25th IMEKO TC4 International Symposium
23rd International Workshop on ADC and DAC Modelling and Testing
IMEKO TC-4 2022
Brescia, Italy / September 12-14, 2022

Regional Interlaboratory Comparison of Measuring Systems for Current Transformers Accuracy Testing

Dragana Naumovic-Vukovic[1], Slobodan Skundric[1], Marko Cukman[2], Darko Ivanovic[2], Ivan Novko[3], Miroslav Bonic[3]

[1] Electrical Engineering Institute Nikola Tesla JSC, Koste Glavinića 8a, Belgrade, Serbia,
draganav@ieent.org
[2] Končar – Instrument Transformers Inc, Ulica Josipa Mokrovića 10, Zagreb, Croatia,
marko.cukman@koncar-mjt.hr, darko.ivanovic@koncar-mjt.hr
[3] Končar – Electrical Engineering Institute Ltd, Fallerovo šetalište 22, Zagreb, Croatia,
mbonic@koncar-institut.hr, inovko@koncar-institut.hr

Abstract **– The paper describes an intercomparison of measuring systems for current transformers accuracy testing between three laboratories Koncar - Instrument Transformers, Koncar - Electrical Engineering Institute and Electrical Engineering Institute Nikola Tesla. All laboratories are accredited according to EN/ IEC 17025: 2017 standard. The obtained discrepancies in ratio and phase errors are within participant's declared measurement uncertainties. All laboratories have confirmed their competence ($|E_n|\leq 1$) for the applied measurement methods, in accordance with EN ISO/ IEC 17043.**

I. INTRODUCTION

The laboratories accredited according to standard EN/IEC 17025:2017 for calibration and testing, have to demonstrate how they ensure the validity of their results. The best way to fulfil requirements for monitoring the validity of the calibration and testing results, standard EN/IEC 17025:2017, point 7.7, is through the comparison with the results of other laboratories where it is available and appropriate [1]. Comparison can be achieved through participation in proficiency testing (PT schemes) or/and participation in interlaboratory comparison (ILC) [1]. PT/ILC schemes are an important parameter for the test/calibration laboratories to assure the quality of test and calibration results. For accredited laboratories participation in PT/ILC and getting acceptable and successful results in the area of their declared measurements capabilities is a compulsory periodical activity in terms of EN ISO/IEC 17025. This activity is also required from the national accreditation bodies.

In the field of instrument transformers, accredited PT schemes are very rare. From time-to-time key comparisons occurred, organised between national metrology institutes laboratories [2, 3, 4]. Usually, proficiency of the lower rank laboratories, in the national metrology hierarchy, its verified through bilateral or multilateral comparisons organised by National metrology institutes. [5].

This paper describes the results of an ILC organised between regional leading accredited laboratories in the field of current transformers: Koncar – Instrument Transformers Inc. (LAB1), Electrical Engineering Institute Nikola Tesla JSC, (LAB2) and Koncar – Electrical Engineering Institute Ltd, (LAB3). The participating laboratories are accredited according to standard EN/IEC 17025:2017.

II. MEASURING SYSTEMS

All participating laboratories used measuring systems for current transformers accuracy testing based on differential measuring methods. In this method ratio error and phase displacement of chosen artefact (device under test) compares with the errors of standard current transformer. Measuring systems consists of: standard current transformer, measuring bridge (electronic device for accuracy testing of instrument transformers), standard current burden and current supply. In laboratories LAB1, LAB2 and LAB3, measuring systems originating from different manufacturers were used. Measuring equipment from laboratory LAB1 is directly traceable according to the national standards of Germany. Laboratories LAB 2 and LAB3 have measuring equipment that are traceable according to the national standards of Germany, through the national standards of Serbia and the national standards of Croatia, respectively.
The LAB1 was chosen as the reference laboratory by agreement between participants.

III. TRANSFER CURRENT TRANSFORMER

In this ILC commercial current transformer (CT) was

used as a transfer artefact. The transfer CT of the 1000A/5A ratio, class 0.2 was tested at rated burden of 30VA as well as on 7.5VA. Agreed measuring points were 5%, 20%, 100% and 120% of rated current at 50Hz. Transfer CT has remained stable throughout the ILC.
Laboratories have measured ratio error and phase displacement of the transfer CT following their usual internal testing procedures.

IV. COMPARISON AND EVALUATION

The measurement results (ratio error and phase displacement) for participation laboratories are shown in Fig. 1, 2, 3 and 4. Numerical values for ratio error and phase displacement with expanded uncertainty of measurement for each laboratory participant are presented in tables from. In te tables from 3 to 8 is also presented En number for all participation laboratories.

A. Results

Results for ratio error, for all laboratories, shown in fig. 1 and 2, for all measurements points, are within interval from -0.076% to 0.039% for the rated burden S and within interval from 0.074% to 0.126% for the burden S/4.

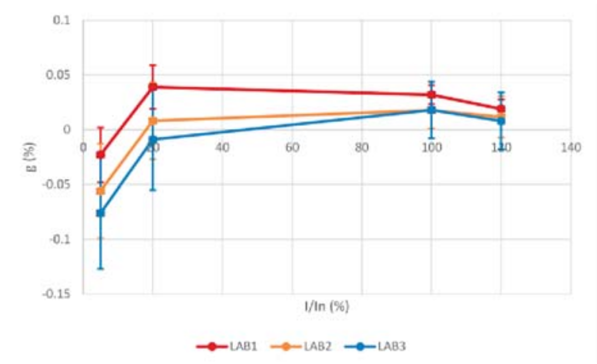

Fig. 1. Ratio error for rated burden 30VA at 50Hz

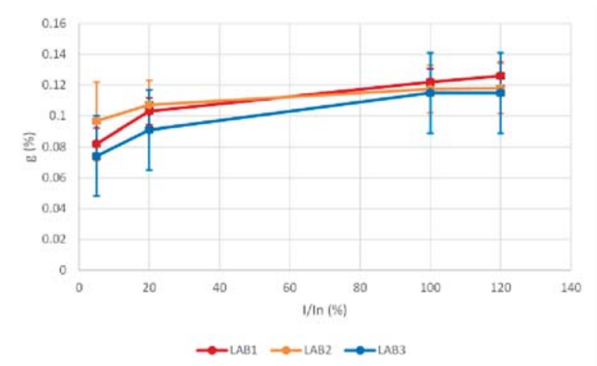

Fig. 2. Ratio error for rated burden 7.5 VA at 50Hz

Results for phase displacement for all laboratories, shown in fig. 3 and 4, for all measurements points, are within interval from 0.32 min to 4,6 min for the rated burden S and within interval from 0.39 min to 3.7 min for the burden S/4. The discrepancy between laboratories in the ratio error is maximum 0.053 % for the rated burden S and 0.02% for the burden S/4. The discrepancy in phase displacement is maximum 2.2 min for the rated burden S and 1.1 min for the burden S/4.

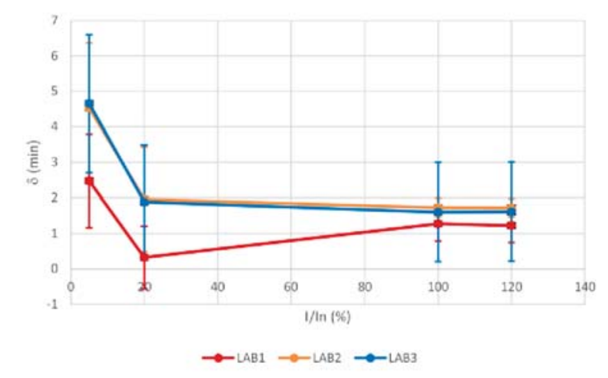

Fig. 3. Phase displacement for 30VA at 50Hz

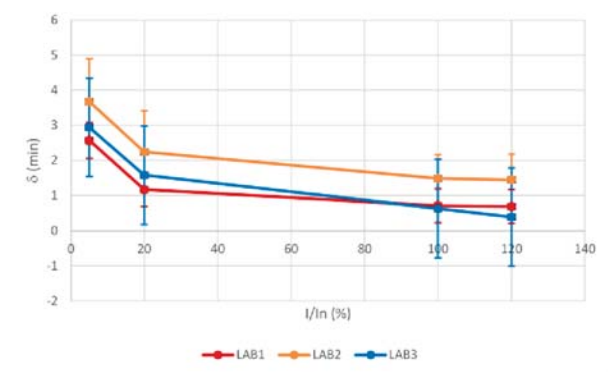

Fig. 4. Phase displacement for 7.5VA at 50Hz

B. Uncertainty budget

The uncertainty budget of the LAB1 and LAB2 results, for ratio error and phase displacement contain five different contributions: type A uncertainty of the measurement, uncertainty of the measuring bridge, uncertainty of the standard CT, burden variations and reference current variation. The uncertainty budget of the LAB3 for ratio error and phase displacement, contain three different contributions: type A uncertainty of the measurement, uncertainty of the measuring bridge and uncertainty of the standard CT. The uncertainty of the primary circuit configuration wasn't considered because all participant laboratories applied pre-agreed disposition for primary circuit.

The expanded uncertainties (k = 2) of all participants laboratories are calculated according to:

$$U(g) = 2 \cdot \sqrt{\sum_i u_i^2(g)} \quad (1)$$

$$U(\delta) = 2 \cdot \sqrt{\sum_i u_i^2(\delta)} \quad (2)$$

The uncertainty budgets for participant laboratories for measuring points 5% and 100% of rated current at rated burden of 30VA are given in the following tables.

Table 1. Type A and B standard uncertainty and expanded uncertainty for ratio error of transfer current transformer (1000A/5A) at rated burden S and measuring points 5%I_n and 100%I_n

Measuring point	Type	*Uncertainty components $u_i(y)$* (%)		
		LAB1	LAB2	LAB3
5% I/I_n	A	0.0115	0.0184	0.0219
	B	0.0050	0.0110	0.0130
Expanded uncertainty (k=2, *p*=95%)		0.0251	0.0430	0.051
100% I/I_n	A	0.00007	0.0026	0.001
	B	0.0087	0.0079	0.0133
Expanded uncertainty (k=2, *p*=95%)		0.0087	0.0167	0.0266

Table 2. Type A and B standard uncertainty and expanded uncertainty for phase displacement of transfer current transformer (1000A/5A) at rated burden and measuring points 5%I_n and 100%I_n

Measuring point	Type	*Uncertainty components $u_i(y)$* (min)		
		LAB1	LAB2	LAB3
5% I/I_n	A	0.603	0.725	0.680
	B	0.255	0.561	0.698
Expanded uncertainty (k=2, *p*=95%)		1.31	1.83	1.95
100% I/I_n	A	0.01	0.08	0.05
	B	0.24	0.11	0.70
Expanded uncertainty (k=2, *p*=95%)		0.48	0.27	1.40

It can be noticed that dominant component of measuring uncertainty at measuring point 5% of rated current, for both ratio error and phase displacement is type A for all participants. At measuring point 100% of rated current dominant component for all participants is type B. The source for the stated trend of uncertainty of measurement is the nature and features of the chosen transfer current transformer.

C. Statistical Evaluation

The statistical method applied for evaluation of the results in this ILC was calculation of En number [6]. For each participant laboratory E_n number is calculated using equation:

$$En = \frac{X_{lab} - X_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \quad (3)$$

where

X_{lab} is the participant's result, LAB1, LAB2 and LAB3

X_{ref} is te reference assigned value:

$$X_{ref} = \frac{X_{LAB1} + X_{LAB2} + X_{LAB3}}{3} \quad (4)$$

Table 3. Numerical values of ratio error with expanded uncertainty of measurement and En number for LAB1

I/In (%)	g_{ref} (%)	U_{ref} (%)	G_{LAB1} (%)	U_{LAB1} (%)	$\lvert E_{n\ LAB1} \rvert$
S = 30 VA					
5	-0.052	0.024	-0.023	0.0251	0.83
20	0.013	0.020	0.039	0.0198	0.93
100	0.023	0.011	0.032	0.0087	0.68
120	0.013	0.011	0.019	0.0087	0.43
S = 7.5 VA					
5	0.084	0.013	0.082	0.0101	0.14
20	0.100	0.011	0.103	0.0087	0.19
100	0.118	0.010	0.122	0.0087	0.28
120	0.120	0.011	0.126	0.0087	0.46

Table 4. Numerical values of phase displacement with expanded uncertainty of measurement and En number for LAB1

I/In (%)	g_{ref} (%)	U_{ref} (%)	G_{LAB1} (%)	U_{LAB1} (%)	$\lvert E_{n\ LAB1} \rvert$
S = 30 VA					
5	3.88	0.99	2.47	1.31	0.86
20	1.38	0.78	0.32	0.88	0.90
100	1.53	0.50	1.27	0.48	0.38
120	1.52	0.50	1.22	0.48	0.43
S = 7.5 VA					
5	3.06	0.64	2.57	0.51	0.60
20	1.66	0.63	1.17	0.48	0.62
100	0.94	0.54	0.71	0.48	0.32
120	0.84	0.55	0.69	0.48	0.21

U_{lab} is the expanded uncertainty of a participant's results, LAB1, LAB2 and LAB3
U_{ref} is the expanded uncertainty of the reference:

$$U_{ref} = \sqrt{U_{LAB1}^2 + U_{LAB2}^2 + U_{LAB3}^2} \quad (5)$$

Table 5. Numerical values of ratio error with expanded uncertainty of measurement and En number for LAB2

I/In (%)	g_{ref} (%)	U_{ref} (%)	G_{LAB2} (%)	U_{LAB2} (%)	$\|E_{n\ LAB2}\|$
S = 30 VA					
5	-0.052	0.024	-0.0559	0.0430	0.09
20	0.013	0.020	0.0081	0.0350	0.11
100	0.023	0.011	0.0177	0.0167	0.24
120	0.013	0.011	0.0117	0.0187	0.05
S = 7.5 VA					
5	0.084	0.013	0.0966	0.0255	0.44
20	0.100	0.011	0.1072	0.0160	0.35
100	0.118	0.010	0.1175	0.0154	0.04
120	0.120	0.011	0.1179	0.0163	0.09

Table 6. Numerical values of phase displacement with expanded uncertainty of measurement and En number for LAB2

I/In (%)	g_{ref} (%)	U_{ref} (%)	G_{LAB2} (%)	U_{LAB2} (%)	$\|E_{n\ LAB2}\|$
S = 30 VA					
5	3.88	0.99	4.528	1.836	0.31
20	1.38	0.78	1.954	1.478	0.34
100	1.53	0.50	1.726	0.261	0.34
120	1.52	0.50	1.720	0.260	0.36
S = 7.5 VA					
5	3.06	0.64	3.674	1.227	0.44
20	1.66	0.63	2.240	1.174	0.43
100	0.94	0.54	1.484	0.680	0.62
120	0.84	0.55	1.443	0.733	0.66

Table 7. Numerical values of ratio error with expanded uncertainty of measurement and En number for LAB3

I/In (%)	g_{ref} (%)	U_{ref} (%)	G_{LAB3} (%)	U_{LAB2} (%)	$\|E_{n\ LAB3}\|$
S = 30 VA					
5	-0.052	0.024	-0.076	0.051	0.43
20	0.013	0.020	-0.009	0.046	0.43
100	0.023	0.011	0.018	0.026	0.16
120	0.013	0.011	0.008	0.026	0.17
S = 7.5 VA					
5	0.084	0.013	0.074	0.026	0.35
20	0.100	0.011	0.091	0.026	0.33
100	0.118	0.010	0.115	0.026	0.11
120	0.120	0.011	0.115	0.026	0.17

Satisfactory criterion for measuring results is $|E_n| \leq 1$. Evaluated values for E_n number for each laboratory are presented in tables from 3 to 8. Values for E_n number are also shown in Fig. 5 and 6 for ratio errors and Fig. 7 and 8 for phase displacement.

Table 8. Numerical values of phase displacement with expanded uncertainty of measurement and En number for LAB3

I/In (%)	g_{ref} (%)	U_{ref} (%)	G_{LAB3} (%)	U_{LAB3} (%)	$\|E_{n\ LAB3}\|$
S = 30 VA					
5	3.88	0.99	4.65	1.95	0.35
20	1.38	0.78	1.88	1.60	0.28
100	1.53	0.50	1.60	1.40	0.05
120	1.52	0.50	1.61	1.40	0.06
S = 7.5 VA					
5	3.06	0.64	2.94	1.40	0.08
20	1.66	0.63	1.58	1.40	0.05
100	0.94	0.54	0.63	1.40	0.21
120	0.84	0.55	0.39	1.40	0.30

As presented in tables from 3 to 8 all participant laboratories have E_n number less than 1.0 for both measured ratio errors and phase displacement. Therefore, all participant laboratories confirmed their competence for the applied measurement methods, in accordance with EN ISO / IEC 17043.

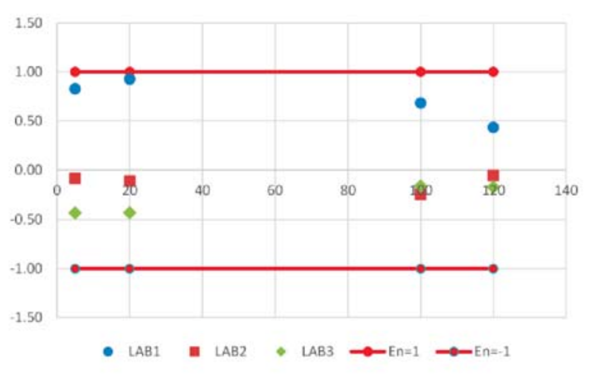

Fig. 5. E_n number for ratio error at S=30VA and measuring points from 5%I_n to 120%I_n for all participant laboratories

V. CONCLUSION

The interlaboratory comparison described in this paper is successfully performed. For ratio error and phase displacement measurement participant laboratories used measurement systems from different manufacturers. Transfer current transformer 1000A/5A, 30VA, class 0.2

remained stable during the comparison. The discrepancy between laboratories in the ratio error measurement is within 0.05 % for the rated burden S and within 0.015% for the burden S/4. The discrepancy in phase displacement measurement is within 2.2 min for *the* rated burden S and 1.1 min for the burden S/4. The obtained discrepancies in ratio and phase errors are within participant's declared measurement uncertainties. The carried out statistical processing of measurement results shows that all laboratories have E_n number less than 1.00. In this way participant laboratories confirmed their competence in accuracy measurement of current transformers and ensured the validity of their results.

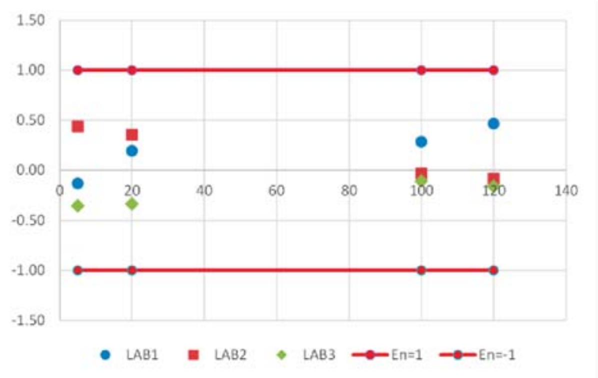

Fig. 6. E_n number for ratio error at S=7.5VA and measuring points from 5%I_n to 120%I_n for all participant laboratories

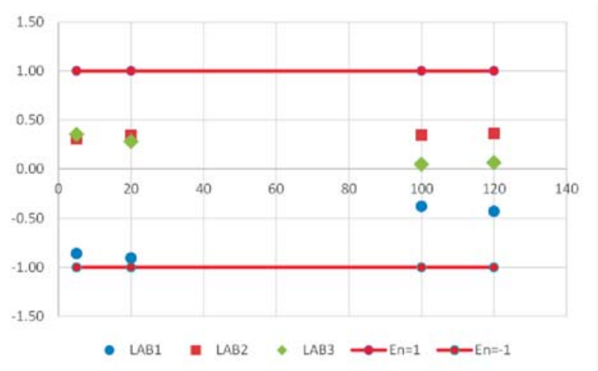

Fig. 7. E_n number for phase displacement at S=30VA and measuring points from 5%I_n to 120%I_n for all participant laboratories

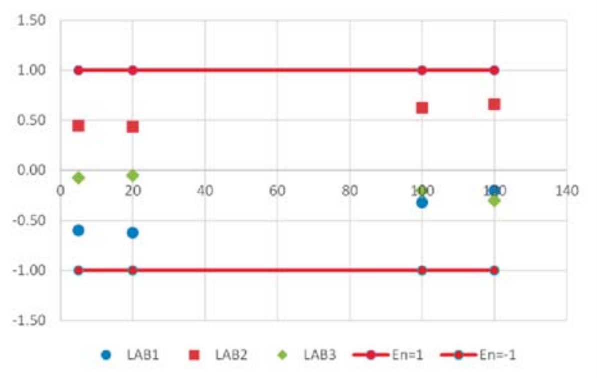

Fig. 8. E_n number for phase displacement at S=7.5VA and measuring points from 5%I_n to 120%I_n for all participant laboratories

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