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Use of a Current Source for Calibrating an Automatic Transformer Test Set

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Abstract **-** This paper describes an innovative procedure for calibrating sets for evaluating instrument current transformer (ICT) errors. The innovation lies in the use of a current source for generating a measured current. There is an adjustable current source at 50 Hz mains frequency with a current transformer on its output. The internal impedance must be sufficiently high to eliminate the methodic error due to calibration. Calibration is carried out by means of a measuring system controlled by a PC through an IEEE 488 bus. Known values of the simulated ratio error and phase displacement are compared with the values measured by the device that is being tested. A software tool determines the simulated and measured error at each calibration point and determines whether the instrument that is being tested fulfils the parameters stated by the manufacturer.

I. Function and calibration of an automatic transformer test set

Ratio error and phase displacement are determined by a comparative method, the principle of which is shown in Figure 1. Calibrated and tested instrument current transformers (ICTs) with identical primary and secondary

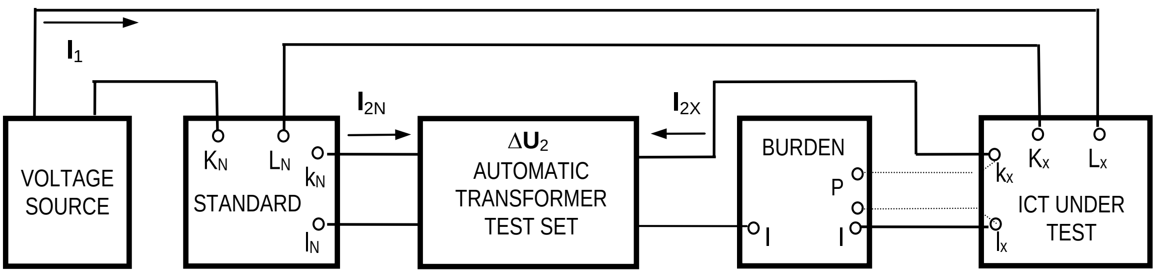

Figure 1. Basic layout for ICT calibration using a standard

currents are fed by a common current $\boldsymbol{I}_1$.
The secondary circuit of the ICT under test is loaded by an electronic or passive burden ***B***. The deviation $\Delta\boldsymbol{I}_2$ between secondary currents $\boldsymbol{I}_{2X}$ and $\boldsymbol{I}_{2N}$ expressed as differences in the ratio error $\Delta\varepsilon_I$ and phase displacement $\Delta\delta_I$ is evaluated by means of an automatic transformer test set (ATTS). ICT errors can be expressed as

$$\varepsilon_{IX} = \Delta\varepsilon_I + \varepsilon_{IN} \quad \delta_{IX} = \Delta\delta_I + \delta_{IN}\,, \tag{1}$$

where ε_{IX} and δ_{IX} are ratio error and phase displacement of an ICT under test (%; '),
ε_{IN} and δ_{IN} are ratio error and phase displacement of a standard ICT (%; ').

Relation (1) expresses that the uncertainty of ATTS affects the resulting uncertainty of the ratio error ε_{IX} and phase displacement δ_{IX}. Regular ATTS checks are therefore necessary.

A. Basic layout for automatic transformer test set calibration

The ATTS calibration principle is shown in the block diagram in Figure 2. Terminals for secondary currents $\boldsymbol{I}_X$ and $\boldsymbol{I}_N$ connecting "k_X", "l_X", "k_N" and "l_N" are connected serially and are fed by a common current $\boldsymbol{I}_2$, which corresponds to the rated value of the secondary current of the ICT under test $\boldsymbol{I}_X$ (e.g. 5 A). Zero readings of the ratio error $\Delta\varepsilon_I = 0$ and phase displacement $\Delta\delta_I = 0$ correspond to this situation in an ideal case. The ratio error and phase displacement are simulated by an additional current source $\Delta\boldsymbol{I}_2$ with adjustable magnitude and phase shift in relation to current $\boldsymbol{I}_2$.

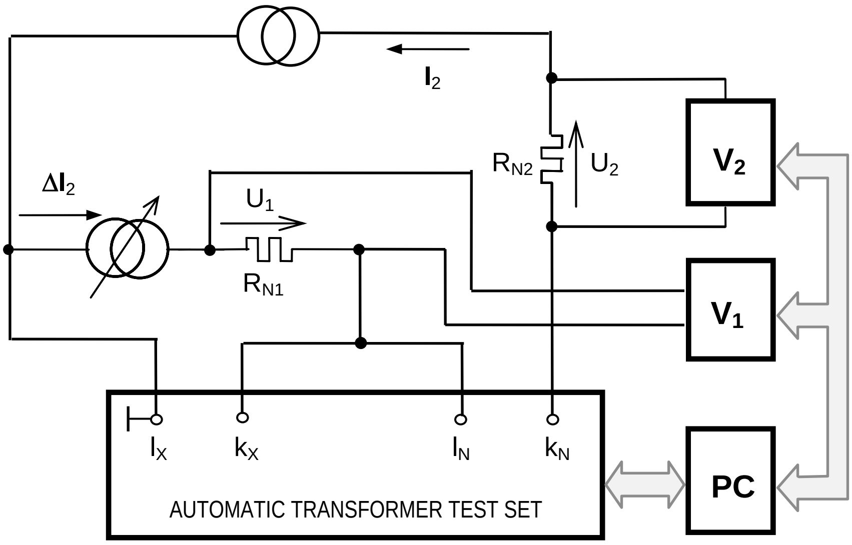

Figure 2. Simulation of errors by an additional current source

If the error current $\Delta\boldsymbol{I}_2$ is in phase with current $\boldsymbol{I}_2$, the phase displacement is zero and a ratio error is simulated, which can be expressed as

$$\varepsilon_I = \frac{\Delta I_{2\varepsilon}}{I_{2\varepsilon}} = \frac{U_{1\varepsilon}}{U_{2\varepsilon}} \frac{R_{N2}}{R_{N1}} \quad , \ (\delta_I = 0) \tag{2}$$

where $U_{1\varepsilon}$ and $U_{2\varepsilon}$ are voltages measured on pick-up resistors R_{N1} and R_{N2} when $\delta_I = 0$.

If current $\Delta\boldsymbol{I}_2$ is shifted by ±90° in relation to current $\boldsymbol{I}_2$, the ratio error is zero and only the phase displacement is simulated, which can be expressed as

$$\delta_I \doteq \mathrm{tg}\,\delta_I = \frac{\Delta I_{2\delta}}{I_{2\delta}} = \frac{U_{1\delta}}{U_{2\delta}} \frac{R_{N2}}{R_{N1}} \quad , \ (\varepsilon_I = 0) \tag{3}$$

where $U_{1\delta}$ and $U_{2\delta}$ are voltages measured on pick-up resistors R_{N1} and R_{N2} when $\varepsilon_I = 0$.
In the first phase, the current sources were realized by means of voltage sources with serial resistors. This arrangement is shown in Figure 3. The values of serial resistors are limited, so when this variant is used a

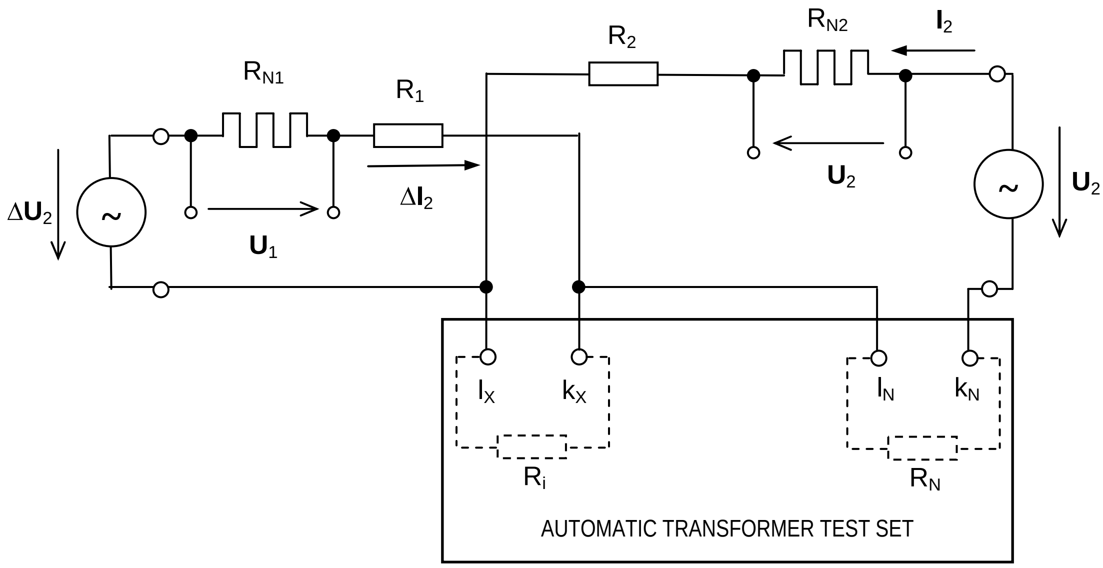

Figure 3. Arrangement of sources for a transformer test set calibration

methodic error arises when measuring currents $\boldsymbol{I}_2$ and $\Delta\boldsymbol{I}_2$. The magnitude of the methodic error depends on the value of resistors R_1 and R_2 connected serially to the voltage source and on the magnitude of inherent resistance R_i of the "X" input of the instrument transformer test set. The relative value of the methodic error with current $\boldsymbol{I}_2$ and $\Delta\boldsymbol{I}_2$ magnitude measurement given by the limited magnitude of resistors R_1 and R_2 can by expressed as

$$\delta(I_2) = \frac{R_i}{R_1}, \quad \delta(\Delta I_2) = \frac{R_i}{R_2}. \tag{4}$$

This error can be corrected by a calculation, but the methodic error can be removed by ensuring that the internal resistances of the current sources are as high as possible.
Using the solution according to Figure 3, it is necessary to select a resistor R_2 with a value of 50 Ω up to 100 Ω. The power dissipation at current 5 A is then 1 250 W up to 2 500 W. This condition is difficult to realize because of the great power dissipation on the resistors. This problem does not arise with a source of current $\Delta\boldsymbol{I}_2$ for error simulation, because the magnitude of $\Delta\boldsymbol{I}_2$ does not exceed 0.5 A for a simulated ratio error of 10 %. It is advantageous to use a current/voltage converter realized by means of an operational amplifier for generating $\boldsymbol{I}_2$ current.

B. Calibrating an automatic transformer test set by means of a current source with an operational amplifier

A connection of the voltage/current converter used for generating current $\boldsymbol{I}_2$ is shown in Figure 4. A current transformer CT must be used on the converter output to ensure a zero DC component of the output current $\boldsymbol{I}_2$. An operational amplifier OA in non-inverting connection controlled by voltage $\boldsymbol{U}_C$ serves as a source of current $\boldsymbol{I}_1$. The output current $\boldsymbol{I}_2$ feeding the ATTS can be expressed as

$$I_2 = p_I \frac{Uc}{R_1} = \frac{N_1}{N_2}\frac{Uc}{R_1}, \tag{5}$$

where p_I is transformation ratio, and N_1 and N_2 are numbers of primary and secondary turns of CT. CT is loaded on its secondary side with a standard resistor R_{N2}, which serves for measurement of the current $\boldsymbol{I}_2$, and with inherent resistances R_N and R_i (see Figure 3). The current $\Delta\boldsymbol{I}_2$ is led in to the "k_x" and "l_x" terminals and in this way the ratio error or phase displacement are simulated. The CT inherent impedance between terminals "A" and "B" must be big enough in comparison with resistance R_i to ensure that current component $\Delta\boldsymbol{I}_2'$ is negligible in comparison with current ΔI_2.

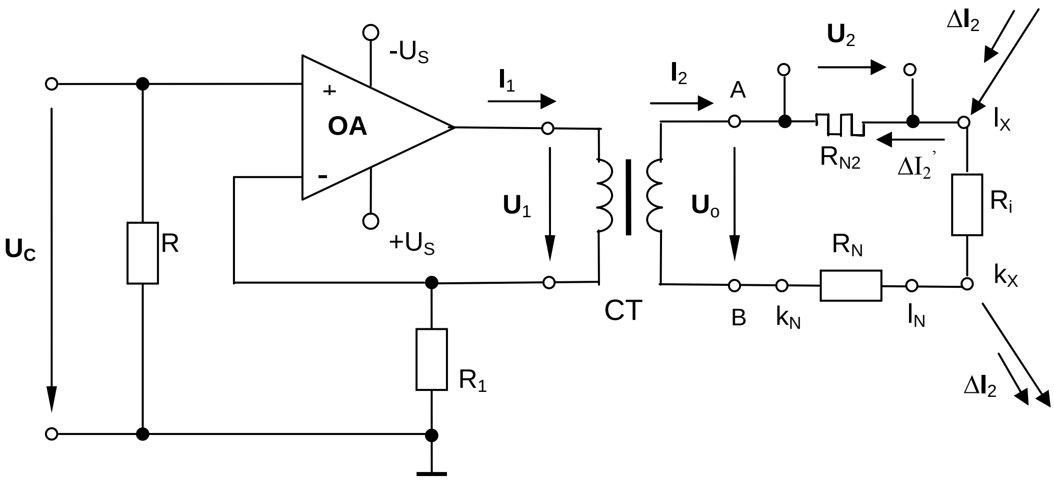

Figure 4. Converter for generation of the current I_2

The complete block diagram for ATTS calibration with a current source realized by means of a voltage/current converter (see Figure 4) is shown in Figure 5. The control voltage $\boldsymbol{U}_C$ of the converter is obtained from a lock-in generator synchronized with the 50 Hz mains. The lock-in generator output voltage $\Delta\boldsymbol{U}_2$ has continuously adjustable amplitude and phase in the range (0 up to 360)° related to voltage $\boldsymbol{U}_C$ and after amplification serves

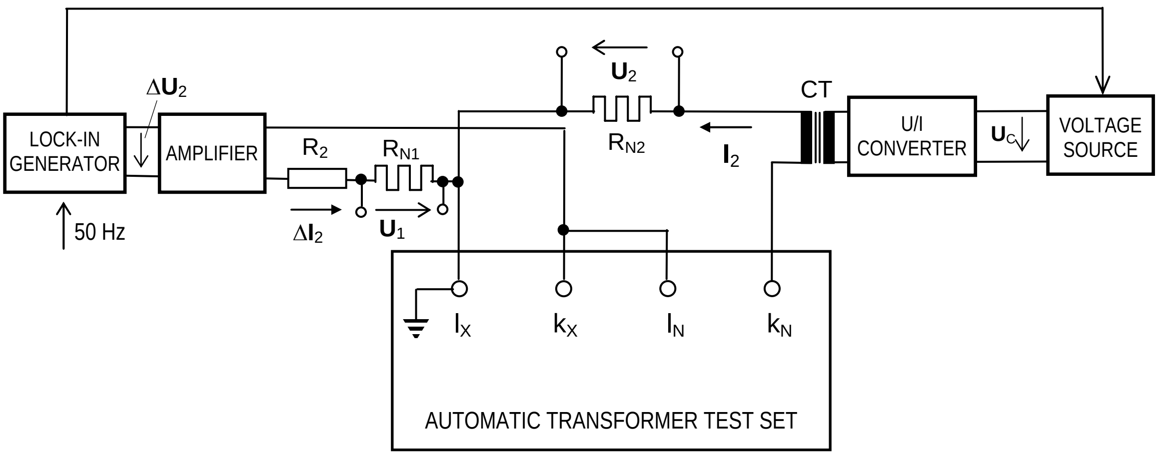

Figure 5. Arrangement of current sources for ATTS calibration

for generating the current $\Delta \boldsymbol{I}_2$ that is used for ratio error and phase displacement simulation. Voltages $\boldsymbol{U}_1$ and $\boldsymbol{U}_2$ are picked up by a measuring system (see Figure 2), and true values of the simulated ratio error and phase displacement are calculated from their values.

II. Conclusions

The system described here is used in the laboratories of the Czech Metrology Institute in Prague for calibrating the Tettex 2767 automatic instrument transformer test set. The system enables a measured current $\boldsymbol{I}_2$ to be generated in the range (0 up to 6) A. The error current simulates a flowing adjustable positive and negative ratio error in the range (0 up to 10) % and phase displacement in the range (0 up to 350) angle minutes of both polarities. The calibration process is controlled by a PC, as shown in Figure 2. The program enables the user to determine the uncertainty of simulated and measured errors, and to specify whether the system under test fulfils the parameters stated by the manufacturer. This work was supported by research program No. MSM6840770015.

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