EFFECT OF MAGNETIZATION ON INSTRUMENT TRANSFORMER ERRORS

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Errors of the instrument current and voltage transformers, caused by waveforms with non-zero DC component were measured and analyzed these are discussed in brief, for a case of nanocrystalline-tape-wound toroidal core.

Keywords: instrument transformer, ratio error, phase displacement, impulse magnetization, DC magnetization

1 INTRODUCTION

The use of instrument current and voltage transformers (ICT, IVT) requires harmonic waveforms of measured current or voltage with a zero DC component. The operating point of the ferromagnetic core moves along the dynamic hysteresis loop lying symmetric to the origin. A voltage or current waveform with a non-zero DC component, caused for example by a lightning strike, can magnetize the ICT or IVT cores in power grids. A similar case can occur when a distribution transformer with power greater than 500 kW is connected to AC supply and a DC current transient component takes effect. ICT errors as a consequence of magnetization depend on the magnetic properties of the transformer core, and are described in [1]. This paper describes the effect of magnetization on errors of ICT with nanocrystalline and Trafoperm cores. There is a description of the effect of magnetization due to a current impulse and due to the action of a steady DC component for ICT, and the effect of impulse magnetization of IVT obtained on the basis of measurement results.

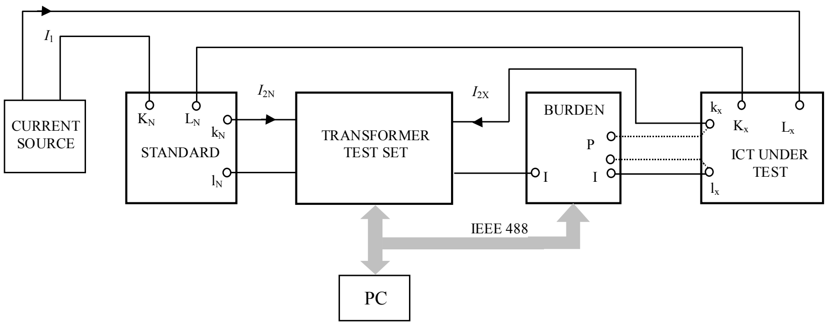

Fig. 1. ICT calibration using a comparative method

2 EVALUATION OF ICT ERRORS

The ratio error ε_I and the phase angle δ_I of an uncorrected ICT may be expressed according to [2] as

$$\varepsilon_I = -\frac{B_1 l \sin(\delta+\varphi)}{\mu_0 N_1 I_1 \mu_{ap}}, \quad \delta_I = \frac{B_1 l \cos(\delta+\varphi)}{\mu_0 N_1 I_1 \mu_{ap}}, \qquad (1)$$

where l represents the length of the mean magnetic path of a toroidal core, δ and μ_{ap} are the loss angle and the apparent permeability at the magnetic induction B_1, $N_1 I_1$ are primary amperturns, φ is the phase shift of the ICT burden, and $\mu_0 = 4\pi\times10^{-7}$ H/m.

A toroidal core wound with a tape made of a nanocrystalline material on an iron basis is nowadays widely used instead of mumetal type materials on a nickel basis [3]. It has similar values of μ_{ap} and δ as a mumetal, and it is substantially less dependent on mechanical stress. Nanocrystalline materials are also cheaper on the world market. Parameters, μ_{ap} and δ change during the core magnetization, so according to (1), the ICT errors also change [4]. The dependence of the ICT error on a core magnetization was measured with the layout as shown in Fig. 1.

The ratio error and the phase displacement are measured using a comparative method, when the ICT under test is compared with a standard [5], [6]. The primary windings of the standard and the ICT under test are connected in series; the secondary current is led into the transformer test set, where the deviation of the two currents is evaluated. The ratio error corresponds to its magnitude deviation, and the phase displacement corresponds to the phase shift of the two phasors. The burden of the ICT under test is connected in series with the evaluating set. A programmable electronic current burden was used, which enables 4-wire connection to eliminate lead resistance. The transformer test set evaluates the difference between the ICT under test and the standard errors. The errors of the tested ICT are given by the formula

$$\varepsilon_{IX} = \varepsilon_{ID} + \varepsilon_{IN}, \quad \delta_{IX} = \delta_{ID} + \delta_{IN}, \qquad (2)$$

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where, ε_{IX}, δ_{IX} are the ratio error and the phase displacement of the tested ICT; ε_{ID}, δ_{ID} are measured errors and ε_{IN}, δ_{IN} are errors of the ICT standard.

The measurement was performed at 50 Hz mains frequency. A Tettex 4764 current comparator with electronic error compensation was used as the standard, with a ratio error ε_{IN} that does not exceed 10 ppm and the phase displacement δ_{IN} does not exceed 0.05 angle minute. For error evaluation, we used the Tettex 2767 automatic transformer test set. The errors of the Tettex 2767 test set and the Tettex 4764 errors can be ignored.

Bias magnetization was provided by the secondary winding using a square current impulse. The layout shown in Fig. 2 was used for evaluating the effect of a constant DC current component I_{DC} on ICT errors. The auxiliary winding N_A was formed by two turns wound on the ICT toroidal core. The biasing (DC) component I_{DC} was generated using the layout shown in Fig. 2.

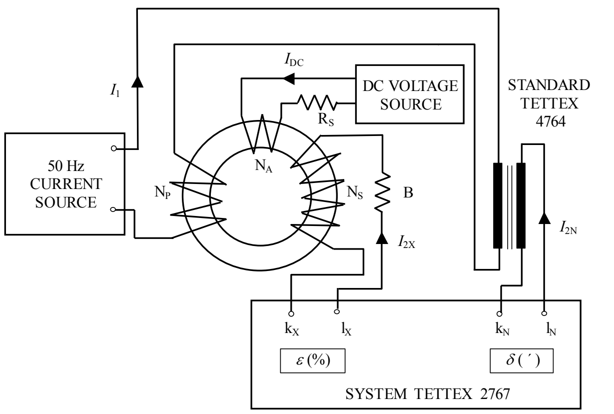

Fig. 2. Measurement of the dependence of transformer errors by sinewave current with dc component

The DC current component I_{DC} was generated by means of an adjustable voltage source with a serial resistor R_S. The magnitude of the resistor R_S was chosen so as not to change the reading of the errors measured by the test set when connecting R_S to the auxiliary winding N_A or when the voltage source output was short-circuited.

The effect of IVT magnetization was investigated only for the case corresponding to an impulse voltage waveform with a non-zero biasing component applied in the IVT primary circuit. The IVT was magnetized by a DC current into its secondary winding before measurement. This achieved the same effect as when a a DC impulse is applied to the primary circuit, which is difficult to perform. The effect of magnetization on IVT errors was measured by analogy, using a comparative method as in the case of ICTs.

3 RESULTS OF THE EXPERIMENT

The magnetizing effect of the ICT core was investigated using an ICT with a toroidal core made of nanocrystalline material. A core with dimensions Ø 140/100 mm, height 20 mm was placed in a protective cover on which were wound 50 turns of secondary winding for rated current I_{2N} = 5 A. The primary winding was realized by one turn for rated primary current I_{1N} = 250 A. All measurements were carried out at the following burdens: 1.836 VA, cosφ =1, and 5 VA, cosφ = 0.8 and 10 VA, cosφ = 0.8. First, in accordance with Fig. 1, ICT errors in the demagnetized state were measured in the range (120 up to 1) % of the primary current rated value I_{1N} at 50 Hz frequency. Magnetization corresponding to a bias (DC) impulse was performed into the secondary winding by a slow change of DC current from (0 up to 20 A), and back to zero.

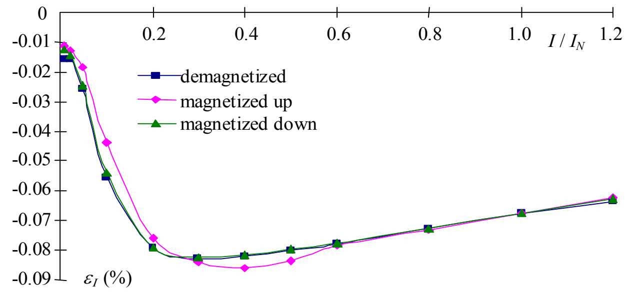

Fig. 3. Ratio error *vs* rated current at 1.836 VA, cosφ = 0

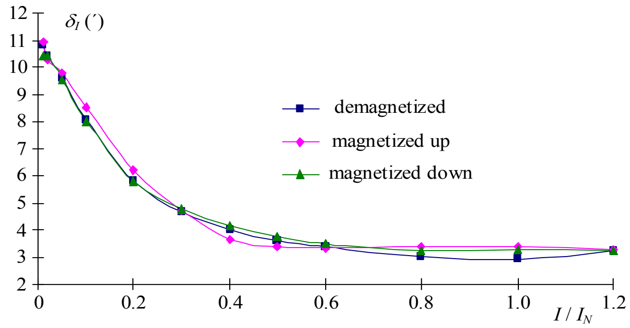

Fig. 4. Phase displacement *vs* rated current at 1.836 VA, cosφ = 0

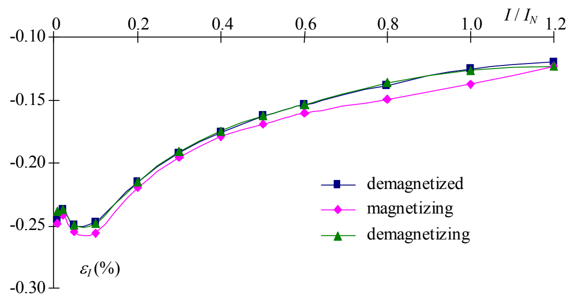

Fig. 5. Ratio error *vs* rated current at 5 W, cosφ = 0.8

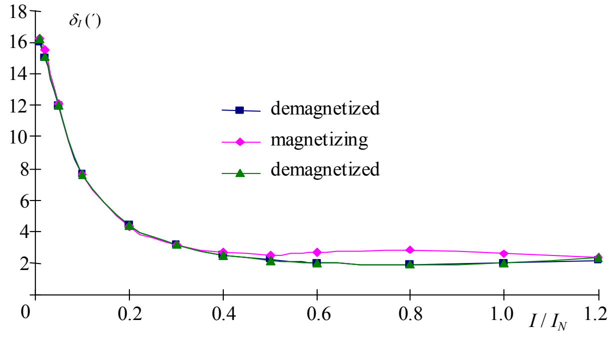

Fig. 6. Phase displacement *vs* rated current at 5 VA, cosφ = 0.8

The errors after magnetization were measured for gradually increasing AC current from 1% up to 120% of the rated value and then for current decreasing back to 1%. The measurement results are shown in Fig. 3 to Fig. 8.

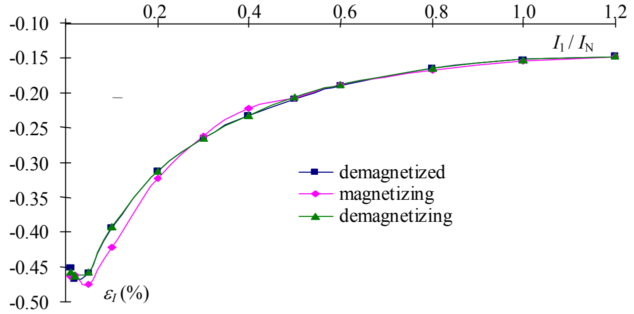

Fig. 7. Ratio error *vs* rated current at 10W cosφ = 0.8

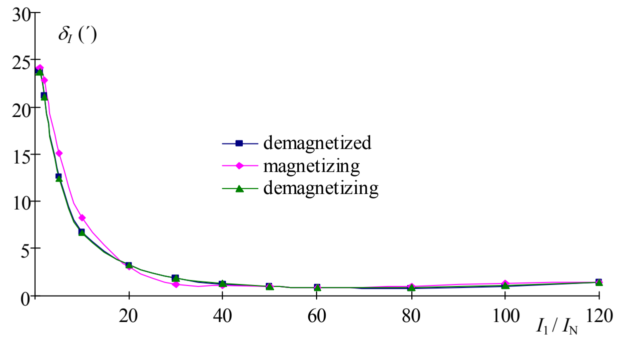

Fig. 8. Phase displacement *vs* rated current at 10VA, cosφ = 0.8

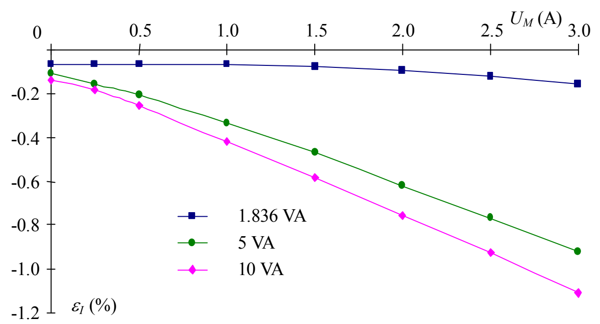

Fig. 9. Ratio error *vs* magnetic voltage at 100 % rated current

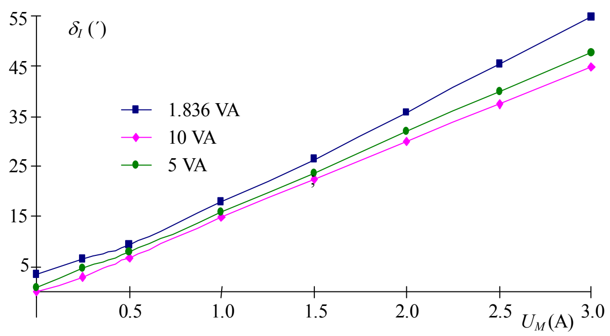

Fig. 10. Phase displacement *vs* magnetic voltage at 100 % rated current

The effect of the constant DC current component on the ICT errors was measured in the layout shown in Fig. 2. The auxiliary winding N_A was formed by two turns, and the serial resistor R_S had a value of 40 Ω. Connecting R_S to the auxiliary winding N_A had no influence on the magnitude of the errors. The effect of the DC component was measured at all burdens and two values of AC primary current I_1: $I_1 = I_{1N}$ and $I_1 = 0.1\, I_{1N}$. The results are shown in Fig. 9 to Fig. 12. The value corresponding to the DC component of the current I_{DC} is given by the magnetic potential $U_{MDC} = N_A I_{DC}$.

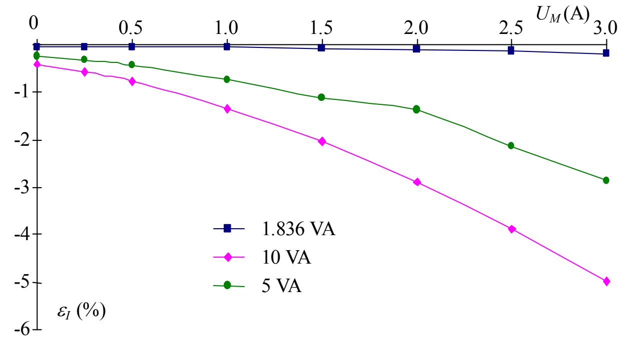

Fig. 11. Ratio error *vs* magnetic voltage at 10 % rated current

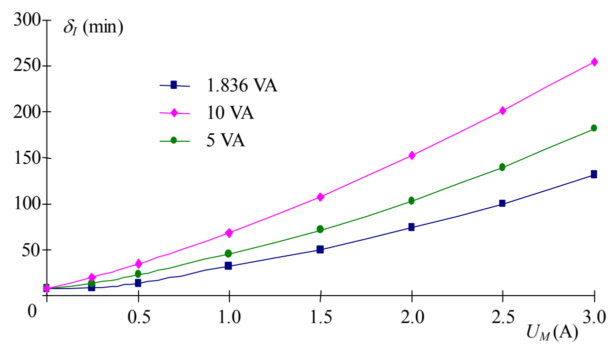

Fig. 12. Phase displacement *vs* magnetic voltage rated current at 10 % rated current

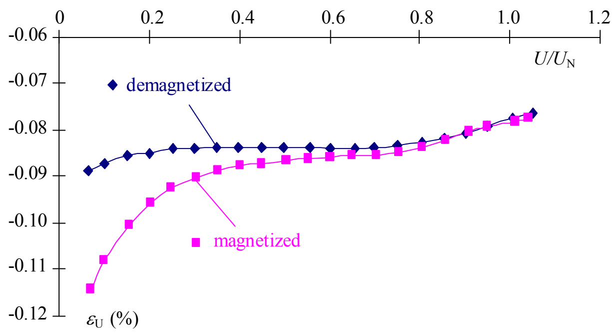

Fig. 13. Ratio error *vs* rated voltage

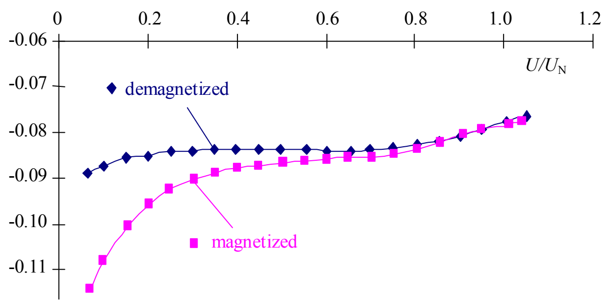

Fig. 14. Phase displacement *vs* rated voltage

When IVT is connected in a power grid, magnetization can occur due to a voltage impulse in the primary circuit. Magnetization with a constant DC voltage component is practically impossible.

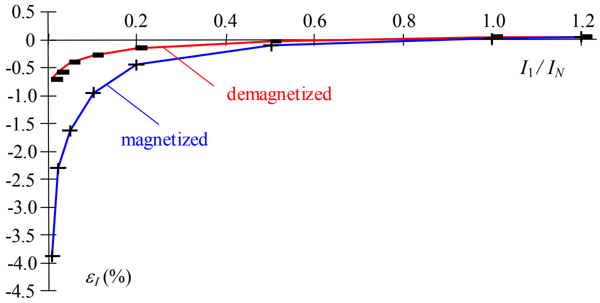

Fig. 15. Ratio error ε_I of ICT with Trafoker core (I_{1N}=50A, I_{2N} = 5A, burden 15W, $\cos\varphi$ = 0) as a function of applied primary current I_N (measured while demagnetizing from 1.2 I_{1N} → 0 and magnetizing from 0 → 1.2 I_{1N}).

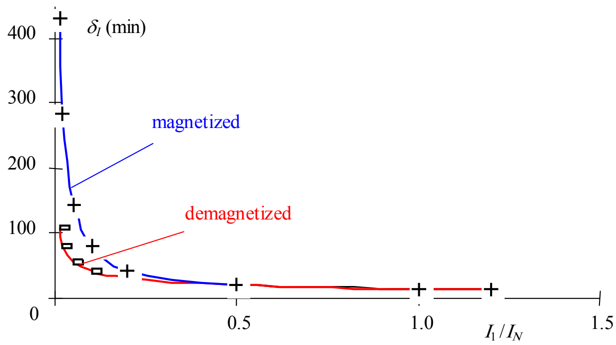

Fig. 16. Phase angle δ_I of ICT with Trafoker core (I_{1N}=50A, I_{2N} = 5A, burden 15W, $\cos\varphi$ = 0) as a function of applied primary current I_N (measured while demagnetizing from 1.2 I_{1N} → 0 and magnetizing from 0 → 1.2 I_{1N}).

The effect of impulse magnetization with a DC current into the secondary winding similarly as in the case of ICT was therefore only simulated. Consequently, the IVT errors were measured with the primary voltage gradually increasing to 120 % of the rated value and decreasing back to zero. The measurement results are shown in Fig. 13 and Fig. 14.

4 CONCLUSION

The results in Fig. 3 to Fig. 7, related to the effect of magnetization of the ICT core by a DC impulse, show clearly that this effect is less substantial for ICT with a nanocrystalline core than for IVT with cores made of Trafoperm-type silicon steel or Permalloy. This is apparent from the results in Fig. 15 and Fig. 18, which are taken from [1]. Errors due to impulse magnetization decrease with increasing burden because induction in the IT core increases. This leads to transformer demagnetization. ICT errors essentially decrease when a constant DC component is actuated, see Fig. 9 to Fig. 12. A DC component corresponding to 1 % of the rated magnetic potential induces up to a tenfold increase in errors at burden 10 W, cosφ = 0.8. When a DC component occurs the ratio error increases and the phase displacement decreases with decreasing ICT burden (see Fig. 9 and 10). That is probably caused by increasing of loss angle δ with increasing of induction *B* according (1). The influence of magnetization on IVT errors is also apparent (see Fig. 13 and 14) in the range up to 60 % of the rated value.

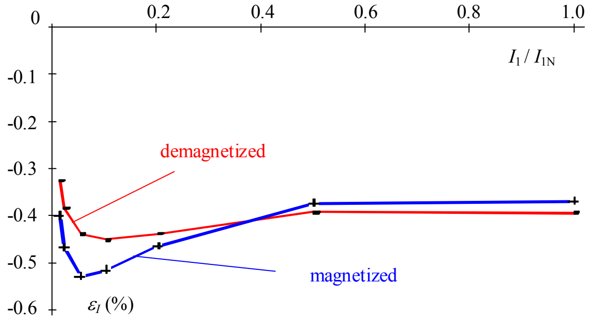

Fig. 17. Ratio error ε_I of ICT with Permalloy PY79 core (I_{1N} = 50A, I_{2N} = 5A, burden 1W, $\cos\varphi$ = 0) as a function of applied primary current I_1 (measured while demagnetizing from I_{1N} → 0 and magnetizing from 0 → I_{1N}).

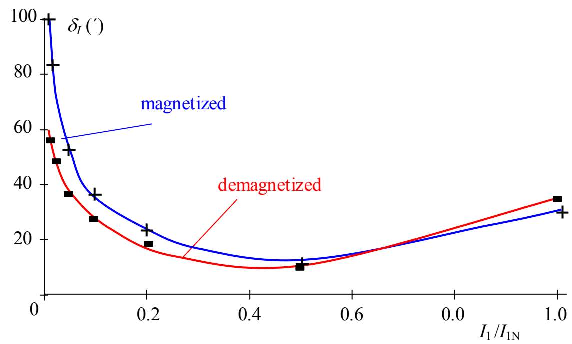

Fig. 18. Phase angle δ_I of ICT with Permalloy PY79 core (I_{1N} = 50A, I_{2N} = 5A, burden 1W, $\cos\varphi$ = 0) as a function of applied primary current I_1 (measured while demagnetizing from I_{1N} → 0 and magnetizing from 0 → I_{1N}).

However, IVT errors do not take effect during operation, because IVTs operate at a rated voltage value and so the core will demagnetize.

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Received 30 September 2010