Reactive Power Quality Assessmentthrough Interlaboratories Comparison

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Abstract – **An independent assessment of the technical performance of laboratories is necessary, in order to assure the validity of measurement results**[1]**. The article presents the assessment of laboratories which participated at an inter-laboratory comparison (ILC) within reactive power field.**
A number of 23 laboratories had participated at this interlaboratories comparison [2] **for a period of 10 months. Laboratories involved in this interlaboratories comparison perform verifications of reactive electrical energy meters. In order to make a correct assessment of these laboratories capabilitiesa travelling measurement standard was used.**

Keywords – **proficiency testing, interlaboratories comparison, reactive power meters**

I.   INTRODUCTION

The main goal of Legal metrology is to control measuring instruments used in commercial transactions, and to assure and to guarantee the correctness ofmeasuring results,

throughout the whole period of use under working conditions, within given permisssible errrors.[3]
The scope of PT was the determination of relative errors of current values (5%· I_b, 10%· I_b, 20%· I_b, 100%· I_b, 200%· I_b) at which the verification of reactive electrical energy meters is performed, the most common being I_b = 5 A.
The testing benchesused by the participating laboratories were self-standing or ad-hoc electricity meter checking systems by associating a three-phase static electricity reactive meter with the possibility of performing relative error calculations with a three-phase voltage source and current for phantom load.

II.   TRAVELING MEASURING STANDARD

Type of proficiency testing scheme was quantitative sequential participation scheme, which had involved the proficiency test item being circulated successivelyfrom the one participant, circulated back to the proficiency testing provider for rechecking, to the next.
Proficiency test item was a 3-phase (rotary) reactive electrical energy meter, A1800 type, Elster Rometrics manufacturer, having the following characteristics:
-    the specified reference voltage
U = 3 x (57.7 V / 100 V… 230 V/ 400 V) ;
-    the specified reference current: 5 A;
-    maximum current: 120 A;
-    specified reference frequency: 50 Hz;
-    accuracy class: 2;
-    constant value: 500 imp/kWARh;
-    4 wire energy meter connection.

Fig. 1. Route of traveling measurement standard

III.   RESULTS & DISCUSSION

The reference laboratory of provider performed the characterization of traveling measurement standard 2 times. The assigned values taken into account were the means of measurement values by the reference laboratory for each established point/value.
The relative measurement errors at each established point of reactive electrical energy, were calculated using the following formula:

$$e_x(\%) = \frac{E_x - E_e}{E_e} \cdot 100 = (\frac{N_x}{N_e} \cdot \frac{C_e}{C_x} - 1) \cdot 100 , \qquad (1)$$

where:
E_x =   reactive electrical energy registered by energy
N_x/C_x meter;
N_x -   the number of pulses counted by meter;

C_x - constant, for this case C_x = 5000 imp./kWARh;
$E_e = N_e/C_e$ - reactive electrical energy registered by standard energy meter of bench
N_e - the number of pulses, from standard energy meter of bench, counted by energy meter of travelling measurement standard;
C_e - constant of standard energy meter of bench.

Measurement results obtained by reference laboratory of provider is presented in Table 1.

Table 1. Measurement results obtained by reference laboratory

measurement point / value (phase values)			connection, loading	mean e_x, %
voltage, V	current, A	sinφ		
230	0.25	1	star, L1L2L3	0.03
	0.5	1	star, L1L2L3	0.03
		0.5i	star, L1L2L3	0.03
		1	star, L1	0.07
		1	star, L1	-0.01
		1	star, L3	0.02
	1	0.5i	star, L1L2L3	0.04
		0.25i	star, L1L2L3	0.04
		0.5i	star, L1	0.05
		0.5i	star, L2	0.00
		0.5i	star, L3	0.02
	5	1	star, L1L2L3	0.03
		0.5i	star, L1L2L3	0.04
		0.25i	star, L1L2L3	0.05
		1	star, L1	0.02
		0.5i	star, L1	0.01
		1	star, L2	0.01
		0.5i	star, L2	0.02
		1	star, L3	0.02
		0.5i	star, L3	0.03
	10	1	star, L1L2L3	0.03
		0.5i	star, L1L2L3	0.05
		1	star, L1	0.01
		0.5i	star, L1	0.01
		1	star, L2	0.01
		0.5i	star, L2	0.03
		1	star, L3	0.02
		0.5i	star, L3	0.03

The evaluation of acceptance criteria for each laboratory was made using the following formula

$$z_{score} = \frac{x_i - X_i}{\hat{\sigma}}, \qquad (2)$$

where

x_i - measurement result of i laboratory, for each measurement point;
X_i - assigned value of PT object;
$\hat{\sigma}$ - assigned PT standard deviation.

Z score [4] criteria:

- $|z| \leq 2$; the score indicates "satisfactory" performance
- $2 < |z| < 3$; the score indicates "questionable" performance
- $|z| \geq 3$; the score indicates" unsatisfactory" performance.

The assigned PT value [5] of PT object was the mean of the measurement results of reference laboratory, for each measurement point, taken in 1 stages, at the beginning and at the end of PT scheme. The participating laboratories had the accuracy request requirements.

For 230 V, the measurement results of each participating laboratory, are presented in Table 2 and score $|z|$ of each laboratory are presented in Table 3.

Figures from 2 to 4 show the errors for 3 x230/400 V, 0.25 A, sin φ =1; L3 230 V, 0.5 A, sin φ =1and L3 230 V, 10 A, sin φ =1. Figures from 5 to 7 show Z score for L1 230 V, 5A, cos φ=0.5i; L2 230 V, 5A, cos φ=0.5i and L3 230 V, 0.5A, cos φ=1.

IV. CONCLUSIONS

The measurement results of this inter-laboratory comparison proved that all participants meet the acceptance criteria of competence.

Moreover, $|z|$ scores were smaller than:

- 1.5 for all laboratories,
  from which, smaller than:
- 0.2 – for 56 % of laboratories
- 0.5 – for 75 % of laboratories
- 1.5 - for 2 laboratories

REFERENCES

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[3] Springer "*Handbook of Metrology and Testing*", Czichos & others, 2011
[4] *Eurachem Guide, The fitness for purpose of analytical methods, 2nd edition*, (2014)
[5] *ISO 13528:2005, Statistical Methods for Use in Proficiency Testing by Interlaboratory Comparisons*, (2005)

Table 2. Measurement results of each laboratory for 230 V

Measurement point (phase values)			Load connection	Error, % (of measurement results of reactive electrical energy for each laboratory)																					
Voltage, V	Current A	sinφ		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
230	0.25	1	star, L1L2L3	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.1	-	0.0	0.2	0.0	-0.1	0.0	-0.2	0.0	0.0	0.0	0.0	-0.2	0.0
	0.5	1	star, L1L2L3	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	-	0.0	0.1	0.0	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	-0.2	0.0
		0.5i	star, L1L2L3	-0.1	0.0	-0.1	0.0	0.0	0.0	-0.1	0.3	-0.1	0.1	-	-0.1	0.0	0.0	0.0	-0.1	-0.2	0.0	-0.1	0.0	0.0	-0.3	0.0
		1	star, L1	0.1	0.1	0.0	0.1	-0.1	0.1	0.0	0.1	-0.1	0.1	0.5	0.0	0.2	0.0	0.0	0.0	-0.1	0.1	0.0	0.0	0.0	-0.3	-0.8
		1	star, L2	-0.1	0.0	-0.1	0.0	0.1	-0.1	0.0	0.1	0.0	-0.1	-	-0.1	0.2	0.0	-0.1	-0.1	-0.2	0.1	-0.1	0.0	0.0	-0.3	0.4
		1	star, L3	0.0	0.0	-0.1	0.0	0.1	0.0	0.0	0.2	0.0	-0.2	-	0.2	0.2	0.0	-0.1	-0.1	-0.2	0.0	0.0	0.0	0.0	-0.2	0.3
	1	0.5i	star, L1L2L3	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	0.2	-0.1	0.1	-	-0.1	0.0	0.0	0.0	-0.1	-0.1	0.0	-0.1	0.0	-0.1	-0.3	0.0
		0.25i	star, L1L2L3	-0.2	0.0	-0.2	0.0	-0.1	0.0	-0.1	0.4	-0.1	0.0	-	-0.2	-0.1	-0.1	0.0	-0.1	-0.3	0.0	-0.2	0.0	-0.2	-0.4	0.0
		0.5i	star, L1	0.0	0.1	0.0	0.0	-1.4	0.1	0.0	0.1	-0.1	0.1	0.8	-0.2	0.1	0.0	0.0	-0.1	-0.2	0.1	0.0	0.0	-0.1	-0.4	-0.2
		0.5i	star, L2	-0.1	0.0	-0.1	0.0	0.2	0.0	0.0	0.2	0.0	0.0	-	0.2	0.0	-0.1	-0.1	-0.1	-0.2	0.0	-0.1	0.0	-0.1	-0.2	-0.8
		0.5i	star, L3	-0.1	0.0	-0.1	0.0	1.1	0.0	0.0	0.3	0.0	0.0	-	0.2	0.0	0.0	-0.1	-0.2	-0.2	-0.1	-0.1	0.0	0.1	-0.4	1.1
	5	1	star, L1L2L3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-	0.0	0.2	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	-0.2	0.0
		0.5i	star, L1L2L3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	-	-0.1	0.0	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0	-0.1	-0.3	0.1
		0.25i	star, L1L2L3	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	0.3	-0.1	0.0	-	-0.2	-0.2	-0.1	0.0	-0.1	0.0	0.0	-0.1	0.0	-0.1	-0.4	0.0
		1	star, L1	0.0	0.0	0.0	0.0	-0.2	0.1	0.0	0.0	0.0	0.0	0.4	-0.1	0.1	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	-0.1	-0.3	-0.5
		0.5i	star, L1	-0.1	0.0	0.0	0.0	-0.3	0.1	0.0	0.1	-0.1	0.0	0.9	-0.2	0.0	-0.1	0.0	-0.1	0.0	0.1	-0.1	0.0	-0.1	-0.4	-0.6
		1	star, L2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	-	-0.1	0.1	0.0	0.2	-0.1	0.0	0.0	0.0	0.0	0.0	-0.2	0.0
		0.5i	star, L2	0.0	0.0	0.0	0.0	0.1	-0.1	0.0	0.4	0.0	-0.1	-	0.2	0.0	0.0	-0.1	-0.1	0.0	0.0	-0.1	0.0	0.1	-0.3	-0.6
		1	star, L3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	-0.2	-	0.2	0.1	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	-0.2	0.6
		0.5i	star, L3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	-	0.2	0.1	0.0	0.0	-0.1	0.0	-0.1	-0.1	0.0	-0.2	-0.3	1.3
	10	1	star, L1L2L3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-	0.0	0.1	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	-0.2	0.0
		0.5i	star, L1L2L3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	-	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	-0.3	0.0
		1	star, L1	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.1	0.0	0.0	0.3	-0.1	0.1	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	-0.3	-0.5
		0.5i	star, L1	-0.1	0.0	0.0	0.0	-0.2	0.1	0.0	0.1	-0.1	-0.1	0.4	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1	-0.4	-0.9
		1	star, L2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	-	-0.1	0.1	0.0	0.1	-0.1	0.0	0.0	0.0	0.0	0.1	-0.3	0.3

		Current	Load connection	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
		0.5i	star, L2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	-0.1	-	0.1	0.0	0.0	-0.1	0.0	0.0	0.1	-0.1	0.0	0.1	-0.2	-0.5
		1	star, L3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	-0.1	-	0.2	0.1	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	-0.2	0.2
		0.5i	star, L3	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	-0.1	-	0.2	0.0	0.0	0.3	0.0	0.0	-0.1	-0.1	0.0	-0.1	-0.3	1.5

Table 3. │z│ Score of each laboratory for 230 V

Measurement point(phase values)			Load connection	Score │z│ for each laboratory																						
Voltage, V	Current, A	sinφ		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
230	0.25	1	star, L1L2L3	0.11	0.01	0.17	0.01	0.02	0.01	0.07	0.29	0.03	0.03	-	0.02	0.18	0.03	0.11	0.08	0.29	0.02	0.02	0.00	0.00	0.31	0.01
	0.5	1	star, L1L2L3	0.08	0.00	0.12	0.01	0.00	0.00	0.05	0.15	0.06	0.01	-	0.03	0.16	0.05	0.12	0.11	0.17	0.03	0.05	0.00	0.00	0.39	0.09
		0.5i	star, L1L2L3	0.15	0.04	0.18	0.03	0.04	0.03	0.11	0.28	0.11	0.02	-	0.11	0.01	0.09	0.06	0.18	0.30	0.03	0.15	0.01	0.09	0.40	0.06
		1	star, L1	0.03	0.00	0.09	0.00	0.20	0.02	0.05	0.02	0.12	0.02	0.45	0.08	0.14	0.03	0.08	0.11	0.20	0.00	0.04	0.03	0.03	0.37	0.84
		1	star, L2	0.07	0.00	0.08	0.01	0.11	0.04	0.02	0.12	0.02	0.07	-	0.05	0.17	0.03	0.09	0.10	0.21	0.06	0.08	0.05	0.02	0.28	0.37
		1	star, L3	0.04	0.00	0.07	0.00	0.06	0.04	0.01	0.20	0.00	0.24	-	0.17	0.20	0.01	0.08	0.15	0.18	0.03	0.03	0.02	0.00	0.21	0.27
	1	0.5i	star, L1L2L3	0.16	0.04	0.13	0.06	0.12	0.03	0.12	0.23	0.13	0.06	-	0.15	0.09	0.12	0.09	0.21	0.21	0.07	0.18	0.03	0.13	0.51	0.01
		0.25i	star, L1L2L3	0.09	0.03	0.08	0.03	0.04	0.01	0.07	0.14	0.04	0.01	-	0.09	0.07	0.06	0.01	0.07	0.12	0.03	0.09	0.00	0.09	0.19	0.03
		0.5i	star, L1	0.09	0.02	0.08	0.03	1.43	0.03	0.08	0.06	0.16	0.03	0.79	0.25	0.01	0.07	0.04	0.14	0.21	0.02	0.05	0.03	0.12	0.45	0.24
		0.5i	star, L2	0.10	0.00	0.09	0.00	0.19	0.01	0.01	0.15	0.01	0.04	-	0.15	0.01	0.06	0.10	0.14	0.22	0.00	0.12	0.02	0.13	0.22	0.79
		0.5i	star, L3	0.08	0.02	0.07	0.01	1.06	0.02	0.01	0.25	0.02	0.03	-	0.14	0.01	0.05	0.07	0.19	0.20	0.10	0.10	0.01	0.03	0.42	1.11
	5	1	star, L1L2L3	0.04	0.03	0.04	0.02	0.04	0.04	0.00	0.00	0.03	0.03	-	0.03	0.20	0.03	0.09	0.12	0.01	0.03	0.04	0.01	0.03	0.40	0.01
		0.5i	star, L1L2L3	0.12	0.06	0.09	0.05	0.08	0.03	0.03	0.13	0.12	0.01	-	0.15	0.09	0.11	0.03	0.21	0.06	0.06	0.15	0.06	0.14	0.51	0.03
		0.25i	star, L1L2L3	0.06	0.02	0.04	0.04	0.02	0.01	0.02	0.09	0.05	0.02	-	0.10	0.11	0.06	0.02	0.07	0.03	0.03	0.07	0.00	0.08	0.19	0.04
		1	star, L1	0.03	0.01	0.02	0.01	0.22	0.04	0.00	0.00	0.01	0.03	0.35	0.13	0.08	0.02	0.05	0.11	0.02	0.01	0.02	0.02	0.07	0.31	0.52
		0.5i	star, L1	0.06	0.02	0.03	0.03	0.26	0.07	0.02	0.08	0.08	0.05	0.89	0.20	0.01	0.06	0.01	0.14	0.04	0.04	0.06	0.02	0.09	0.41	0.62
		1	star, L2	0.03	0.00	0.02	0.02	0.06	0.01	0.01	0.01	0.02	0.04	-	0.07	0.10	0.02	0.21	0.10	0.02	0.03	0.03	0.01	0.01	0.22	0.05
		0.5i	star, L2	0.06	0.02	0.03	0.00	0.10	0.09	0.01	0.36	0.06	0.09	-	0.15	0.01	0.05	0.16	0.15	0.03	0.00	0.07	0.03	0.04	0.32	0.58
		1	star, L3	0.02	0.00	0.02	0.02	0.06	0.03	0.01	0.02	0.01	0.22	-	0.17	0.11	0.01	0.06	0.13	0.01	0.01	0.01	0.00	0.02	0.24	0.56
		0.5i	star, L3	0.07	0.02	0.04	0.01	0.04	0.00	0.01	0.12	0.03	0.07	-	0.16	0.02	0.04	0.07	0.10	0.03	0.09	0.08	0.02	0.18	0.29	1.28
	10	1	star, L1L2L3	0.06	0.01	0.04	0.02	0.03	0.04	0.01	0.01	0.00	0.06	-	0.03	0.17	0.03	0.09	0.15	0.01	0.03	0.06	0.01	0.07	0.40	0.10
		0.5i	star, L1L2L3	0.13	0.06	0.09	0.06	0.09	0.09	0.06	0.09	0.10	0.06	-	0.18	0.15	0.06	0.10	0.10	0.06	0.06	0.16	0.09	0.13	0.52	0.13
		1	star, L1	0.03	0.00	0.01	0.01	0.19	0.03	0.01	0.08	0.02	0.02	0.24	0.11	0.07	0.02	0.03	0.11	0.01	0.03	0.01	0.01	0.05	0.26	0.54

		0.5i	star, L1	0.07	0.01	0.03	0.03	0.18	0.05	0.03	0.09	0.06	0.07	0.34	0.21	0.03	0.04	0.01	0.04	0.01	0.03	0.06	0.03	0.09	0.41	0.89
		1	star, L2	0.03	0.00	0.02	0.01	0.06	0.01	0.00	0.00	0.01	0.02	-	0.08	0.08	0.01	0.04	0.11	0.01	0.03	0.02	0.01	0.04	0.29	0.24
		0.5i	star, L2	0.06	0.01	0.04	0.02	0.10	0.06	0.03	0.06	0.06	0.10	-	0.09	0.01	0.02	0.10	0.06	0.03	0.02	0.09	0.05	0.04	0.26	0.50
		1	star, L3	0.03	0.00	0.02	0.02	0.05	0.03	0.00	0.00	0.00	0.15	-	0.16	0.09	0.01	-0.05	0.14	0.00	0.02	0.02	0.00	0.00	0.24	0.17
		0.5i	star, L3	0.07	0.01	0.03	0.01	0.03	0.02	0.02	0.10	0.02	0.10	-	0.16	0.00	0.01	0.25	0.05	0.01	0.09	0.08	0.03	0.16	0.29	1.44

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
■	0.03	-0.06	0.02	-0.11	0.04	0.01	0.02	-0.03	0.27	0.01	0.05		0.01	0.18	0.01	-0.06	-0.04	-0.21	0.01	0.01	0.03	0.03	-0.23	0.02
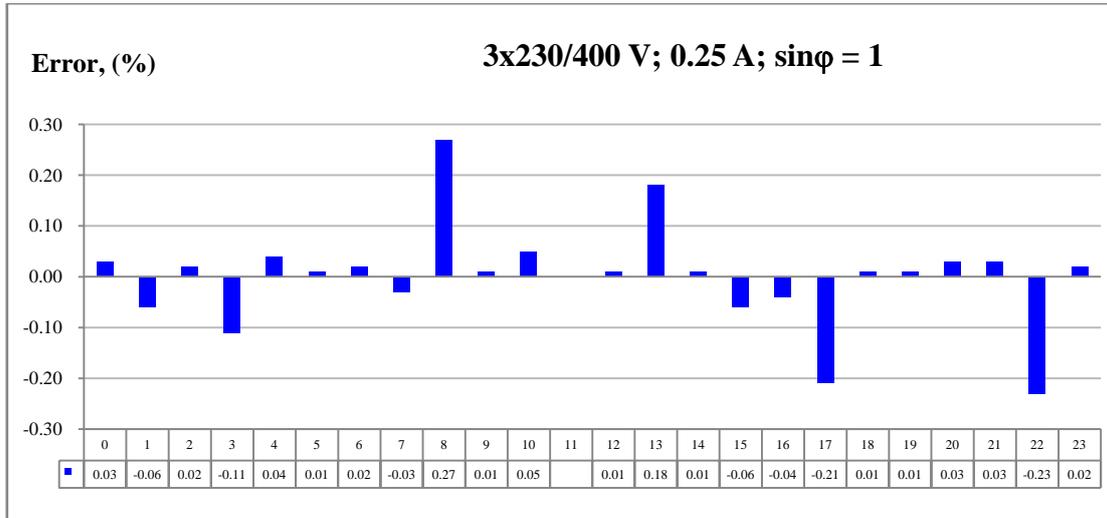
Fig. 2. Error for 3 x 230/400 V; 0.25 A, sinφ = 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	0.02	-0.02	0.02	-0.05	0.02	0.08	-0.02	0.03	0.22	0.02	-0.22		0.19	0.22	0.01	-0.06	-0.13	-0.16	-0.01	-0.01	0.00	0.02	-0.19	0.29
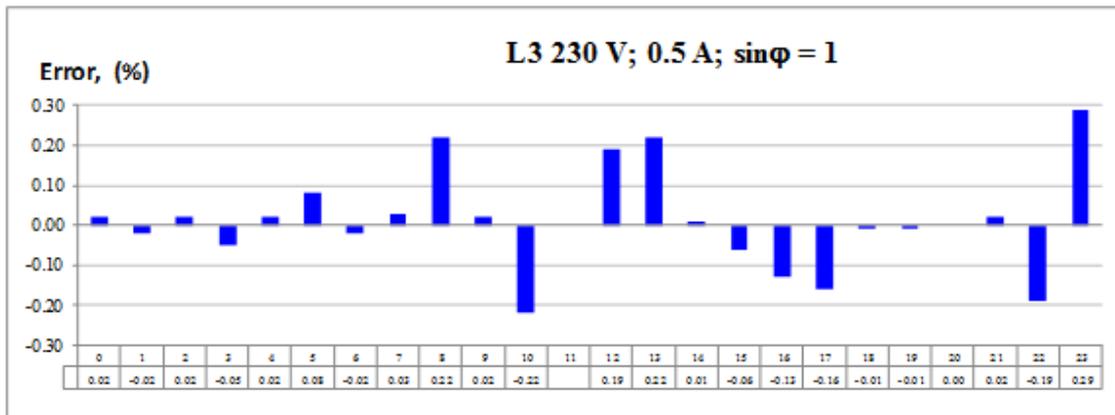
Fig.3. Error for L3 230 V; 0.5 A, sinφ = 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	0.02	-0.01	0.02	0.00	0.04	0.07	-0.01	0.02	0.02	0.02	-0.13		0.18	0.11	0.03	-0.03	-0.12	0.02	0.00	0.00	0.02	0.02	-0.22	0.19

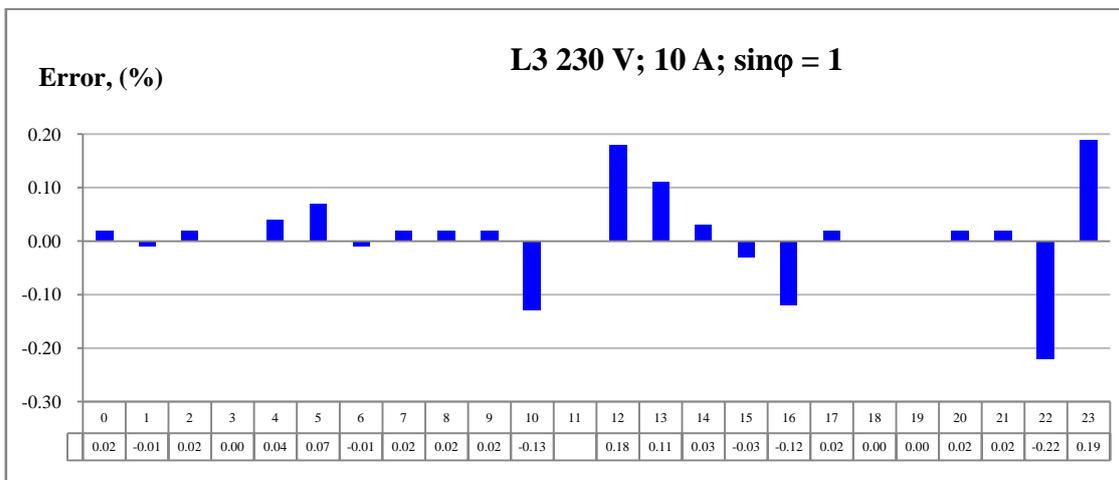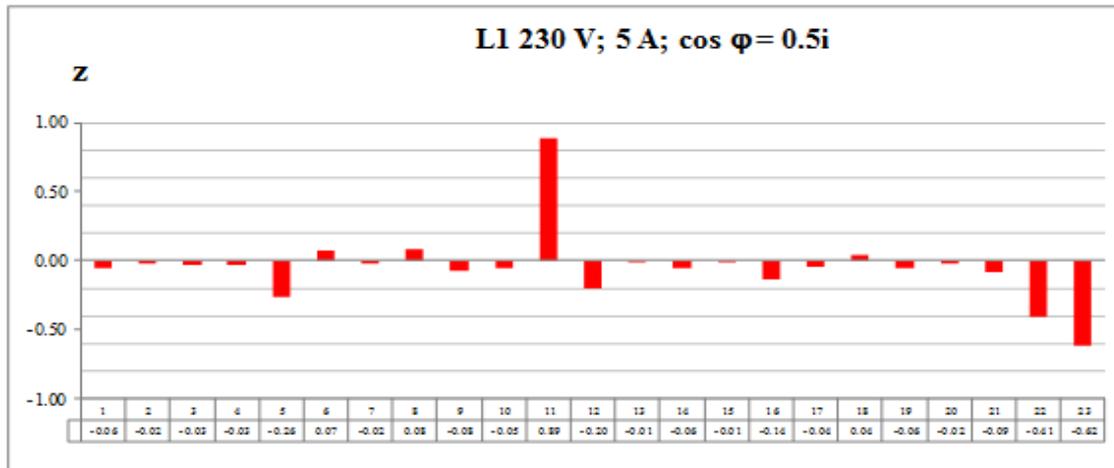*Fig. 4. Error for L3 230 V; 10 A, sinφ = 1*

*Fig. 5. **Z score** for L1 230 V; 5 A, cosφ = 0.5i*
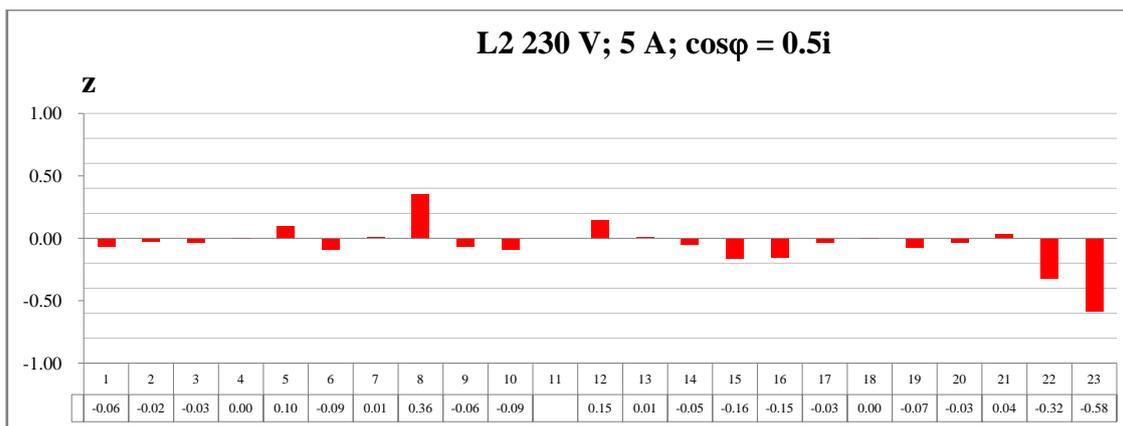
*Fig. 6.**Z score** for L2 230 V; 5 A, cosφ = 0.5i*
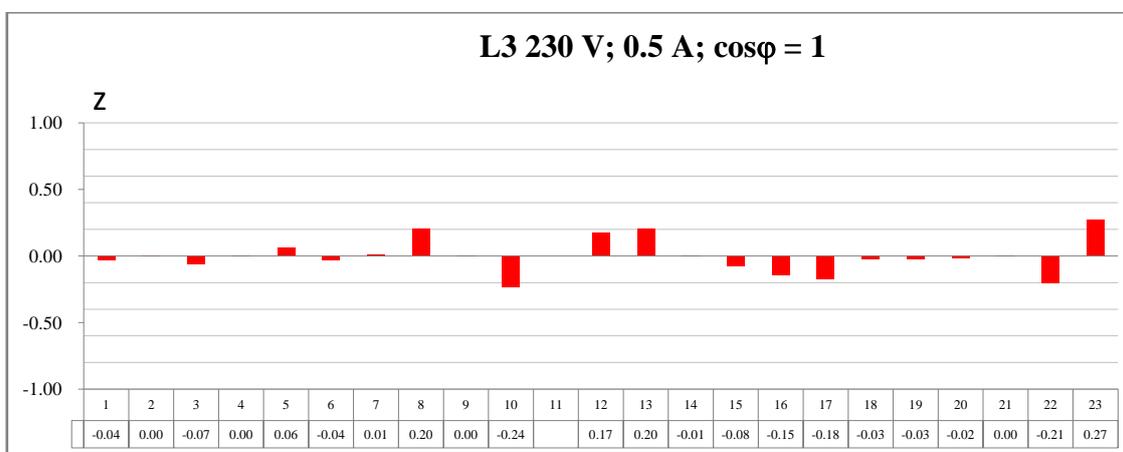
*Fig. 7. **Z score** for L3 230 V; 0.5 A, cosφ = 1*