BULLETIN OF THE POLISH ACADEMY OF SCIENCES
TECHNICAL SCIENCES, Vol. 59, No. 4, 2011
DOI: 10.2478/v10175-011-0067-1

Operation of voltage transformer in grids with distorted signals

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Abstract. Non-sinusoidal currents and voltages caused by nonlinear loads appear in power grids more and more frequently. Determination of the voltage transformer accuracy in such conditions makes a problem. Firstly, due to lack of definition of errors for distorted signals and secondly, typical measurement bridges do not accept higher harmonics. In the paper, the new definition of transformation error for distorted voltages has been proposed and some measurement results have been presented.

Key words: voltage transformer, distorted signal, higher harmonic, accuracy, error.

1. Introduction

Voltage transformers are intended to power measurement instrumentation and protective devices in power grids. The core made of ferromagnetic material that is used in inductive voltage transformer is a nonlinear element. However, in normal operation the primary and secondary voltage changes from 80% to 120% of rated voltage. In such conditions and for typical magnetic materials used in magnetic circuits of inductive voltage transformers the magnetization curve slightly differs from a straight line. This causes, of course, negligible distortion of magnetizing current. This means also that while analysing the operation of voltage transformer we can use vector diagrams representation. This aspect of a problem concerning a level of nonlinearity of a voltage transformer for fundamental frequency 50Hz has been described in many publications and is not a subject of consideration of the authors.

One of the possible application of the voltage transformer is a perfect transformation of a voltage from the primary to secondary side. Analysis of the accuracy of transformation presents a significant problem. Voltage transformer errors are defined in the standards as ratio error and phase displacement. Rated (acceptable) values of these errors are determined by the class of accuracy of a transformer. Measurements of these errors are usually realized by special bridges that are making measurements in a selective way to meet standard definitions and are analysing only sinusoidal signals (non-distorted) e.g. of power frequency. This aspect of a problem, which is described in details in [1] also is not a subject of consideration of the authors.

Nowadays, non-sinusoidal currents and voltages caused by nonlinear loads appear in power grids more and more frequently [2–7]. Determination of voltage transformer accuracy in such a conditions makes a double problem. Firstly, due to lack of definition of errors for distorted signals and secondly, typical measurement bridges do not accept higher harmonics.

Last time we can meet in the publications [8–9] descriptions of applying voltage transformers to systems for measuring power of harmonics what means the power generated by current and voltage components of a frequency higher then 50Hz. In this case the change of phase displacement between voltage and current of the specific harmonic that is caused by voltage transformer can have significant implication. Also, this aspect of a problem is not a subject of consideration of the authors.

Otherwise, the authors of the paper focused on the problem of accurate transformation of distorted voltage, what means voltage containing higher harmonic components up to 2 kHz from primary to secondary side of a voltage transformer.

2. A new approach

In the case of transformation of distorted signals the authors suggest to determine voltage transformer accuracy by the instantaneous values of the waveform which is the difference between primary voltage waveform and secondary voltage waveform (differential voltage). Finally, the True RMS value of that differential voltage waveform is determined.

For such characterized accuracy the so called True RMS error of voltage transformer has been defined.

This error can be expressed as percentage of primary voltage (1):

$$\text{True RMS error}_{\%} = \frac{100}{U_1}\sqrt{\frac{1}{T}\int\limits_0^T (u_2 \cdot k_R - u_1)^2\, dt}, \quad (1)$$

where U_1 – RMS value of primary voltage (True RMS), u_1 – primary voltage waveform, u_2 – secondary voltage waveform, T – duration of one cycle of the differential voltage waveform, k_R – rated transformation ratio.

In the particular case when $k_R = 1$, the formula can be expressed as (2):

$$\text{True RMS error}_{\%} = \frac{100}{U_1}\sqrt{\frac{1}{T}\int\limits_0^T (u_2 - u_1)^2\, dt}. \quad (2)$$

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One should mention that so defined error gives the true information on ability of the voltage transformer to transfer the distorted primary voltage on the secondary side but it does not contain separate information about ratio error and phase displacement since these errors do not have the right definitions while the primary voltage and secondary voltage are distorted.

3. Tested voltage transformer and measurement circuit

The voltage transformer 100 V/100 V was used during tests. Transformer subjected to test has the ratio $k_R = 1$, therefore is possible to use simple measurement circuit presented in Fig. 1 for determining True RMS error according formula (2).

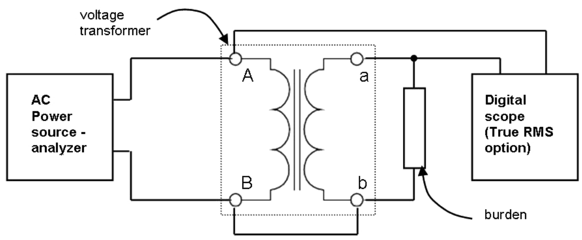

Fig. 1. Measurement circuit for determining accuracy of voltage transformer with distorted primary voltage

The measurement circuit contains source of voltage *AC Power Source – Analyzer HP 6813B* that allows to generate distorted signals with arbitrary contribution of higher harmonics (up to 40 harmonic). This distorted voltage has been applied to A-B primary winding terminals and the differential voltage between A-a terminals has been measured. It should be noticed that in order to get the differential voltage the B-b terminals have to be connected. Measurements have been done by digital scope *Tektronix TDS 680C*.

In that scope the advanced options for measuring True RMS value of displayed waveforms have been used. The voltage transformer has been loaded with 200 Ω resistive burden, which in the range of frequency up to 2 kHz maintained constant value of impedance.

4. Measurement results

In the circuit (Fig. 1) the following measurements have been done:

a) measurement of accuracy of voltage transformer while applying to it sinusoidal voltage 100 Vrms in the frequency range from 50 Hz to 1950 Hz,

b) measurement of accuracy of voltage transformer while applying to it distorted voltage 100 Vrms containing fundamental harmonic and successive odd harmonic of 30% contribution.

Sample waveforms of distorted primary voltage and differential voltage in the presence of harmonics are presented in Figs. 2 and 3.

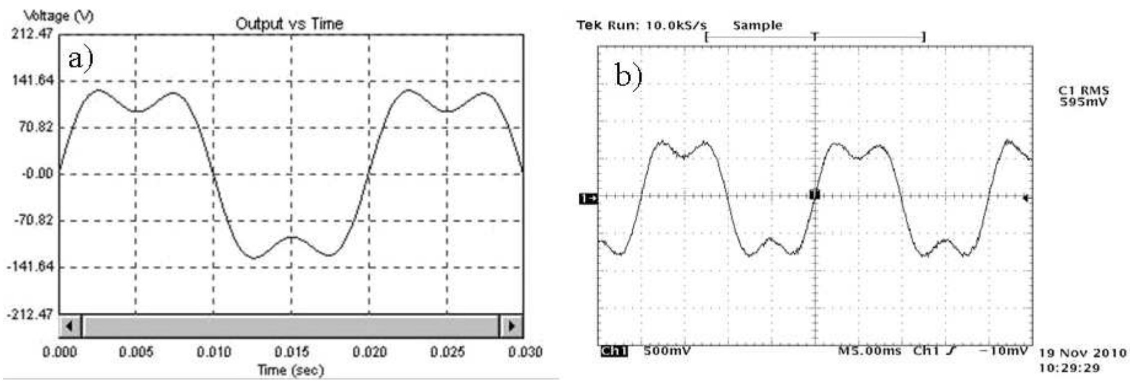

Fig. 2. Primary voltage of 3-harmonic contribution (a) and differential voltage of 3-harmonic contribution (b)

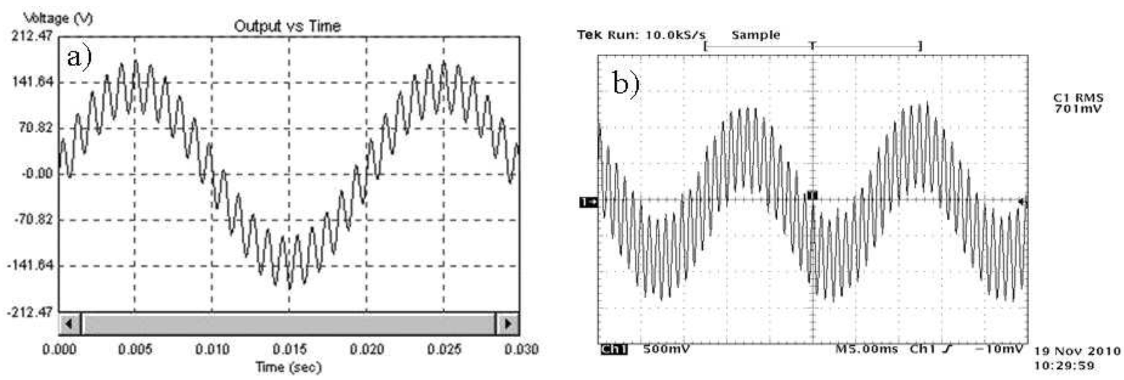

Fig. 3. Primary voltage of 21-harmonic contribution (a) and differential voltage of 21-harmonic contribution (b)

The results of measurements are shown in Fig. 4.

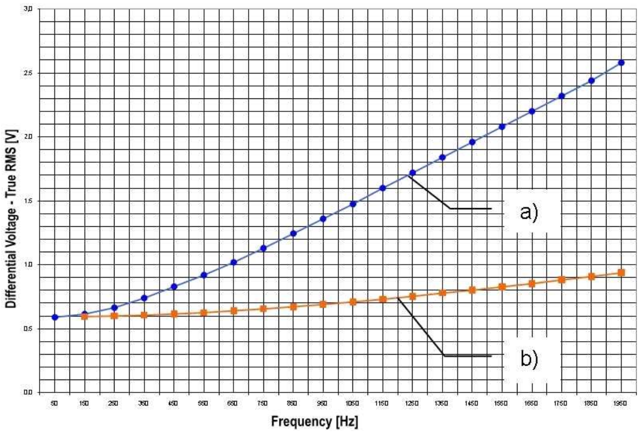

Fig. 4. Impact of successive harmonic on True RMS value of differential voltage: a) while applying sinusoidal voltage in the frequency range from 50 Hz to 1950 Hz, b) while applying distorted voltage containing fundamental harmonic and successive odd harmonic of 30% contribution

It should be noticed that the change of frequency of the applied sinusoidal voltage provokes significant increase of the differential voltage up to 2.6V, whereas the change of frequency of the applied voltage containing fundamental harmonic and successive odd harmonic of 30% contribution causes increase of the differential voltage up to 0.95 V only.

Next, the impact of the level of applied voltage of specific harmonic frequency on the accuracy of voltage transformer has been investigated.

Figure 5 presents measurement results that show how the accuracy of tested voltage transformer depends on the level of applied voltage.

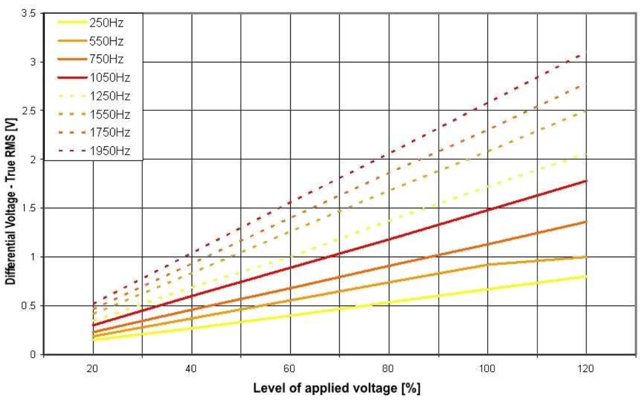

Fig. 5. Impact of the level of applied voltage on differential voltage

The same results but presented as relative to primary rms voltage are shown in the Fig. 6.

From the diagrams (Figs. 5 and 6) it can be seen that the differential voltage (True RMS value) increases with raising frequency while the *True RMS Error* keeps the constant value with the change of applied voltage in the range 20–120%.

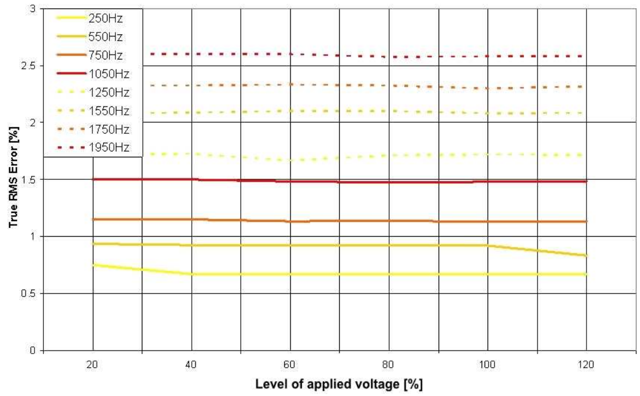

Fig. 6. Impact of the level of applied voltage of specific harmonic frequency on True RMS Error

5. Conclusions

- Laboratory investigation that was carried out allows to treat voltage transformer as a low-pass filter of approximate frequency response $U_2/U_1 = f(f)$ shown in the below placed diagram (Fig. 7).

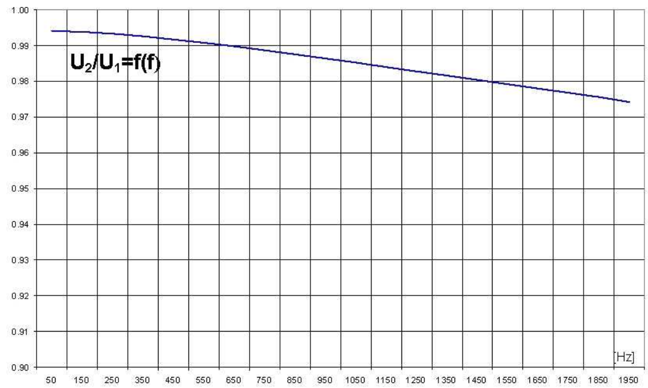

Fig. 7. The approximate frequency response of the voltage transformer

- In order to manifest more clearly the phenomena that appear with higher harmonics the investigations were carried out for the 30% contribution of specific harmonic. As a matter of fact the contribution of higher harmonics is usually significantly less so the value of *True RMS error* should be respectively lower.
- The concept for determining the accuracy of voltage transformer in presence of higher harmonics that has been proposed by the authors is relatively simple to realize because of the fact that instrumentation for measuring the True RMS value is commonly available.
- The solution of the problem how to determine the accuracy of voltage transformer of ratio other then 1 will be the subject of authors' further investigations.
- We can meet in some publications such a statement: "in the presence of higher harmonics ratio error or phase displacement is increasing/decreasing …". According to the authors' opinion a statement of this kind seems to be unjustified. Giving an explanation of our opinion it should be realized that the ratio error and the phase displacement con-

cept concerns only 50 Hz non-distorted signals and these errors while measured by measurement bridges do not depend on the content of higher harmonics in the signal.

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