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CALIBRATION OF INSTRUMENT CURRENT TRANSFORMERS WITH ATYPICAL SECONDARY CURRENT

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Abstract – Methods enabling a determination of errors ε_I and δ_I for a high transformation ratio difference between a standard and tested instrument current transformers (ICT) are described in this article. A widespread method uses an automatic transformer test set for the measurement of a difference between a standard and tested ICT. A method transforming secondary currents to voltages and an indirect method using error measurement from magnetizing current are also described.

Keywords: current transformer, errors, lock-in amplifier

1. DESCRIPTION OF USED METHODS

Majority of ICT has a normalized secondary current I_{2N} = 5 A or 1 A. Comparison methods described in [1], [2] and [3] are used for ICT testing. These methods enable to determine a deviation between a standard and tested ICT given by a ratio error ε_I and phase displacement δ_I. By means of a frequently used automatic transformer test set it is possible to compare ICTs with different transformation ratio. The simplified arrangement of measurement is in Fig.1.

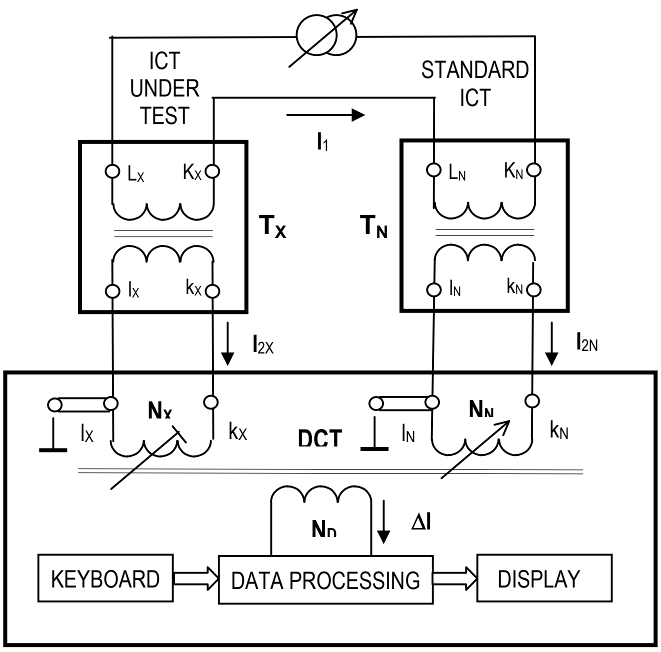

Fig.1. Method with an automatic transformer test set.

The secondary circuit of the tested and standard ICT are connected to the primary windings of the differential current transformer DCT. The ratio of secondary currents and the number of DCT windings must fulfill the condition

$$N_X / N_N = I_{2N} / I_{2X}\ . \qquad (1)$$

The possibility to change the DCT winding number N_X and N_N allows ICT testing with different ratios and different secondary currents in a defined range. The typical parameter of the test set described in [2] is $0.5 \leq I_{2N}/I_{2X} \leq 100$ in the range of secondary current I_{2X} = 0,1 A up 5 A. In this case the maximum accuracy is preserved. If $100 < I_{2N}/I_{2X} < 500$ and secondary current $I_{2X} \leq 0{,}1$ A the test set operates with reduced accuracy. The range of secondary currents I_{2X} and I_{2N} is 50 mA up to 5 A.

It is evident that by a big difference of transformation ratio of both ICT the accuracy of these methods decreases.

A principle of another method for ICT testing with different secondary currents is obvious from a block diagram in Fig.2.

The ICT under test T_X and a standard T_N have the same values of rated primary current $I_{1X} = I_{1N}$. The ICT under test T_X is loaded by a real rated burden R_X and the standard T_N is loaded by a precise resistor R_N. If the resistor R_N is chosen so that

$$R_N = R_X . p_N / p_X, \qquad (2)$$

where $p_N = I_{1N}/I_{2N}$ is transformation ratio of standard ICT,
$p_X = I_{1X}/I_{2X}$ transformation ratio of tested ICT,

then by zero or equal errors T_X and T_N is $U_{2X} = U_{2N}$.

If errors of tested transformer T_X compared with the standard transformer T_N are small, phasors U_{2X} and U_{2N} differ only slightly in magnitude and phase shift. The difference voltage can be expressed as

$$\Delta\boldsymbol{U} << \boldsymbol{U}_{2X}; \quad \Delta\boldsymbol{U} << \boldsymbol{U}_{2N}. \qquad (3)$$

According to the phasor diagram in Fig.3 it is possible to consider the phasors $\mathbf{U}_{2X}$ and $\mathbf{U}_{2N}$ as parallel and the errors of tested transformer to express as

$$\varepsilon_I = \frac{\Delta U_\varepsilon}{U_{2N}} = \frac{\Delta U}{U_{2N}} cos\varphi\ ; \quad \delta_I = \frac{\Delta U_\delta}{U_{2N}} = \frac{\Delta U}{U_{2N}} sin\,\varphi\ , \qquad (4)$$

where ΔU and φ is differential voltage and its phase shift

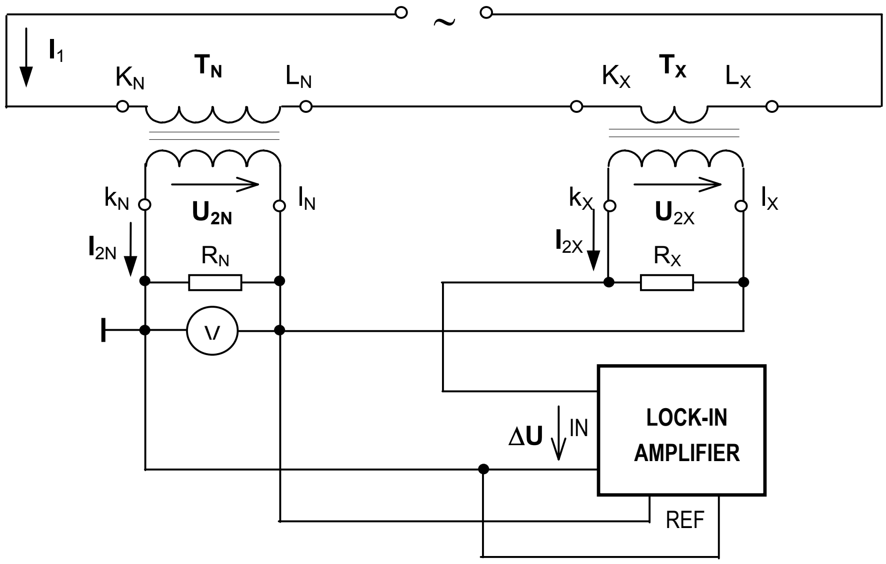

Fig.2. Principle of comparison method

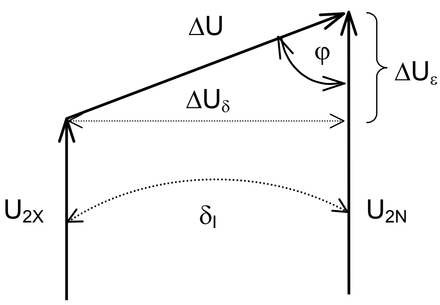

Fig.3. Part of phasor diagram

related to the voltage U_{2N}.

A lock-in amplifier on whose reference input is applied U_{2N} is used for their measurement. A character of the error ε_I will be determined from the sign of the phase shift φ so that the positive error corresponds plus sign of φ and conversely.

In a special case an indirect method according to Fig.4 can be used for ICT error determination. Secondary winding

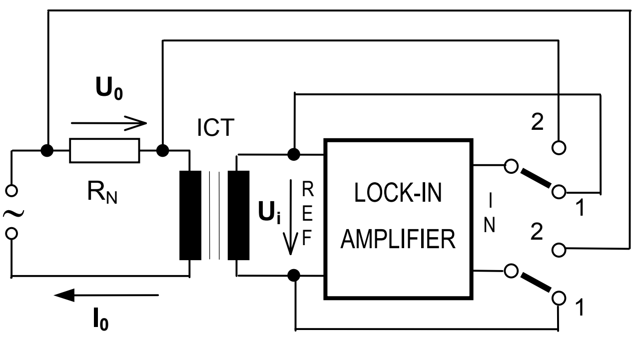

Fig.4. Principle of indirect method

of ICT is not loaded and it is connected to the reference input of a lock-in amplifier. By the switching a switch to position 1 the voltage U_i is brought on the lock-in amplifier input 1 and its magnitude will determined from the formula

$$U_I = \frac{I_1}{p_I}\sqrt{(R_2 + R_B)^2 + X_B^2}\ , \qquad (5)$$

where U_i is secondary open-circuit voltage corresponding to the primary current I_1, $p_I = I_1/I_2$ is transformation ratio, R_2 is the resistance of ICT secondary winding N_2, $R_B = B \cos\psi$ is real component of the burden B and $X_B = B \sin\psi$ is imaginary component of the ICT burden **B**, ψ je phase shift of burden.

The voltage U_i is adjusted by regulation of magnetizing current I_0. After switching the switch to the position 2 the magnitude of the voltage U_0, corresponding to the current I_0, and its phase shift β are measured. If errors of tested ICT are small, then in the phasor diagram in Fig.5 $N_1I_0 << N_1I_1$ and $N_1I_0 << N_2I_2$ (N_1 and N_2 is number of primary and secondary

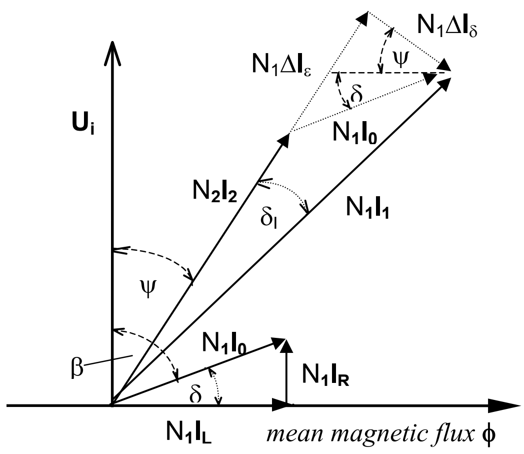

Fig.5. Phasor diagram

turns, I_1 and I_2 is primary and secondary current). So the ratio error and the phase displacement can be expressed as

$$\varepsilon_I = -\frac{N_1 \Delta I_\varepsilon}{N_1 I_1} = -\frac{N_1 I_0}{N_1 I_1}\sin(\delta+\psi) = -\frac{U_0}{R_N I_1}\sin\left(\frac{\pi}{2}-\beta+\psi\right)$$

$$\delta_I = \frac{N_1 \Delta I_\delta}{N_1 I_1} = \frac{N_1 I_0}{N_1 I_1}\cos(\delta+\psi) = \frac{U_0}{R_N I_1}\cos\left(\frac{\pi}{2}-\beta+\psi\right) \quad (6)$$

This method can be used only for ICT, which does not have any error compensation. By adjusting of the voltage U_I corresponding to the current I_1 according to (5) any influence of leakage inductance is not respected.

2. RESULTS OF MEASUREMENT

Errors of an ICT GOERZ type 4432 were measured by means of above mentioned methods. The transformation ratio of this ICT p_I = (0,2; 0,5; 1; 2; 5; 10; 20; 50 and 100) A/0,05 A. The rated burden is B = 70 Ω real and the DC resistance of secondary winding R_2 = 20 Ω. Ratio error and phase displacement were measured for the transformation ratio 100 A/0,05 A and real burden 70 Ω.

The current comparator Tettex 4764 with the set ratio 100 A/1 A served as a standard and the automatic transformer test set Tettex 2767 was used for error evaluation by the measurement performed according to the Fig.1. The on the test set adjusted transformation ratios were I_{PX}/I_{SX} = 100 A/0,05 A and I_{PN}/I_{SN} = 100 A/1 A.

The current comparator Tettex 4764 with the set ratio p_N = 100 A/5 A loaded with a standard resistor R_N = 0,1 Ω was used by the measurement method according to the Fig.2. The transformation ratio of the ICT under test was p_X = 100 A/0,05 A and its secondary winding was loaded with a standard resistor R_X = 10 Ω connected serially with a resistor R = 60 Ω so that the total burden corresponded with the rated burden R_B = 70 Ω. The values of R_N, R_X, p_N and p_X corresponded with the equation (2).

The error determination by means measurement of a no-load current was carried out according to the Fig. 3. Values of secondary voltage corresponding with the primary current were calculated according to (5) for R_2 = 20 Ω; R_B = 70 Ω; X_B = 0.

The lock-in amplifier Stanford Research SRS 830 was used for error measurement according to the Fig. 2 and 4. The error dependence was measured for (120; 100; 50; 20 and 10) % I_{1N}. The measured results are in Table 1.

TABLE I. Measurement results of ICT errors.

I_1 [% I_{1R}]	Method see Fig.1		Method see Fig.2		Method see Fig.4	
	ε [%]	δ [′]	ε [%]	δ [′]	ε [%]	δ [′]
120	+0,012	-0,21	+0,013	-0,57	-0,113	-5,3
100	+0,012	-0,20	+0,013	-0,55	-0,111	-5,6
80	+0,012	-0,17	+0,014	-0,52	-0,109	-5,9
50	+0,011	-0,18	+0,016	-0,52	-0,105	-6,1
20	+0,011	-0,14	+0,021	-0,51	-0,104	-7,1

3. CONCLUSIONS

All described methods were used for ICT GOERZ type 4432 calibration for the transformation ratio 100 A/0,05 A and real burden 70 Ω. By use of the transformer test set Tettex 2767 (see Fig.1) the secondary current rated value of the ICT under test was 0,05 A. This value represents the minimum value of measured current and the test set operates with a reduced accuracy.

The method using standard resistors and lock-in amplifier (see Fig.2) provides a sufficient sensitivity in the full range of measured currents. This method required a precise ratio of used resistors because a measurement error depends on this ratio directly.

The indirect method (see Fig.4) can be used only for ICTs without any correction of ratio error and phase displacement. From the results in the Table 1 it is obvious that the ICT under test is corrected. The correction of ratio error is performed by means of a secondary winding modification, the phase displacement correction by means an inductance connected to an additional secondary winding.

The measured results according to the Fig.1 and 2 show good agreement corresponding with an uncertainty of used resistors.

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