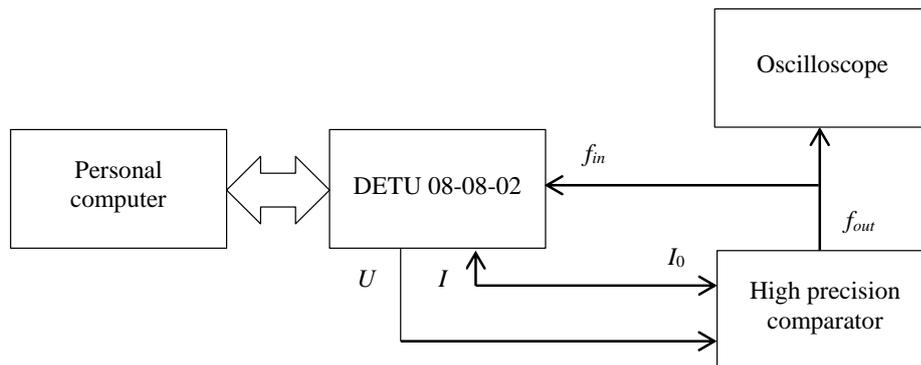


Figure 3. Calibration scheme of high precision comparator with using of the DETU 08-08-02

The measurement model in accordance with the calibration scheme written in absolute form [5]:

$$P_x = \frac{1}{T} \int_0^T p(t) dt = f(U, I, \varphi) = P_0 + \Delta_{HPC} + \Delta_{DETU} = P_0 + \Delta_{HPC} + \Delta_{NSE} + \Delta_S, \quad (1)$$

where:

P_0 – real value of power;

Δ_{HPC} – standard deviation value of the calibration means;

Δ_{NSE} – non-exclusion of systematic error of the DETU 08-08-02;

Δ_S – standard deviation of the DETU 08-08-02.

The measurement model in accordance with the calibration scheme written in relative form [5]:

$$\hat{P}_x = P_{0r} + \delta_{HPC} + \theta_{DETU} = P_{0r} + \delta_{HPC} + \theta_{TT} + \theta_{DC} + \theta_{\varphi} + \theta_t + \theta_{S_D}, \quad (2)$$

where:

P_{0r} – real value of power (in relative form);

δ_{HPC} – standard deviation value of the calibration means (in relative form);

θ_{TT} – error of thermoelectric transducer;

θ_{DC} – measurement error of the DC voltage;

θ_{φ} – error caused by deviation of phase angle between current and voltage;

θ_t – error caused by instability of the temperature during calibration;

θ_S – standard deviation of the DETU 08-08-02(in relative form).

Calibration of three phase high precision comparator was made in thermo stated and screened laboratory. That's why the influence of external factors on the calibration is eliminated [6]. In processing the measurement results is used the method of reduction to the direct measurements. It allows to ignore correlation arising from the use of a common measure in the calculations. The calibration process is fully automatic mode with the operator's work area on DETU 08-08-02. Specialized software allows to make the series of measurements at different voltages, currents, phase shift angles and frequencies. Software window of the DETU 08-08-02 for this regime is presented on Figure 4 (for PF = 1.0). The calibration results for $U = 240$ V, $I = 2$ A, PF = 0.5 Lag is shown on Figure 5a, and its statistical representation is shown on Figure 5b.

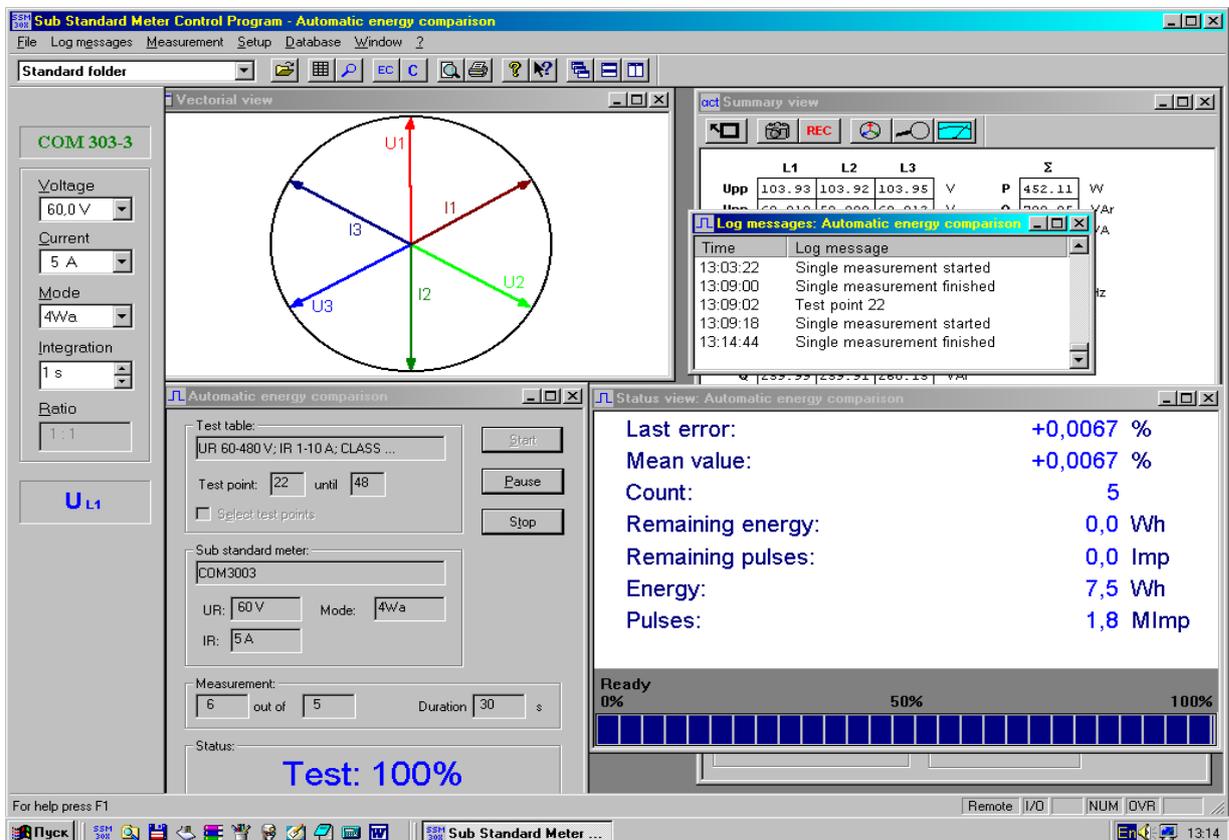


Figure 4. Software window of the DETU 08-08-02

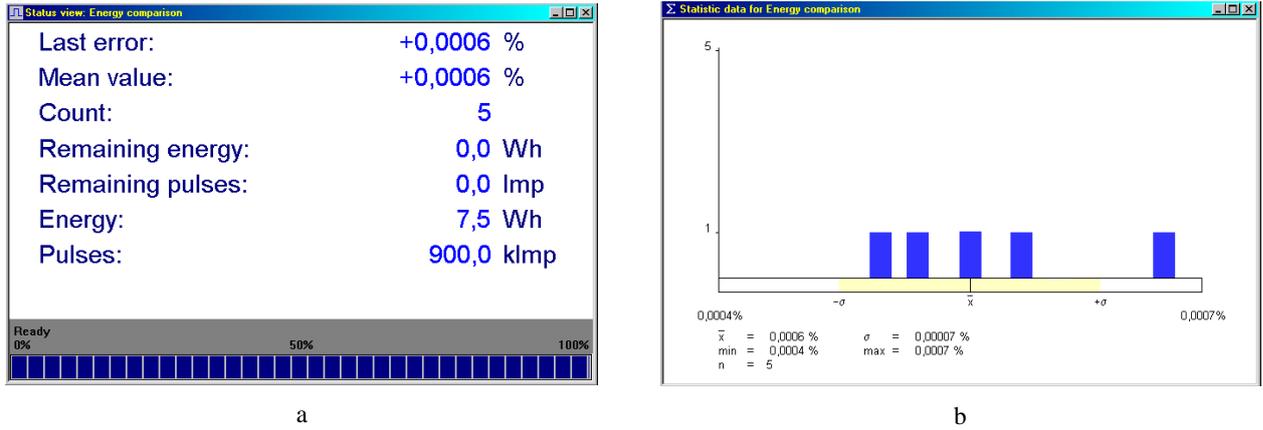


Figure 5. Calibration results and its statistical representation

During the calculation of the total standard uncertainty are taken into account components of type A and B as relative standard uncertainties. The uncertainty which is associated with the scattering of the relative difference between readings of calibrated three phase high precision comparator and DETU 08-08-02 (component of type A) is calculated automatically with the help of software of the DETU 08-08-02.

$$u_A(\hat{P}_x) = S_{cal}, \quad (3)$$

where: S_{cal} – automatically calculated standard deviation.

Evaluated standard uncertainty for non-exclusion of systematic error is presented in relative form: $\theta_{DETU} = \theta_{IT} + \theta_{DC} + \theta_{\phi} + \theta_t$.

We have a uniform distribution within the boundaries of non-exclusion of systematic error (coverage factor is $k = \sqrt{3}$) – component of type B, and is equal to $u_{B1}(\hat{P}_x) = \theta_s / k = 4,04 \cdot 10^{-5}$.

Uncertainty component of the DETU 08-08-02 derived from the value of its random component of the claimed error is equal to standard deviation (component of type B) is $u_{B2}(\hat{P}_x) = 6 \cdot 10^{-6}$.

The combine relative standard uncertainty of the outcome measurement of the electrical power is determined by the formula:

$$u_c(\hat{P}_x) = \sqrt{(u_A(\hat{P}_x))^2 + (u_{B1}(\hat{P}_x))^2 + (u_{B2}(\hat{P}_x))^2}. \quad (4)$$

The effective number of degrees of freedom ν_{eff} is calculated accordance to JCGM 100 [7] as:

$$\nu_{eff} = \nu_{effA} [u_c(\hat{P}_x) / u_A(\hat{P}_x)]^4. \quad (5)$$

The relative expanded uncertainty of the outcome measurement of the electrical power is determined by the formula:

$$U = t(P, \nu_{eff}) \cdot u_c(\hat{P}_x), \quad (6)$$

where: $t(P, \nu_{eff})$ – coverage probability of approximately 95 %.

Calibration uncertainty budget for PF = 1.0, 0.5 Lead; 0.5 Lag is shown in the Table 2 ($f = 50$ Hz).

Table 2 – Calibration uncertainty budget

i	Quantity	x_i	$u(x_i)$	Distribution	ν_i	c_i	$u_i(y)$
1	Error of the RM 15-04 ($\mu\text{W}/\text{VA}$)	$u_A(\hat{P}_x) = S_{cal}$	$u_A(\hat{P}_x)$	rectangular	n	1	$u_A(\hat{P}_x)$
2	Error of the DETU 08-08-02 – from converter, resistor and multimeter ($\mu\text{W}/\text{VA}$)	$u_{B1}(\hat{P}_x) + u_{B2}(\hat{P}_x)$	$u_B(\hat{P}_x)$	rectangular	∞	1	$u_B(\hat{P}_x)$
y	Combine relative standard uncertainty of measurements	$\sum x_i$	$u_c(\hat{P}_x)$	rectangular	∞		$u_c(\hat{P}_x)$
Expanded uncertainty: U ; confidence level: 95 %, coverage factor: $k = 2$							

III. Calibration results

Calibration results for three phase high precision comparator for voltage values in range from 60 to 240 V, current values in range from 0.01 to 10 A and power factors (PF = 0.5 Lead; 1.0; 0.5 Lag) are shown below in the Table 3 ($f = 50$ Hz).

Table 3 – Calibration results ($\mu\text{W}/\text{VA}$)

Current, A	Power factor	Voltage, V					
		240		120		60	
		Measurement result	Expanded uncertainty	Measurement result	Expanded uncertainty	Measurement result	Expanded uncertainty
10	0.5 Lead	-11.0	1.2	-18.0	1.0	-21.0	0.9
	1	4.0	2.5	-5.0	0.9	2.0	0.9
	0.5 Lag	21.0	6.2	8.0	0.9	12.0	9.5
5	0.5 Lead	-11.0	4.0	-44.0	0.9	-43.0	0.9
	1	-10.0	2.5	12.0	1.0	22.0	0.9
	0.5 Lag	11.0	1.7	-67.0	0.9	87.0	0.9
2	0.5 Lead	18.0	2.2	-11.0	1.0	-11.0	0.9
	1	-6.0	1.7	-1.0	0.9	5.0	1.2
	0.5 Lag	6.0	2.2	13.0	5.1	28.0	5.1
1	0.5 Lead	-22.0	1.7	-25.0	0.9	-27.0	0.9
	1	1.0	1.7	-3.0	0.9	6.0	0.9
	0.5 Lag	24.0	1.7	22.0	1.2	40.0	1.2
0.5	0.5 Lead	-29.0	1.2	-33.0	0.9	-34.0	1.2
	1	-15.0	1.0	-18.0	1.0	-0.9	0.9
	0.5 Lag	4.0	1.7	1.0	0.9	20.0	0.9
0.2	0.5 Lead	-3.0	1.0	-5.0	0.9	-6.0	1.0
	1	20.0	0.9	18.0	1.0	26.0	0.9
	0.5 Lag	45.0	4.9	45.0	5.7	61.0	5.9
0.1	0.5 Lead	4.0	0.9	1.0	0.9	59.0	1.0
	1	9.0	0.9	4.0	0.9	13.0	0.9
	0.5 Lag	14.0	1.2	10.0	1.2	27.0	1.0
0.05	0.5 Lead	9.0	0.9	5.0	0.9	5.0	0.9
	1	26.0	0.9	23.0	1.0	29.0	1.2
	0.5 Lag	44.0	1.0	40.0	0.9	54.0	1.0
0.02	0.5 Lead	-11.6	1.0	-19.0	0.9	-11.8	1.0
	1	22.0	1.0	20.0	0.9	26.0	0.9
	0.5 Lag	16.1	5.7	16.0	6.5	16.9	5.1
0.01	0.5 Lead	-40.5	1.0	-40.2	1.2	-40.9	0.9
	1	53.0	1.0	52.0	0.9	56.0	0.9
	0.5 Lag	56.0	1.2	50.3	1.2	51.5	1.4

The comparison usually are conducted at $U = 120$ V, $I = 5$ A, PF = 0.5 Lead; 1.0; 0.5 Lag (Figure 6). This figure is shown that those calibration results are linearly dependent. It's makes possible to predict the results of the calibration in general.

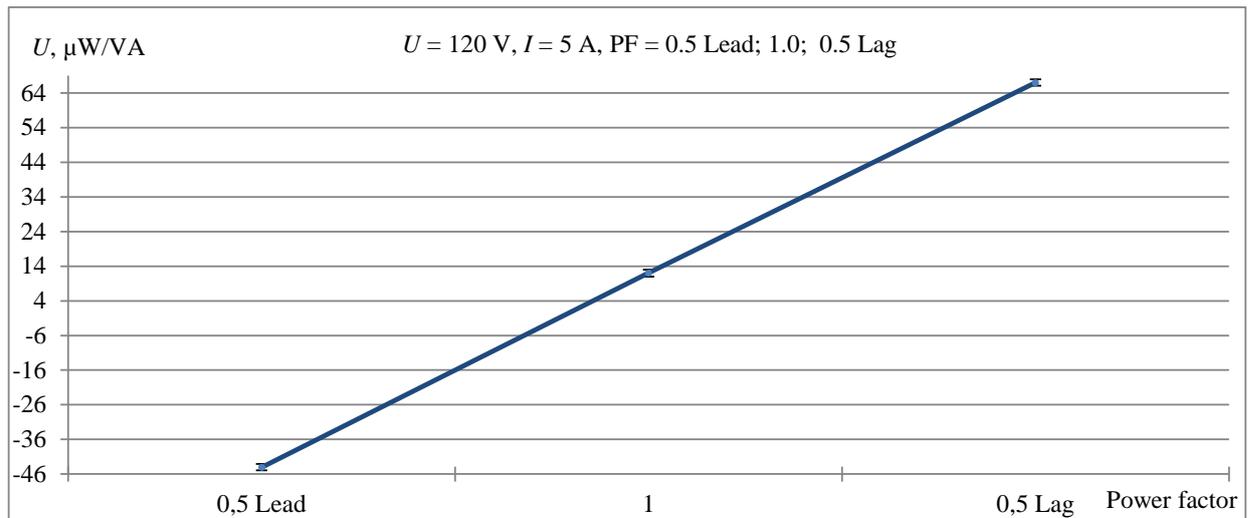


Figure 6. Graphic illustration of calibration results for $U = 120 \text{ V}$, $I = 5 \text{ A}$, $\text{PF} = 0.5 \text{ Lead}; 1.0; 0.5 \text{ Lag}$

IV. Conclusions

SE “Ukrmetrteststandard” (UMTS) were developed calibration procedures for working standards of active electric power. Those calibration procedures can ensure traceability of measurements of electrical power and using for calibration of working standards except for the working standards of the bases have to Ukraine and the Republic of Moldova, Republic of Georgia. The proposed method of the uncertainty estimating of the calibration results with using of the DETU 08-08-02.

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