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INSTRUMENT TRANSFORMER ACCURACY TESTING BY DFT METHOD

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Abstract -Instrument transformer accuracy testing by the method based on integration of DFT and virtual instrument concept, composed of standard hardware (osciloscope, PC) and specific software is outlined. The structure of the realized virtual instrument for accuracy test of current transformer by DFT method is shown. The method has experimentally verified and compared with measurements made with the classical complex Hohle compensator.

Keywords: Instrument transformer, accuracy testing, DFT, virtual instrument.

1. INTRODUCTION

There are several methods and devices for testing the accuracy of instrument transformers. Most fregueently used is differential method. Scientific and technical advances open up new possibilities and approaches in this area of metrology. Some examples worth noting are the idea put forth by specialists from PTB on the digital separation of error components based on the descrete Fourier transformation (DFT) of the measured signal [1], or the virtual instrument concept for testing instrument transformer accuracy [2].

The paper presents measuring method and devices for accuracy test of instrument transformers based on integration of DFT and virtual instruments concept.

2. MATHEMATICAL MODEL

The structure of virtual instrument for accuracy test of current transformer by DFT method is show at the block diagram in Fig.1. The differential method assumes that there is a reference transformer T_N with a transformer ratio n_N equal to the rated ratio n_X of current transformer T_X being verified. The voltage u_N coresponds to the secondary current i''_N of the reference transformer T_N , while the diferential voltage u_d corespodents to the complex error of the current transformer T_X. Equations which describe the ratios of these voltages and their relation to the amplitude error g and phase error δ of the current transformer T_X are:

$$g \cong \frac{I_{d1}}{I_{N1}} \cdot \cos\varphi \cdot 100 = \frac{U_{d1}}{U_{N!}} \cdot \frac{R_N}{R_d} \cdot \cos\varphi \cdot 100 \qquad [\%] \qquad (1)$$

$$\delta \cong \frac{I_{d1}}{I_{N1}} \cdot \sin\varphi \cdot 100 = \frac{U_{d1}}{U_{N1}} \cdot \frac{R_N}{R_d} \cdot \sin\varphi \cdot 3440 \qquad [\,'\,] \qquad (2)$$

Equations (1) and (2) contains two approximations; firstly, the angle δ has been replaced by $\tan\delta$, and secondly, terms δ^2 and g^2 have been neglected, so $1+\delta^2 \cong 1$ and $1+g^2 \cong 1$. The first approximation, for a phase error of 100′ creates a difference of only 0,028′. If we neglect the second order approximations, this generates a relative error of the phase (amplitude) error equal to the amplitude (phase) error of tested transformer:

$$g = \frac{\Delta\delta}{\delta} \qquad (3)$$

According to expression (3), if the amlitude error is 1%, then the error in measuring a phase error of 50′ is egualto 0.5′, which is acceptable. Namelly, in high accuracy class instrument transformers (e.g. 0.1), for a phase error of 10′ the error is only 0.01′. In instrument transformer accuracy testing devices in which the signals are procesed by a microcomputer, these approximations can be avoided. Moreover, the accuracy of error measurement depends mostly on the accuracy with wich signals U_d and U_N are processed accordind to expressions (1) and (2).

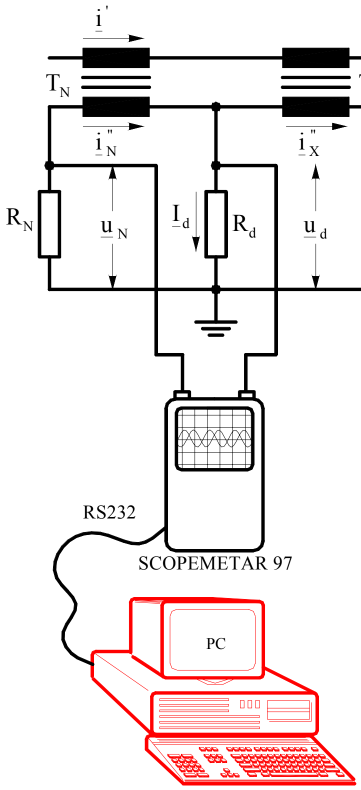

Fig.1 The virtual instrument structure

J.B. J. Fourier stated that a periodic function *f(t)* could be represented as a summation of sines and cosines:

$$f(t)=\frac{a_0}{2}+\sum_{1}^{k}a_k\cos(k\omega_1 t)+\sum_{1}^{k}b_k\sin(k\omega_1 t) \qquad (4)$$

where a_k and b_k are the real expansion coefficients.

Instruments which sample waveforms and store the sampled values in memory can perform mathematical analyses on the stored data. One of the most useful is the discrete Fourier transform (DFT). Since the instrument is digital both the time function and its Fourier transform must be discrete. A finite time record, *T,* must be used to implement DFT. If N equally spaced points are taken in the time interval *T*, than the spacing betwin time points is *T/N,* as on Fig. 2, assuming that each sample is used in the algorithm to implement DFT.

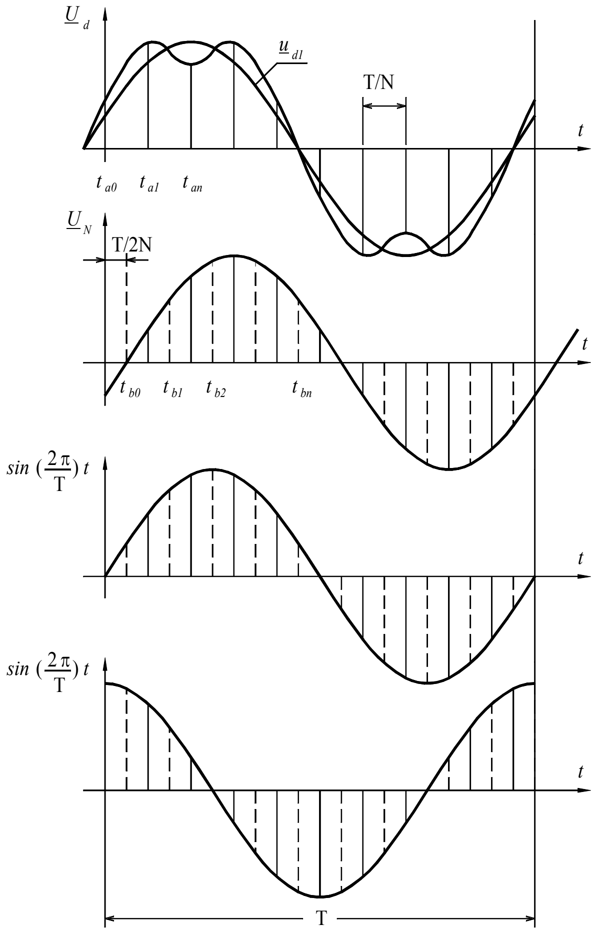

Fig.2 DFT of voltages u_d and u_N

The real expansion coefficients for voltages u_{d1} and u_{N1} are given by equations (5), (6) and (7), (8), respectively:

$$a_{d1}=\frac{2}{N}\sum_{n=0}^{N-1}u_d(t_{an})\cos(2\pi\omega_0 t_{an}/T) \qquad (5)$$

$$b_{d1}=\frac{2}{N}\sum_{n=0}^{N-1}u_d(t_{an})\sin(2\pi\omega_0 t_{an}/T) \qquad (6)$$

$$a_{N1}=\frac{2}{N}\sum_{n=0}^{N-1}u_N(t_{bn})\cos(2\pi\omega_0 t_{bn}/T) \qquad (7)$$

$$b_{N1}=\frac{2}{N}\sum_{n=0}^{N-1}u_N(t_{bn})\sin(2\pi\omega_0 t_{bn}/T) \qquad (8)$$

Voltages u_{d1} and u_{N1} are represented by DFT coefficients, so on the basis of these coefficients, according to equations (1) and (2), the corresponding amplitude g_x and phase δ_x error equations, of tested instrument transformer T_x , are:

$$g_x=\frac{b_{d1}b_{N1}+a_{d1}a_{N1}}{a_{N1}^2+b_{N1}^2}\cdot\frac{R_N}{R_d}\cdot 100+g_N \qquad (9)$$

$$\delta_x=\frac{a_{d1}b_{N1}-b_{d1}a_{N1}}{a_{N1}^2+b_{N1}^2}\cdot\frac{R_N}{R_d}\cdot 3440+\delta_N \qquad (10)$$

The equations (9) and (10), expresing the amplitude g_x and phase δ_x errors as functions of DFT coefficients, R_N , R_d , g_N and δ_N , are comlex, but that mathematical model is both very accurate and easy to implement by PC.

3. VIRTUAL INSTRUMENT

The method based on integration of DFT and virtual instrument concept, composed of standard hardware (osciloscope, PC) and specific software is outlined. The structure of electronic devices is generally dictated by the mathematical model.

Apart from a few electronic modules, here we have a standard structure, characteristic for the majority of electronic instruments operating in conjuction with a PC. What really makes this hardware do the necessary task is the dedicated software.

The basic characteristics of the software for virtual instruments are:
- object oriented programming,
- simulation of operation of the measurement instrument in the whole application range in order to analyze measurement errors and to test for the correct operation,
-calibration of the instrument and correction of measurement results,
- computer processing of the digital measurement signal,
-visual presentation of results of measurement, archiving and printing.

The voltages u_N and u_d are acquired by dual/channel digital osciloscop, through serial interface RS232 they are input into PC and , by the DFT method both voltages U_{1n} and U_{1d} and phase shift of first harmonics are calculated.

Fig. 3 shows the front panel of the virtual instrument ad hoc desiged for displaing the waveform of the differential voltage u_d from dual/channel osciloscop.. The software package is designed for realisation and programming of virtual instrument that combines all thecharacteristics of object and graphic programming wich simplifies and makes faster the task of writing particular applications.

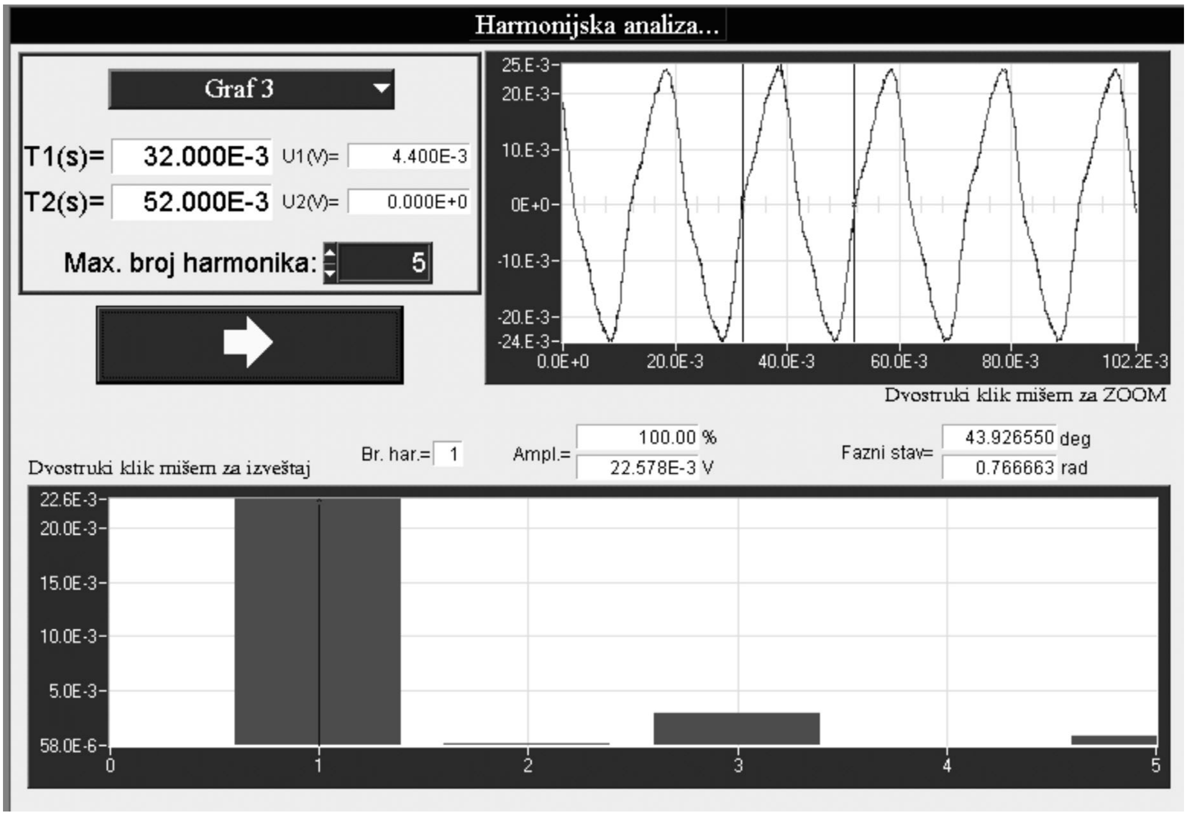

Fig. 3. The outlook of PC screen with menu

4. THE EXPERIMENTAL VERIFICATION

According to Fig.1 the elements of the circuit are:
- T_x , tested transformer, »FMT«, type STEM-0010, No 9432, ratio of 200A/5A, 15VA, accurecy class 1.
- $T_{N,}$ reference transformer, »Hartmann & Braun«, type Ti50/s, Nr.540 371, accuracy class 0.02.
- $R_{N,}$ AC reference resistor, »Hartman&Braun«, 0,4008Ω, accuracy class 0,02.
- R_d, AC reference resistor, »Tettex«, type1108A, 5Ω, accuracy class 0,05.
- Scopemeter »Fluke«, type 97, two-chanel,50 MHz.
- Standard configuration PC on Windows platform.

The same current transformer T_x was also tested with the Hohle compensator. Test results are given in Table I.

The curent transformer accuracy test results made by two different methods,the new one and classical one, show a very good degree of coincidence.

While the complex numerical processing of the digital measurement signal is not a specific problem, the simple processing of analog input measurement signals is certainly an advantage of this method. Upon analyzing the measurement errors of individual elements, as well as that of the device as awhol, we have estimated the following:

- uncertainty in amplitude error measurement is ±1% of the measured error and ±0,02%.
- uncertainty in phase error measurement is ±1% of the measured error and ±2′.

TABLE I. The results of current transformer T_x accuracy testing

meth-od	S (VA)		$0{,}05I_N$	$0{,}2I_N$	$1{,}0I_N$	$1{,}2I_N$
DFT	15	g (%)	-0,93	-0,63	-0,55	-0,61
		δ (′)	31,9	20,9	16,7	19,1
	3,75	g (%)	-0,25	-0,11	-0,02	-0,03
		δ (′)	25,2	16,1	9,0	9,2
Hohle	15	g (%)	-0,89	-0,59	-0,54	-0,60
		δ (′)	37,0	22,1	17,6	21,8
	3,75	g (%)	-0,19	-0,08	-.0,01	-0,02
		δ (′)	30,0	19,2	9,8	10,0

5. CONCLUSIONS

The main advantages of the VI-DFTmethod are that strong, flexible and standard hardware combined with powerful, flexible and easily changeable software, resulting, compared to the classical concept in improved performances, reduced cost and time of development.

The experimental test performed on the realised system show the validity of the followed approach and very good degree of coicidence with classical instruments.

The concept proposed and the hardware and software structures presented are strong enough to support laboratory and on-site, standard and non standard, accuracy testing of instrument transformer.

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