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Ensuring the validity of the calibration results of current transformers through intralaboratory comparison

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***Abstract* – The calibration laboratories accredited according to the standard ISO/IEC 17025:2017 should continuously monitor the validity of measurement results. By ensuring the validity of calibration results, the laboratory also monitors its own performance. There are several different techniques for confirming the validity of results and they are a matter of choice and capability of the accredited laboratory. The paper describes two different methods that the Laboratory for testing and calibration of the Nikola Tesla Institute of Electrical Engineering uses in intralaboratory comparison as a technique for ensuring the validity of current transformer calibration results. Statistical processing of the obtained results shows that the E_n number at all measurement points is satisfactory, which confirms the competence of the Institute's Laboratory in the field of current transformer calibration.**

I. INTRODUCTION

Accuracy testing is usually related to the production process of instrument transformers and the procedures conducted in manufacturers' quality control laboratories. In order to achieve the required accuracy class, the ratio error and phase displacement are measured and monitored several times during production. The most important inspection is the final inspection, carried out individually on each transformer as part of routine testing. This measurement determines the ratio error and phase displacement of the produced transformer and irrevocably declares its accuracy class. Accuracy testing is of particular importance for measuring transformers that are in operation and used for billing electricity measurements. In the Republic of Serbia, legal metrology addresses this function of measuring transformers through mandatory initial inspection before they are put into use within billing measurement systems [1]. Accuracy testing is also conducted periodically on transformers in operation, especially when there is suspicion of malfunction [2]. Both during the initial inspection and planned or unplanned periodic inspections of instrument transformers, accuracy testing actually verifies compliance with the declared accuracy class [3]. The calibration procedure is associated with national and accredited laboratories that, within the hierarchy of national and legal metrology, are above manufacturer laboratories. Their primary task is to calibrate working and reference standard current and voltage transformers [4].

Accuracy testing of instrument transformers, both in the laboratory and in the field, at the Nikola Tesla Institute of Electrical Engineering (NTIEE) has a tradition of over 60 years. Over the decades, the NTIEE has achieved significant results and international reputation in this field, including in the development of measurement methods and devices for instrument transformer accuracy testing. Thus, measurement systems for accuracy testing of instrument transformers, developed and produced at the NTIEE, are used both in the laboratories of manufacturers and distribution companies in almost all former Yugoslav countries, as well as in the national laboratories of Serbia, Canada, and Singapore [5, 6].

The Laboratory for Testing and Calibration of NTIEE (Laboratory) accredited the methods for accuracy testing and calibration of instrument transformers, already during its first accreditation in 2001, in accordance with the SRPS ISO/IEC 17025 standard [7]. As an accredited laboratory, the NTIEE's Laboratory is obliged to regularly monitor its performance. Monitoring performance of the laboratory is possible through comparison with the results of other laboratories by participating in interlaboratory comparisons or proficiency testing schemes, as well as through ensuring the validity of testing and calibration results it conducts. There are several different techniques for ensuring the validity of the results [7]. In the field of testing and calibration of measuring transformers, the Laboratory uses techniques such as: intermediate checks on measuring equipment and standards, replicate tests or calibrations using the same or different methods, retesting or recalibrating retained items, and intralaboratory comparison. Additionally, the NTIEE's Laboratory regularly participates in both international interlaboratory comparisons and proficiency schemes organized by the Directorate for Measures and Precious Metals, Serbia.

Ensuring the validity of results involves the application of statistical methods in accordance with internationally accepted methodology and standards [8]. By analyzing data obtained in this way, it is possible to manage and improve laboratory activities, all with the aim of confirming the reliability of the obtained measurement results and preventing the irregular reporting of inaccurate measurement results.

One of the conditions for maintaining accreditation granted by the Accreditation Body of Serbia is the implementation of the aforementioned competence verification procedures.

This paper presents the results of an intralaboratory comparison in the field of current measuring transformer testing. The intralaboratory comparison was carried out by comparing the accuracy test results of a current transformer using two different measurement methods.

II. APPLIED MEASURING METHODS

Testing the accuracy and calibration of current transformers in the accredited NTIEE Laboratory can be carried out using various measurement methods and devices [4, 5, 9]. Regardless of the applied measurement method and device, the calibration and accuracy testing of measurement transformers are performed in accordance with national and international standards for current transformers at specific reference current and burden values [10, 11].

The two most commonly used methods for testing the accuracy of current transformers are the differential method (DIF) and the current comparator method (KSK). Both methods are based on comparison of secondary currents of the transformer under test and the reference transformer of the same or approximately the same transformation ratio, i.e. on measuring the difference between their currents.

Each of the measurement methods mentioned above implies the existence of a measurement system consisting of a group of measuring instruments and devices. In the case of the DIF method, the measurement system includes: a standard current transformer, a device for ratio error and phase displacement measurement, a standard burden, and a regulated primary current source. In the KSK method, the measurement system includes: a compensated current comparator, a device for ratio error and phase displacement measurement, and a standard burden. The specificity of the compensated current comparator is that it simultaneously serves as both a reference transformer and a source of primary currents. Compensated current comparator, as a standard transformer, has a long record of calibrations at various test conditions and very well stability over time. It is used as a reference standard transformer in this comparison.

The metrological characteristics of the applied measurement systems in this comparison are very similar and have been verified by calibrating each individual system element to determine its actual errors. The errors of the applied systems are included in the evaluation of measurement uncertainty.

The measurements were conducted in two stages. The first stage involved testing a pre-selected conventional current transformer, the artifact, using the measurement system based on the KSK method [12, 13]. In the second stage, the measurement system based on the DIF method [13] was applied.

The selected artifact in this intralaboratory comparison is a conventional inductive current transformer, used as a working reference standard in the Laboratory, with a rated transformation ratio of 25 A / 5 A, rated power of 10 VA, and an accuracy class of 0.5. This transformer has time-stable errors, which have been verified through repeated testing.

III. RESULTS OF INTRALABORATORY COMPARISON

Measuring results for ratio error and phase displacement of DUT, T_X, are presented in Fig. 1, Fig. 2, Fig. 3 and Fig. 4.

The artifact, current transformer T_X, was tested by each method individually at the standard prescribed measurement points of 5 %, 20 %, 100 %, and 120 % of the rated current (I / In) and at a quarter and rated burden, i.e. at burden of 2.5 VA, $\cos(\varphi)$ = 1, and at 10 VA and $\cos(\varphi)$ = 0.8 [11].

During the measurements conducted in the Laboratory, the following testing conditions were ensured: ambient temperature from 19 °C to 22 °C; network voltage frequency 50 Hz ± 1 Hz; network voltage distortion less than 5 %.

The differences between measurement results (ratio error and phase displacement), shown in Figures 3.1 to 3.4, obtained using two different methods, were within the limits of 0.056 % and 5.16 minutes at the rated power, and within 0.066 % and 5.4 minutes at a quarter of the rated power.

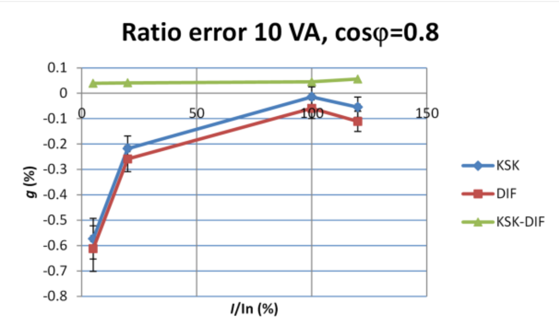

Fig. 1. Measured value of the ratio error of the Tx artifact, using KSK and DIF methods for the rated burden S =10 VA and cos(φ)=0.8

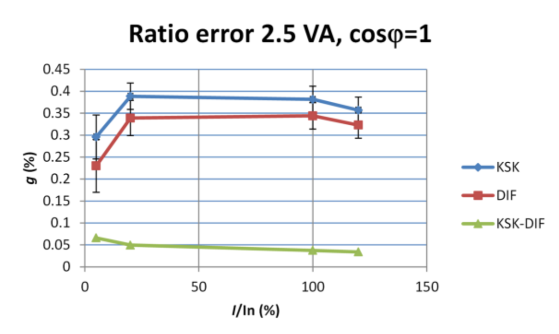

Fig. 2. Measured value of the ratio error of the Tx artifact, using KSK and DIF methods for the rated burden S=2.5 VA and cos(φ)=1.0

IV. EVALUATION OF MEASUREMENT RESULTS

The standard method commonly used for evaluating performance in inter-laboratory comparisons or accredited proficiency testing schemes is the calculation of the E_n number [14]. In the case of the described intra-laboratory comparison, this statistical method for processing results was also adopted. According to the standard [8], the E_n number is calculated using the formula:

$$E_n = \frac{x_i - X_{ref}}{\sqrt{U_i^2 + U_{ref}^2}} \qquad (1)$$

Where, in the case of intralaboratory comparison:

• X_{ref} is the agreed reference value of the error (ratio error or phase displacement) measured using the measurement system based on the KSK method, which was chosen as the reference.

• U_{ref} is the expanded measurement uncertainty of the measurement system based on the KSK method,

• x_i is the measured value of the error (ratio error or phase displacement) using the measurement system based on the DIF method,

• U_i is the expanded measurement uncertainty for the measurement system based on the DIF method.

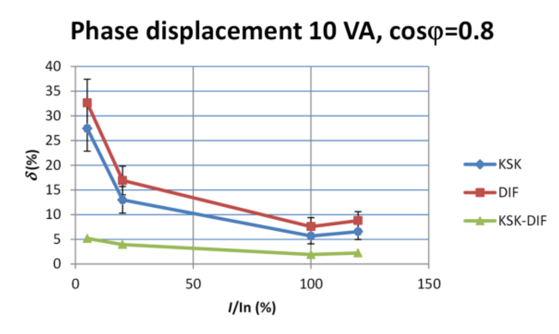

Fig. 3. Measured value of the phase displacement of the Tx artifact, using KSK and DIF methods for the rated burden S=10 VA and cos(φ)=0.8

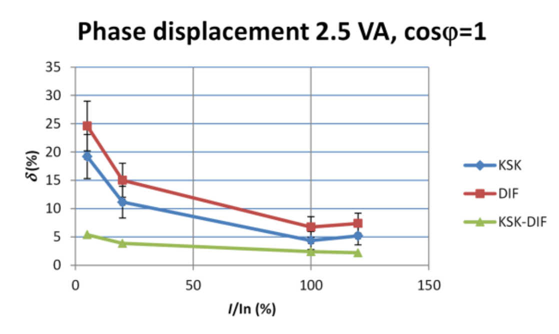

Fig. 4. Measured value of the phase displacement of the Tx artifact, using KSK and DIF methods for the rated burden S=2.5 VA and cos(φ)=1.0

The measurement uncertainty associated with the results of this intralaboratory comparison, for both applied measurement methods, is given as the expanded measurement uncertainty obtained by multiplying the standard measurement uncertainty by the expansion factor k=2, which for a normal distribution corresponds to a coverage probability of approximately 95 % [15]. The components of measurement uncertainty considered in its evaluation are: standard deviation of the measurements, the effect of the reference transformer's error, the effect of the error of measuring device for accuracy testing and its resolution, the effect of the reference load, and the reference current [16].

The acceptance criterion for the comparison results is $|E_n| \leqslant 1.00$. When the E_n number criterion is met, it is considered that the participating laboratories in the comparison have demonstrated their competence. Otherwise, if the participating laboratory did not meet the requirements for competence it has to review and analyze the obtained result in order to identify its cause.

In the case of described intralaboratory comparison, the criterion $|E_n| \leqslant 1.00$ was also satisfied, which is a measure of the Laboratory's competence, indicating that the laboratory possesses adequate measurement equipment, is familiar with the calibration method, has qualified personnel who can adequately assess the measurement uncertainty of the specific measurement. In this way, the Laboratory demonstrates the validity of the accreditation awarded by the Serbian Accreditation Body.

The obtained measurement results with the calculated uncertainties of measurement for ratio error and phase displacement, and the calculated E_n numbers, are shown in Tables 1, 2, 3 and 4.

Table 1. E_n number for ratio error, at Sn=10 VA and cos(φ)=0.8

***I*/*I*n**	**5 %**	**20 %**	**100 %**	**120 %**
g_{KSK} (%)	-0.5730	-0.2181	-0.0143	-0.0548
U_{KSK} (%)	0.08	0.05	0.04	0.04
g_{DIF} (%)	-0.6120	-0.2590	-0.0595	-0.1108
U_{DIF} (%)	0.09	0.05	0.04	0.04
E_n	**0.77**	**0.98**	**0.78**	**0.90**

Table 2. E_n number for ratio error, at Sn=2.5 VA and cos(φ)=1

***I*/*I*n**	**5 %**	**20 %**	**100 %**	**120 %**
g_{KSK} (%)	0.2959	0.3886	0.3815	0.3569
U_{KSK} (%)	0.05	0.03	0.03	0.03
g_{DIF} (%)	0.2300	0.2940	0.3440	0.3130
U_{DIF} (%)	0.06	0.04	0.03	0.03
E_n	**0.91**	**0.94**	**0.98**	**0.90**

Table 3. E_n number for phase displacement, at Sn=10 VA and cos(φ)=0.8

***I*/*I*n**	**5 %**	**20 %**	**100 %**	**120 %**
g_{KSK} (%)	27.44	12.97	5.66	6.55
U_{KSK} (%)	4.6	2.7	1.6	1.6
g_{DIF} (%)	32.60	16.90	7.56	8.78
U_{DIF} (%)	4.8	2.9	1.8	1.8
E_n	**0.77**	**0.98**	**0.78**	**0.90**

Table 4. E_n number for phase displacement, at Sn=2.5VA and cos(φ)=1

***I*/*I*n**	**5 %**	**20 %**	**100 %**	**120 %**
g_{KSK} (%)	19.20	11.15	4.36	5.20
U_{KSK} (%)	3.9	28	1.6	16
g_{DIF} (%)	24.60	15.01	6.76	7.39
U_{DIF} (%)	4.4	3.0	1.8	1.8
E_n	**0.91**	**0.94**	**0.98**	**0.90**

In the given tables it is observed that the E_n number is between 0.77 and 0.98, which is close to 1. This is a consequence of the fact that measuring equipment used in both the KSK and DIF methods has almost identical metrological characteristics and therefore very close estimated measurement uncertainties. The stability of the artifact, as well as both measurement systems, is satisfactory, so the type A measurement uncertainty component in both cases was of the same order of magnitude.

V. CONCLUSIONS

One of the conditions for maintaining the accreditation of the Nikola Tesla Institute of Electrical Engineering's Laboratory, according to the SRPS EN/IEC 17025 standard, is the regular demonstration of competence through national and international inter-laboratory comparisons or proficiency testing schemes, and ensuring the validity of testing and calibration results. The goal of these activities is to confirm the credibility of the obtained measurement results and prevent the reporting of inaccurate measurement results by the accredited laboratory.

This paper presents the process of ensuring the validity of testing/calibration results through intra-laboratory comparison of two measurement methods for testing the accuracy of current measurement transformers. The object of testing, the artifact, was a conventional current transformer of accuracy class 0.5, which has time-stable errors verified through repeated testing. The results of the artifact testing using the measurement system based on the KSK method were declared as reference, and these were compared with the results obtained by testing the same artifact with the measurement system based on the DIF method.

The statistical method for calculating the E_n number and the criterion for satisfactory comparison results, i.e., $|E_n| \leqslant 1.00$, were used for processing the results of the intra-laboratory comparison. The evaluation of the results, which included the evaluation of measurement uncertainty, showed satisfactory E_n values for all measurement points in the comparison. This demonstrated the competence of the Institute's Laboratory, confirming that the laboratory possesses adequate measurement equipment, is familiar with the testing/calibration method, has qualified personnel, and is capable of appropriately assessing the measurement uncertainty of accuracy testing/calibration (amplitude and phase error measurement) of current transformers.

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