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CALIBRATION OF HIGH ACCURACY CLASS STANDARD CURRENT TRANSFORMERS

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Abstract – Main characteristic of high accuracy class current transformers is very small amplitude and phase errors (approximately 10 ppm). Such an error is a reason of complexity and sensitiveness of that metrological task. This paper presents a new method for high accuracy class current transformers calibration simultaneously with two different measuring apparatus. The method is presented as well as measuring scheme and calibration results. Estimation of uncertainty of measurement shows that this method has better results than separated calibration methods.

Keywords: current transformers, calibration, uncertainty of measurement

1. INTRODUCTION

According to the existing standards [1] instrument transformers are classified in five classes: 0,1; 0,2; 0,5; 1,0 and 3,0. Verification of metrological characteristics of these transformers assumes corresponding measuring equipment and standards with at least few times higher accuracy than transformers under testing. It means that errors of standard transformers must be less than ± 0,02% (200 ppm) for amplitude error and ± 2,0' (600 ppm) for phase error. In the recognized metrological system with the hierarchy of standards, accuracy of working standards is checked by higher-class standards (secondary, primary and national standards). Due to mentioned reasons, the errors of national and secondary standards must be less than 0,005% (50 pap) for amplitude error and ± 0,2' (60 pap) for phase error. An assessed value of these errors has the level of about 10 ppm. Amplitude and phase errors of these standards can be measured with high accuracy about few ppm but only for the transformation ratio 1:1. This is so called auto-calibration method that does not require usage of other standards transformer with higher accuracy class. Because of the same current in secondary and primary winding, measured amplitude and phase errors are actually inherent errors of standard current transformers under testing. Experimental measurement of errors for transformation ratio different from the ratio 1:1 can be realised in two ways. The first one is by the comparison of the tested current transformer with the other standard transformer with the same transformation ratio. Amplitude and phase errors of standard transformer mention above have to be the same or lower then tested one. The second way is indirectly by comparison with transfer standard [2].

Mentioned comparison is usually realised as intercomparison between different laboratories. Therefore, in the case of unequal measuring conditions, deviations between results from different laboratories may appear.

Using simultaneous calibration method presented in this paper, this problem can be eliminated. During simultaneous measurement, certain influence can be neglected and as a consequence measurement accuracy and reliability can be increased additionaly [3].

2. MEASURING METHODS

Differential method and current comparator method are usually used for the calibration of standard current transformers.

1.1. Differential method

The differential method assumes that there is a reference standard current transformer T_N with transformer ratio n_N equal to the rated ratio n_X of the current transformer T_X being verified. It measures the differential voltage $\underline{U}_d$, i.e. the differential current $\Delta\underline{I}$. This current is compared to the secondary current $\underline{I}_R$ (or secondary voltage) in order to determine the complex error $\underline{G}$ of the tested transformer T_X. Complex error i.e. value of amplitude and phase error is measured by complex compensator.

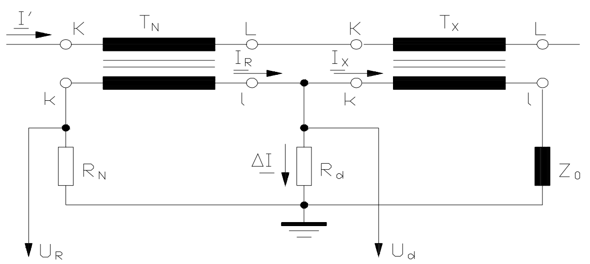

Fig.1. Differential method for calibration of current transformers

2.2 *Current comparator method*

The method of the compensated current comparator (CCC) [4] permits the current comparator to replace the reference transformer and primary current source. As shown in Fig. 2, the current comparator is supplied from a controlled current source I_{2N} on the secondary winding side N_2. In the primary winding of the comparator, N_1, and the primary winding of the current transformer under test, T_X, a current I_1 is flowing which induces current I_{2X} in the secondary of the tested transformer. In order to secure the transfer of energy from the secondary to the primary, it is necessary for the current transformer to have a corresponding magnetic circuit. This role is played by the magnetic shield, which has a dimension sufficient to transfer the rated power (order of 2 kW). The magnetic shield, therefore, has a double function. Thus, this current transformer transforms the secondary current into the primary with a given, non-negligible error.

The basic idea behind this device is that the compensation winding, N_k, with its current, I_k, almost completely compensates this error. The compensation winding of large cross section copper wire has low impedance and presents a nearly ideal current loop through which flows the error current of the current comparator, but also the error current of the transformer under test. The detection winding voltage reflects only the current error I_G of the tested transformer. This is nullified by the feedback loop current I_G', placing the measurement core into a state of zero magnetic flux. This current is in correspondence with the complex error of the tested transformer, which is measured by the complex compensator.

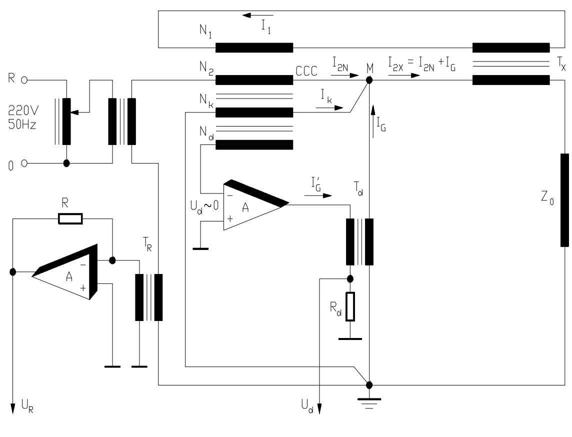

Fig. 2. Compensated current comparator method for calibration of current transformers

2.3 *Simultaneous calibration method*

Calibration of standard current transformers is usually performed using two independent methods in different time intervals. This way of comparison does not provide completely the equal conditions of measurement in a sense of outdoor influences. Simultaneous calibration method, fig. 3, solves the problems of external influences.

Compensated current comparator is a current supply for elements in both methods (differential and current comparator). A common element of both methods is current transformer under test T_X. Secondary circuit of transformer T_X is connected with both devices for transformer accuracy testing "2767" (differential method) and "INST-2A" (compensated current comparator method). Both devices are based on microprocessor, and data processing of signals measured by different methods are performing within them. Device type "INST-2A" is connecting with PC by serial connection RS232, and device type "2767" by parallel connection IEEE488. For this simultaneous measurement, special software is developed for conduction of measurement, result representation and final data processing.

3. APPLIED MEASURING DEVICES

Current transformer under test is current transformer with electronic errors compensation, type EST-5000, produced in the Electrical Engineering Institute "Nikola Tesla", with rated amplitude error ± 0,005% (50 ppm) and phase error ± 0,1' (30 ppm). In both methods, applied measuring devices have the similar metrological characteristics, but different manufacturers.

Devices applied in compensated current comparator method are developed and realized in Electrical Engineering Institute "Nikola Tesla". As standard current transformer, the compensated current comparator type KSK-1000 is used. Its rated metrological characteristics are: amplitude error ± 0,001% (10 ppm) and phase error ± 0,05' (14,7 ppm). Rated accuracy of the microprocessor based device for transformer accuracy testing type INST-2A is ± 0,2% of measured value and ± 0,002% for amplitude error measurement and ± 0,2% of measured value and ± 0,01' for phase error measurement [5].

Devices used in differential method have been manufactured by "Tettex Instruments". Standard current transformer is current transformer with electronic compensation of errors type 4764. Its rated amplitude error is ± 0,001% (10 ppm) and rated phase error is ± 0,05' (14,7 ppm). The device for transformers accuracy testing, type 2767 measures errors of current transformer under test. Rated accuracy of this device is ± 0,5% of measured value ± 10 ppm ± 1 digit for amplitude error measurement and ± 0,5% of measured value ± 0,034' (10 ppm) ± 1 digit for phase error measurement. Standard current transformer type 4764 has a valid certificate of calibration issued by manufacturer. It is directly traceable to the standards of PTB (Pysikalishe Technische Bundesanstalt).

4. CALIBRATION RESULTS

Calibration of current transformer type EST-5000 is realised in the Electrical Engineering Institute "Nikola Tesla" Calibration Laboratory. Provided testing conditions were: ambient temperature from 19ºC to 22ºC, relative humidity from 30 % to 35 %, atmosphere pressure from 95 kPa to 105 kPa, frequency 50 Hz ± 1 Hz, distortion of network voltage less than 5 %. Transformation ratios of 5A/5A and 100A/5A were calibrated at rated burden (5,0 VA) and at real burden of measuring installation (0,0 VA).

Calibration certificate for standard current transformer "4764" is issued for referent currents: 5% I_n, 10% I_n, 20% I_n, 50 % I_n, 100 % I_n, 120 % I_n and 200 % I_n, (I_n is a rated current). Simultaneously calibration is also provided for these referent currents.

A calibration result is given in tables 1 and 2. Abbreviation in table 1 and 2 means: KSK - compensated current comparator method and DIF - differential method.

It is obvious from tables 1 and 2 that amplitude error differences between KSK and DIF methods are greater at lower values of referent current (5% I_n). This is probably the result of electromagnetic influences, offset and electronic drifts of applied measuring instruments. Phase error differences between the two methods are greater for 5 A primary current (max difference is -8.7 min) than for 100 A primary current (max difference is -5.5 min). This effect is caused by capacitive currents influence on phase error of a current transformer.

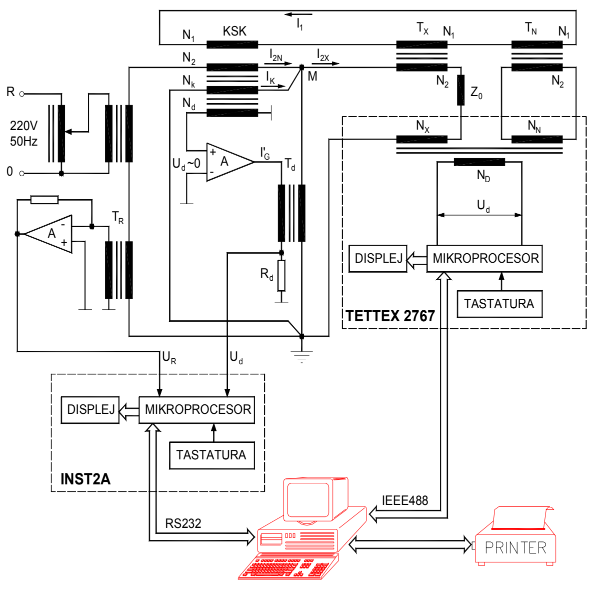

Fig. 3. Simultaneous calibration method

5. UNCERTAINTY OF MEASUREMENT ESTIMATION

For both differential and compensated current comparator methods, mathematical models of amplitude and phase errors are the same. Mathematical model for amplitude error is:

$$g_{aTx} = g_{aM} + g_{aRS} + \Delta g_{aD} + \Delta g_{aDrez} + \Delta g_{aBur} + \Delta g_{aIref} \quad (2)$$

Abbreviations and symbols that used in this equation are: g_{aTx} is real error of current transformer under test T_X; g_{aM} is measured amplitude error of transformer T_X; g_{aRS} is amplitude error of applied (corresponding) reference standard current transformer; Δg_{aD} is measurement error of applied device for transformer accuracy testing, Δg_{aDrez} is an error caused by the resolution of applied device for transformer accuracy testing; Δg_{aBur} is an error due to the applied burden and Δg_{aIref} is an error due to reference current measurement.

Measurement of phase error can be described as:

$$g_{\delta Tx} = g_{\delta M} + g_{\delta RS} + \Delta g_{\delta D} + \Delta g_{\delta Drez} + \Delta g_{\delta Bur} + \Delta g_{\delta Iref} \quad (3)$$

Abbreviations and symbols used in equation 3 are: $g_{\delta Tx}$ is real error of current transformer under test T_X; $g_{\delta M}$ is measured phase error of transformer T_X; $g_{\delta RS}$ is phase error of applied (corresponding) reference standard current transformer; $\Delta g_{\delta D}$ is error of phase error measurement of applied device for transformer accuracy testing, $\Delta g_{\delta Drez}$ is an error caused by the resolution of applied device for transformer accuracy testing; $\Delta g_{\delta Bur}$ is an error due to the applied burden, $\Delta g_{\delta Iref}$ is an error due to reference current measurement.

It is obvious from equations 2 and 3 that the sources of uncertainty of measurement are different and complex. In this analysis the most important components are considered below.

Contribution to the standard uncertainty caused by repetition of measurement assigned as $u_1 = u(g_{aM})$, type A, has a Gauss distribution.

Contribution to the standard uncertainty due to amplitude error of applied reference standard current transformer, assigned as $u_2 = u(g_{aRS})$, type B, has a rectangular distribution.

Contribution to the standard uncertainty due to error of amplitude error measurement of applied reference device for current transformer accuracy testing , assigned as $u_3 = u(g_{aD})$, type B, has a rectangular distribution.

Contribution to the standard uncertainty due to resolution of amplitude error measuring by applied reference device for current transformer accuracy testing , assigned as $u_4 = u(g_{aDrez})$, type B, has a rectangular distribution.

Contribution to the standard uncertainty due to error of applied burden, assigned as $u_5 = u(g_{aBur})$, type B, has a rectangular distribution.

Contribution to the standard uncertainty caused by reference current I_{ref} measurement, assigned as $u_6 = u(g_{aIref})$, type B, has a rectangular distribution.

Contributions to the standard uncertainty of amplitude error are equal as for the phase error measurement. There are assigned respectively from u_7 to u_{12}.

Combined uncertainty of measurement for amplitude error is calculated using equation 4.

$$u_c(g_{aTx}) = \left[\sum_{i=1}^{6} (c_i \cdot u_i(g_{ai}) \right] \quad (4)$$

Combined uncertainty of measurement for phase error is calculated using equation 5.

$$u_c(g_{\delta Tx}) = \left[\sum_{i=1}^{6} (c_i \cdot u_i(g_{\delta i}) \right] \quad (5)$$

Sensitivity factors c_i in equations 4 and 5 are equal to 1 except for c_5, c_6, c_{11} and c_{12}. These factors are calculated from characteristics of amplitude and phase error for tested transformer, as a function of reference current and applied burden [6]. Factors c_5, c_6, c_{11} and c_{12} have to be calculated for each measuring point according to [1], i.e. for 5%, 20%, 100%, 120% and 200% of reference current at the same burden.

In simultaneous calibration method current supply is equal for both apparatus as well as applied burden. Through the both apparatus (apparatus for differential method and apparatus for compensated current comparator method) circulate the current of the same value. Owing to that, influences of reference current and burden on measuring errors are equal for both methods. Thus, components of uncertainty of measurement due to reference current and common burden can be neglected. Consequently, calculation of sensitivity factors c_5, c_6, c_{11} and c_{12} is not necessary.

Table 1. Calibration results for transformation ratio 5A/5A (in ppm)

5A/5A		Method				Difference	
S_n	$\%I_n$	KSK		DIF		KSK-DIF	
		p_i	δ	p_i	δ	p_i	δ
0VA (2VA)	5	0	-5.8	2	-7.9	-2	2.1
	10	0	-2.1	1	0.9	-1	-3.0
	20	0	-0.6	0	3.8	0	-4.4
	50	0	0.0	1	5.3	-1	-5.3
	100	0	0.1	0	6.5	0	-6.4
	120	0	-1.0	0	5.6	0	-6.6
	200	0	-2.3	-1	5.0	1	-7.3
5VA	5	1	6.6	3	4.7	-2	1.9
	10	2	9.9	2	12.1	0	-2.1
	20	2	11.4	2	15.9	0	-4.5
	50	1	12.4	2	18.5	-1	-6.1
	100	1	12.5	2	19.7	-1	-7.2
	120	1	11.9	1	19.4	0	-7.5
	200	1	10.4	2	19.1	-1	-8.7

Table 2. Calibration results for transformation ratio 100A/5A (in ppm)

100A/5A		Method				Difference	
S_n	$\%I_n$	KSK		DIF		KSK-DIF	
		p_i	δ	p_i	δ	p_i	δ
0VA (2VA)	5	8	-5.8	-1	-0.3	9	-5.5
	10	6	-1.5	9	-3.5	-3	2.1
	20	5	0.8	7	-1.5	-2	2.2
	50	4	2.1	6	0.0	-2	2.1
	100	3	2.4	5	0.6	-2	1.8
	120	3	2.0	5	0.0	-2	2.0
	200	2	0.8	4	-0.6	-2	1.4
5VA	5	7	6.3	11	3.2	-4	3.1
	10	6	10.3	9	8.2	-3	2.1
	20	4	12.0	6	10.6	-2	1.4
	50	3	13.4	5	12.1	-2	1.4
	100	1	12.4	4	12.1	-3	0.3
	120	1	12.0	3	11.5	-2	0.5
	200	0	11.2	2	10.6	-2	0.6

Based on the analysis of measurement errors and the applied instructions for expression of uncertainty in measurement [7], it has been established that the estimation of the combined uncertainty of measurement is based on contributions of uncertainty due to resolution of applied devices and due to accuracy of applied reference standards and devices. Reduction of uncertainty of measurement obtained applying this method has been experimentally approved. Calculated uncertainty budgets for amplitude and phase errors are given in tables 3 and 4.

Table 1. Uncertainty budget for amplitude error (in ppm)

Quantity	Standard uncertainty	Distribution	Sensitivity coeficient	Uncertainty contribution
g_{aRS}	5.8	rectangular	1	5.8
Δg_{aD}	from 11.5 to 103.9	rectangular	1	from 11.5 to 103.9
Δg_{aDrez}	0.6	rectangular	1	0.6
Coverage factor:	k=1.65	Coverage: 95%	Expended uncertainty: from 21.3 to 171.7	

Table 1. Uncertainty budget for phase error (in ppm)

Quantity	Standard uncertainty	Distribution	Sensitivity coeficient	Uncertainty contribution
g_{fRS}	8.5	rectangular	1	8.5
Δg_{fD}	2.9	rectangular	1	2.9
Δg_{fDrez}	0.6	rectangular	1	0.6
Coverage factor:	k=1.65	Coverage: 95%	Expended uncertainty: 14.9	

6. CONCLUSION

According to the tables 1 and 2, deviations between results are from – 2 ppm to 9 ppm for amplitude error and from – 9 ppm to 3 ppm for phase error. These differences are calculated for large extent of referent currents from 5 % I_n to 200 % I_n and for applied burden of 2 VA and 5 VA. These differences are lover than estimated measuring uncertainty of measuring standards and devices used in simultaneous calibration method. Considered measuring method could be also of great interest for the intercomparison of current transformers standards.

REFERENCES

[1] IEC 60044-1 Instrument Transformers – Part 1: Current Transformers, Edition 1.2, 2003-02

[2] S.A.C. Harmon, L.C.A. Henderson, A.J. Wheaton, ″Comparison of the Measurement of Current Transformers EUROMET Projects 473 and 612″, *CPEM*, Conference Digest pp 546-547, Ottawa Canada, 2002.

[3] D. Naumovic-Vukovic, S. Škundric, "Calibraton of apparatus for accuracy testing instrument transformers" Electrical Engineering Institute "Nikola Tesla", Digest of papers, vol. 18, pp 195-204, Belgrade, 2007. (YU ISSN 0350-8528); (D. Naumovic-Vukovic, S. kundric "Etaloniranje merne aparature za ispitivanje tačnosti mernih transformatora", Elektrotehnički institut „Nikola Tesla", Zbornik radova, vol. 18, str. 195-204, Beograd, 2007. (YU ISSN 0350-8528))

[4] W. J. M. Moore, P. N. Miljanić, *The Current Cimparator*, P.Peregrinus Ltd, 1988, London

[5] S.Škundrić, D.Kovačević, D.Naumović-Vuković, "The Role and Importance of software application in instrument transformers accuracy testing", *XVIII World Congress*, 2006, TC-4, Rio de Janeiro, Brazil, Sept. 2006.

[6] D. Naumović-Vuković, S. Škundrić, R. Dereta, „Uncertainty of measurement for current transformers callibration in Electrical Engineering Institute "Nikola Tesla" Laboratory", *Serbian Congress of Metrology*, Digest of papers, pp. 385-394, Zlatibor, Srebia, Sept. 2007. (D. Naumović-Vuković, S. Škundrić, R. Dereta, „Merna nesigurnost etaloniranja strujnih mernih transformatora u Laboratoriji Elektrotehničkog instituta „Nikola Tesla", Kongres Metrologa, Zbornik radova, str. 385-394, Zlatibor, septembar 2007.)

[7] SO, *Guide to the expression of uncertainty in measurement*, Int. Org. for Standardization, Geneva, Switzerland, 1993.