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TRANSFER OF DISTURBANCES THROUGH THE VOLTAGE TRANSFORMERS

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This article was based on fragments of the authors' PhD dissertation and relates only to part of the considerations contained in it. The objects of the publication are metrological analysis of the voltage transformers operation during the transfer of distorted voltages. These considerations provide an introduction to establish the relationship between the metrological characteristics of voltage transformers of different constructions and their accuracy during evaluation of the voltage quality supplied to customers through the low and medium voltage power networks.

1. INTRODUCTION

The main problem of the dissertation was the examination of the electromagnetic disturbances transfer from primary circuits to secondary circuits of the voltage transformers and the determination of the level of transmission from their work environment. The problem was that the content of higher harmonics in the primary voltage caused an increase in the processed signal frequency band and deterioration of the metrological properties of the voltage transformer, which caused additional measurement errors for both the processed higher harmonic in the voltage as well as the frequency – 50 Hz. In accordance with the standard [1] voltage quality should be tested to 40 harmonic of the signal, which is 2000 Hz. However, compatibility standards specify the levels of voltage higher harmonic in the public low-voltage power supply systems and industrial networks for conducted disturbances to a frequency of 9 kHz [2] [3], therefore, considerations were extended for frequencies from 50 Hz to 9 kHz.

2. EQUIVALENT CIRCUIT

Working conditions of the voltage transformer windings and its magnetic circuit during the transfer of higher frequency voltages or distorted signals as well as its metrological properties are being changed [4]. This effect is the result of the capacities of the windings influence as well as the change of the voltage transformer magnetic circuit properties caused by higher harmonic of the disturbance signal [4] [5]. The analysis of the voltage transformers operation for various bands of the primary voltage frequencies requires considering the proper equivalent circuits for the selected range. During measurements and simulations of the distorted voltages transfer for frequencies of the disturbance voltage to 9 kHz or higher frequency voltages, transformation through the voltage transformer extended equivalent circuit was applied (regarding the classical equivalent circuit of the voltage transformer [5]). This equivalent circuit (fig. 1) gives considerations to capacities of the voltage transformer windings and between them for the analyzed frequency band (50 Hz – 9 kHz).

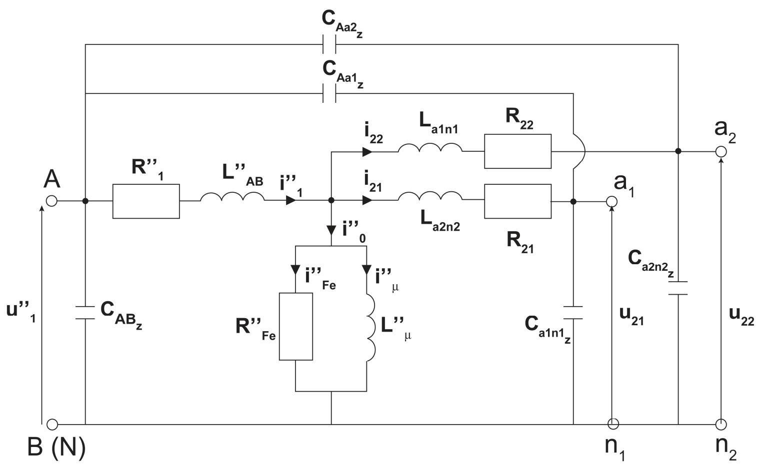

Fig. 1. The equivalent circuit of the voltage transformer with two secondary windings for frequencies to 10 kHz [4][5]

In this diagram the following designations were used (symbols with two dashes indicate elements converted to the secondary side): C_{Aa1z}, C_{Aa2z}, C_{ABz}, C_{a1n1z}, C_{a2n2z} – the corresponding equivalent capacities: between windings; of primary or secondary winding, $R"_1$ – the resistance of the primary winding, R_{21}, R_{22} – the resistances of the corresponding secondary winding, $R"_{Fe}$ – the resistance imagining the active losses in the magnetic core, L''_{μ} – the main inductance, L''_{AB} – the leakage inductance of primary winding, L_{a1n1}, L_{a2n2} – the leakage reactances of the corresponding secondary winding, u''_1 – the primary voltage, u_{21}, u_{22} – the corresponding secondary voltage, i''_1 – the current of the primary winding, i_{21}, i_{22} – the current of the corresponding secondary winding.

Metrological examinations and analysis of conductive disturbances transfer were made in conjunction with considerations regarding the voltage transformer electromagnetic compatibility, which, in accordance with standard [3], are limited for frequencies to 9 kHz. In addition, to appropriate for a given frequency range equivalent circuit of the voltage transformer, it is necessary to use proper measurement methods for determining the effective value of voltages, currents and active or reactive power for distorted signals. In the analyzed frequency band it is possible to estimate that the capacities are related only with the windings. In considerations it is necessary to calculate equivalent capacities as a sum of proper elementary capacities between given voltage transformer clamps. For higher frequencies capacities must be considered separately and the equivalent circuit fig. 1 is not correct [4] [6].

3. TESTED VOLTAGE TRANSFORMERS

Tested voltage transformer models (A and B) have two secondary windings for a rated rms voltage of 100 V, while the rated rms value of the primary voltage is 2000 V. The accuracy class of the tested voltage transformers is 0.5 and rated power of each secondary windings is 25 VA. Between the magnetic core and the secondary winding as well as between the windings insulation is placed. The thickness of this layer depends on difference of the voltages between insulated elements and this determines the coupling capacities between the windings as well as between them and the magnetic core. The increase in the winding diameter increases the resistance and reactance of the windings and this results in rising voltage transformer errors. In addition, the increase in the thickness of the insulation between the primary and secondary windings leads to a reduction of the coupling capacity between them. The thickness of the insulating layer between the core and primary windings determines the values of all the windings regarding the magnetic core of the voltage transformer. Model B, because of the lower insulation thickness compared with the model A, is characterized by smaller values of the parameters R and X of the windings. The magnetic core of both models was the same. Laboratory tests were also made on a voltage transformer type UDZ 24 manufactured by the ABB company. It is a 0.5 class voltage transformer with one secondary winding and a voltage ratio of 2000 V / 100 V. It is used for the supply of the indoor measurement devices and protection circuits [4].

4. LABORATORY RESEARCH

The objective of the study was to determine the values of the basic harmonic transfer factor for different frequencies of disturbance voltages and to calculate the particular harmonic transfer factor for different values of primary voltage and loads of the voltage transformers secondary windings. Laboratory research was made in the developed measuring system, in which to the primary sides of the tested voltage transformer models the voltages of power network frequency with a specified share of the higher harmonic from frequency range 200 Hz – 9000 Hz were applied. The values of a given disturbance signal harmonic and basic harmonic of the voltage before and after transfer through the tested voltage transformer were determined. The laboratory tests consisted of the simultaneous observation of the primary and secondary currents and voltages of the voltage transformers and the analysis of the higher harmonics contents [7] [8]. Two measuring circuits designed to meet the standards [9] were used. The first with separated oscilloscopes for measurements of both sides voltages and both sides currents of the tested voltage transformer (fig. 2). In the second measuring circuit oscilloscopes were connected separately to primary and secondary sides and each was used for both voltage and current observation.

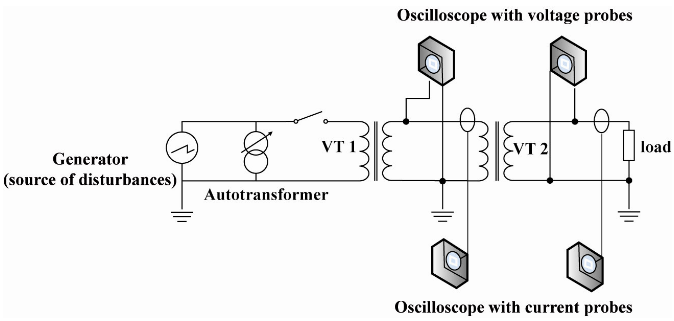

Fig. 2. Diagram of the measuring circuit

In figure 2 the following designations were used: VT1 – the high side voltage supplying transformer, VT2 – the tested voltage transformer. The oscilloscopes were supplied with proper probes for the observation of high voltages and currents. This solution enables one to determine the voltages and currents curves on primary and secondary sides of the tested voltage transformer and to calculate the level of their distortion. The source of conductive disturbances was a voltage generator with adjustable voltage frequency.

The particular harmonic transfer factor T_u was designated from the THD factors for a given harmonic of the disturbance voltage determined before and after the transfer through the voltage transformer [4], which is:

$$T_U = \frac{\frac{U_{KT}}{U_{0T}}}{\frac{U_K}{U_0}} \cdot 100\% \qquad (1)$$

where: U_{KT} – the rms value of a given harmonic of the disturbance voltage after transfer through the voltage transformer, U_{0T} – the rms value of the basic harmonic of the voltage (50 Hz) after transfer through the voltage transformer, U_K – the rms value of a given harmonic of the disturbance voltage before transfer through the voltage transformer, U_0 – the rms value of the basic harmonic of the voltage (50 Hz) before transfer through the voltage transformer.

5. TRANSFER OF DISTURBANCES

In figure 3 the results of calculation of the particular harmonic transfer factors T_u for 40% of rated primary voltage U_n and rated load S_n of the tested voltage transformers are presented.

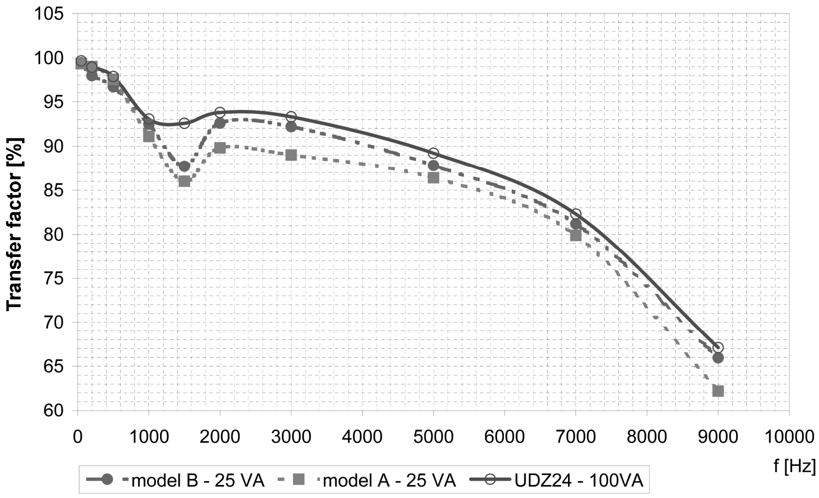

Fig. 3. Change of the particular harmonic transfer factors for 40% U_n and S_n

The share of disturbance harmonic in the supply voltage of the transformer in the entire range of the tested frequency of disturbances was constant and equal to 5% of the rms primary voltage. The largest average value of the particular harmonic transfer factor for primary voltage 40% U_n and load S_n appears for a voltage transformer type UDZ 24 in the whole range of the frequencies tested. The lowest average value of this factor was observed for voltage transformer model A. Laboratory research made for small changes of disturbances frequency shows that for frequency 1750 Hz of the disturbance voltage the value of the particular harmonic transfer factor increases. This is connected with the ferroresonance phenomena caused by the equivalent capacity of the primary winding (fig. 1). The results of studies of primary winding reactance versus frequency show that for frequency of disturbance signal 1500 Hz there is an increase in the winding reactance, which causes an increase in the damping coefficient of the transformer and the reduction of the transfer. For a disturbance voltage frequency near a resonance frequency the reactance of the winding decreases and reaches a minimum value for the frequency of 1750 Hz, which explains the sharp increase in the transfer factor. Above this frequency the reactance of the winding is capacitive and increases with frequency in the tested range up to 9000 Hz [4].

The increase in the primary voltage to a rated value for a rated load caused a decrease in the transfer factor for the resonance frequency for about 5% in the models A, B and increase for about 2% for a transformer UDZ 24 (fig. 4).

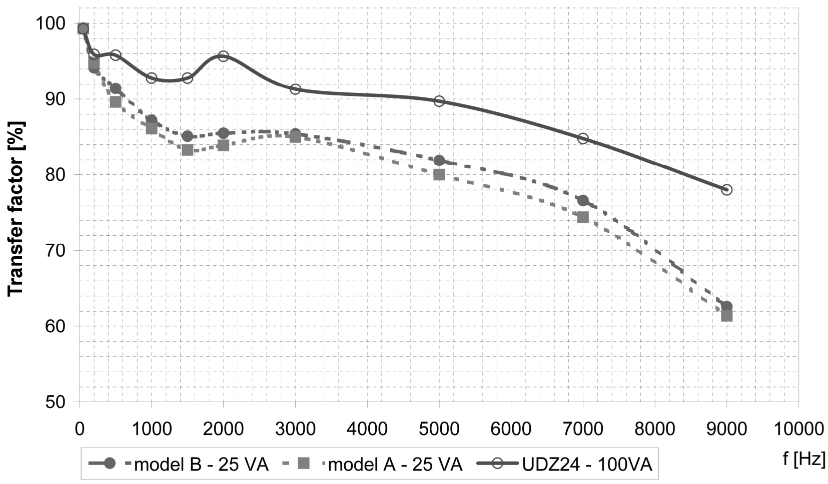

Fig. 4. Changes of the particular harmonics transfer factors for U_n and S_n

Model A has the smallest values of the transfer factor for the investigated frequency of conductive disturbances irrespective of the values of supply voltage and load. The voltage transformer type UDZ 24 is characterized by the highest values of these factors in the frequency range up to 9000 Hz.

In the analysis of the disturbances transfer problem not only the amplitude of transferred voltage but also the change of the phase displacement of the primary voltage particular harmonic after transfer through a given voltage transformer is important (fig. 5).

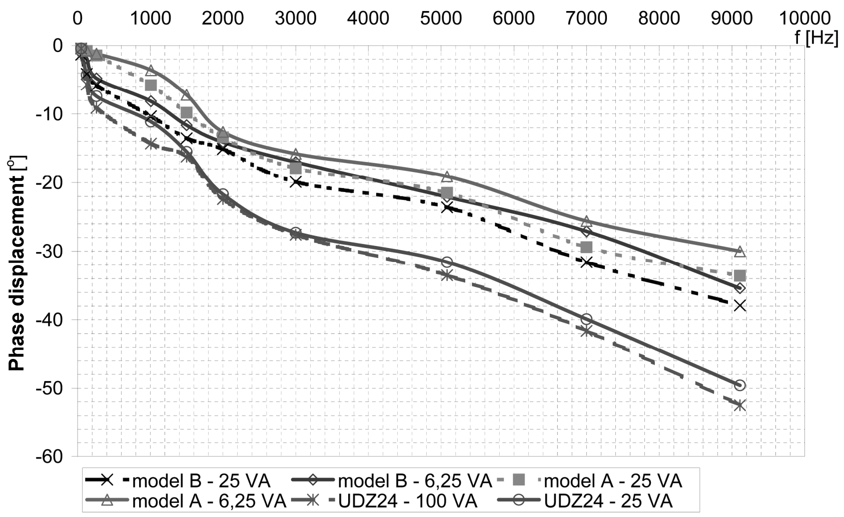

Fig. 5. Change of the particular harmonic phase displacement for U_n and S_n or 25% S_n

The highest value of the phase displacement (in the entire range of the tested frequencies) was observed for the voltage transformer type UDZ24 loaded with rated power. The lowest value of the phase displacement was noticed for model A loaded with 25% S_n. An increase in the load of the secondary winding causes an increase in the phase displacement (for a given harmonic of the voltage), while for the voltage transformer type UDZ 24 the change of the phase displacement with a load was the smallest [4].

6. ACCURACY FOR DISTORTED VOLTAGES

In the next phase of laboratory research errors of the tested voltage transformers during the transfer of distorted voltages were determined. The deterioration of the sinusoidal primary voltage was caused by interferences which are the result of transferred conductive disturbances. The frequency of disturbances was limited to 9 kHz and had a selected value of 5% of the rms value of the primary voltage applied to the tested transformer. Interference voltages cause an increase of the voltage error of all the tested voltage transformers. When the load of the secondary winding was 25% S_n the voltage error of voltage transformer model B increased by about 0.23%, for model A by about 0.1% and voltage transformer type UDZ 24 by about 0.3%. The load of voltage transformers with rated power (for the same value of interferences) causes an increase in the voltage error of model B by about 0.26%, of model A by about 0.45% and for voltage transformer type UDZ 24 by about 0.2%. The change of this error for the tested transformers and 40% U_n shows figure 6.

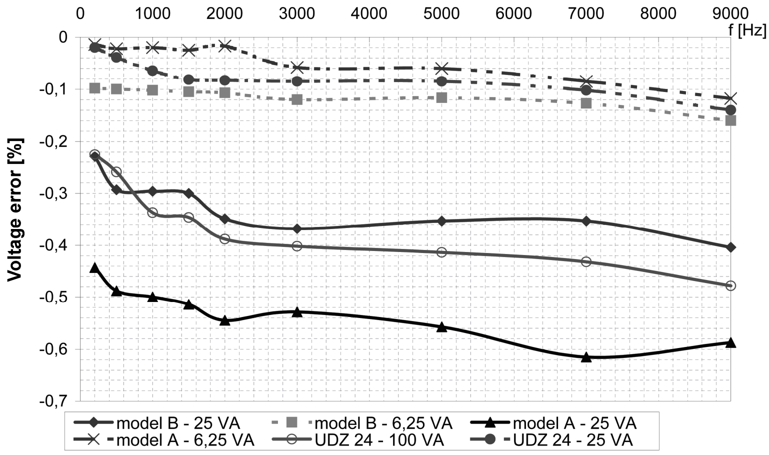

Fig. 6. Change of the voltage error for 40% U_n

An increase of the rms value of the primary voltage to 120% U_n (with a proportional increase in the rms value of the interference voltage) caused an increase in the interference influence (fig. 7).

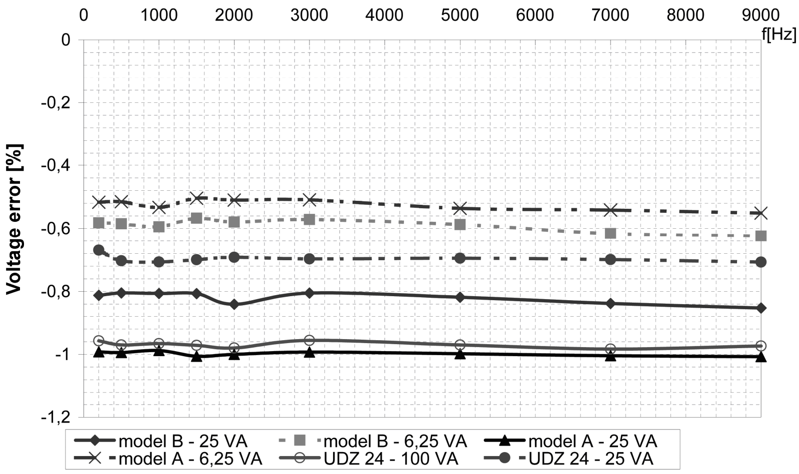

Fig. 7. Change of the voltage error for 120% U_n

An increase of the load power of the secondary winding to the rated value caused a further increase in the interference influence on voltage errors and for voltage transformer model B this error increases by about 0.72%, for model A by about 0.77% and for voltage transformer type UDZ 24 an increase of voltage error only by about 0.52%. It should be noted that the lowest influence of interferences on the voltage error was observed for different operation conditions of the tested voltage transformers: for model A, when the primary voltage applied was 40% U_n and the load was 25% S_n, for model B for 40% U_n and S_n, while for voltage transformer type UDZ 24 for 120% U_n and S_n.

The influence of interference voltage on the phase displacement of the primary voltage basic harmonic (50 Hz) is presented in figure 8.

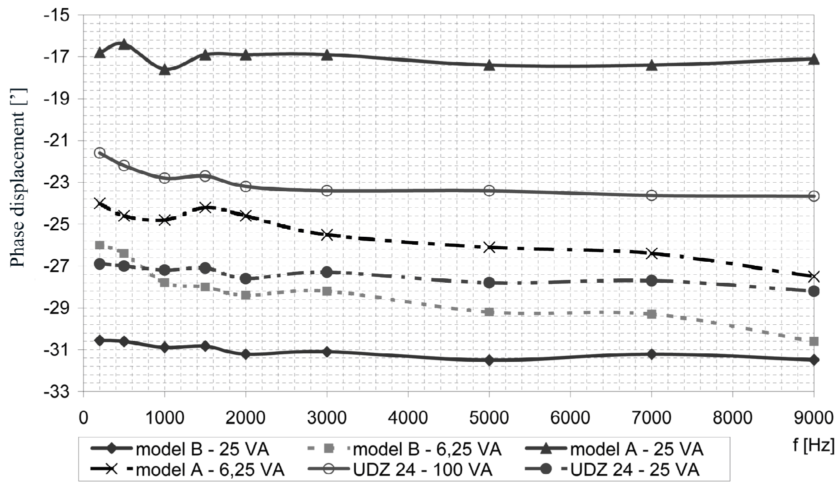

Fig. 8. Change of the phase displacement for 120% U_n

For an increased primary voltage to 120% U_n the highest increase in the phase displacement (-37 min.) was observed for model B loaded with rated power, while the lowest (-21 min.) was noticed for model A with the same load. This increase in the primary voltage for rated load of the secondary winding causes an increase of the interference influence on voltage transformers phase displacement for model B and the voltage transformer type UDZ 24, while for model A the result is opposite. When a voltage transformer is loaded with smaller power (25% S_n), then a change of the primary voltage does not cause a significant change of the phase displacement [4].

7. CONCLUSIONS

- A higher harmonic of the interference voltage causes an increase in the voltage error and the phase displacement of the tested voltage transformers.
- The construction parameters of the voltage transformer winding system have a significant influence on the transfer of conductive disturbances.
- A change of the voltage transformer errors during the transfer of distorted voltages is not determined by the frequency of the interference signal (in the tested frequency range) but depends on the share of interferences in the voltage.

- An increase in the conductive disturbances frequency causes a decrease in the particular harmonic transfer factor and an increase in this harmonic phase displacement after transfer through a voltage transformer.
- Distorted voltages cause deterioration of the voltage transformer metrological properties and its accuracy during the estimation of voltage quality.

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TRANSFER ZABURZEŃ PRZEZ PRZEKŁADNIKI NAPIĘCIOWE

Streszczenie

Artykuł powstał na podstawie fragmentów rozprawy doktorskiej i dotyczy jedynie części rozważań w niej zawartych. Przedmiotem publikacji są wyniki analiz właściwości metrologicznych przekładników napięciowych przy transformowaniu napięć odkształconych. Rozważania te stanowią wstęp do ustalenia zależności między charakterystykami metrologicznymi różnych konstrukcji przekładników napięciowych a dokładnością oceny jakości energii elektrycznej dostarczanej do odbiorców za pomocą sieci elektroenergetycznych.

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