Application of Instrument Transformers in Power Quality Assessment

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Abstract— **To assess the quality of electricity supply through the power networks it is necessary to use instrument transformers or other devices for measuring voltages and currents of considerable values. In many terminals the quality of electric energy is significantly deteriorated and this result in the occurrence of the conducted disturbances in the primary signal of the instrument transformer which cause deterioration of its metrological characteristics. The main indicators to determine the level of periodic waveforms distortion are RMS and average values, total harmonic distortion (THD), crest and shape factors. Laboratory tests consisted of determining these parameters in the system with and without instrument transformers for pre-defined and repeatable distorted waveforms of instrument transformers primary windings supply voltage. The tests were performed for voltage (1000V / 100V) and current (5A / 5A) transformers. On the basis of comparison between values of designated parameters used in estimation of the power quality, obtained for measurements of the same distorted waveforms, in measuring circuits with and without instrument transformers additional errors caused by their operation is determine. It was found that higher harmonic from disturbance signal in the primary circuits of both voltage and current transformers causes increase of errors during the transfer of the signal basic harmonic (50 Hz). Furthermore, in the case of disturbance signals which frequencies are higher than 50 Hz the decrease in transfer ratio and increase of the higher harmonic phase displacement after transfer by the instrument transformer is noticeable. It must therefore be concluded that during the transfer of distorted signals through the instrument transformers their errors are increased in relation to the value defined for sinusoidal signals which frequency is 50 Hz. This leads to additional error in determining the parameters of voltages and currents used to define the power quality.**

Keywords- current transformers; voltage transformers; power quality; THD factor; transfer factor; distorted voltage and current.

I. INTRODUCTION

The concept of power quality provides a set of values characterizing the waveforms of voltage and supply current, which is a prerequisite for ensuring the correct operation of electrical loads. Impact on power quality have both its suppliers and customers. Suppliers because of the electricity networks, ie with adequate load capacity and stiffness of the supply voltage. Customers due to operating electrical devices, which may impact the power quality [1] [2] [3].

The parameters characterizing the power quality can be divided into groups on: the frequency of supply voltage and current, the RMS value of voltage sags and dips [4], waveform shape and symmetry of the voltages and currents in the three phase systems [1][5]. One of the main indicators to determine the quality of voltage and current is a factor of harmonic distortion (THD). Indirectly, by defining the level of signal distortion, the power quality may be also determine by crest and form factors. Assessment of the power quality of supplied electricity in the power system requires the use of instrument transformers or other devices designed for measuring significant values of voltages and currents [6] [7].

In the case of low power quality conducted disturbances occurring in the primary signal of the instrument transformer cause deterioration of its metrological characteristics [8] [9] [10] [11] [12]. This phenomenon is also represented by an unfavorable change of the instrument transformer equivalent circuit parameters [13]. The aim of the study is to determine the additional error in fixing the coefficients characterizing the power quality of voltage and current caused by the operation of the instrument transformers.

II. MEASUREMENT METHOD AND OBJECT

Studies involving determination of the factors characterizing the power quality were made in the measurement system shown in Figure 1a with the use of voltage and current transformers and directly in the circuit presented in Figure 1b. Used digital power meter model Yokogawa type WT 1600 allows direct measurement of voltage and current particular harmonics content and RMS values in the range of frequency to 5000 Hz and RMS values of currents to 50A and voltages to 1025V [14] [15].

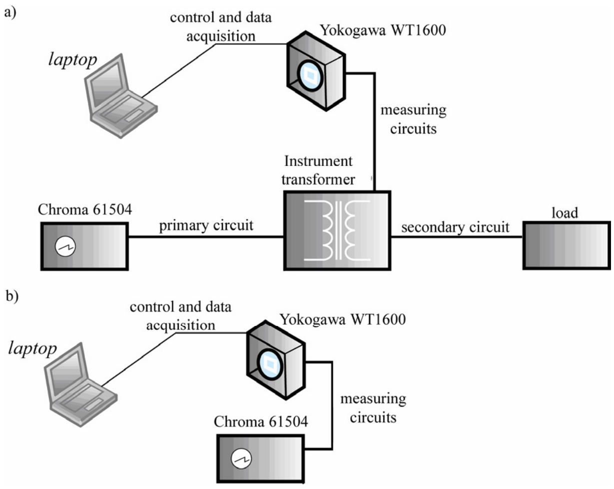

Figure 1. Measuring circuit

Used analyzer allows instantaneous measurements of the voltage and current waveforms parameters like RMS and average values, THD_I, THD_U, form and crest factors which are used during the laboratory studies to estimate the influence of the tested instrument transformers on power quality assessment. AC power source model Chroma type 61504 was used for generation of the distorted voltage waveforms which main frequency was 50 Hz with the specified content of the conductive disturbances (to 40th harmonic including - 2000 Hz [17]).

III. Results of the Laboratory Research

The first stage of laboratory tests was to determine the current and voltage waveforms on the primary (I1, U1) and secondary (I2, U2) sides of the current transformer for rated value of the primary current 5A of frequency 50 Hz without additional conducted disturbance generated in the current transformer primary winding supply voltage for rated load of the secondary winding 5 VA (Fig. 2).

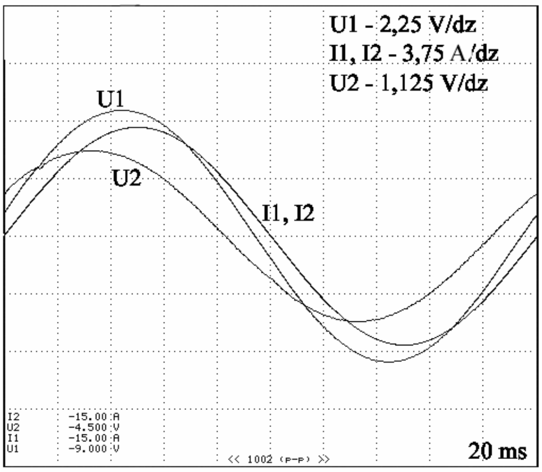

Figure 2. Current transformer primary and secondary sides voltages and currents waveforms for rated primary current RMS value 5A (50 Hz) without conduced disturbances for rated load of the secondary winding 5 VA

The shapes of current and voltage curves are practically sinusoidal and are characterized by a small content of higher harmonics. Crest and form factors of the current transformer primary and secondary voltage and current have the same value equal to 1.42, respectively for the crest factor and 1.11 for the form factor. The percentage difference in the RMS value of primary and secondary currents is equal to -0.14%. This value results from the current transformer accuracy determined for primary current frequency of 50 Hz in accordance with standard [16].

In order to determine the level of harmonics in the primary current and voltage waveforms measurements of particular harmonic RMS values were made (fig. 3).

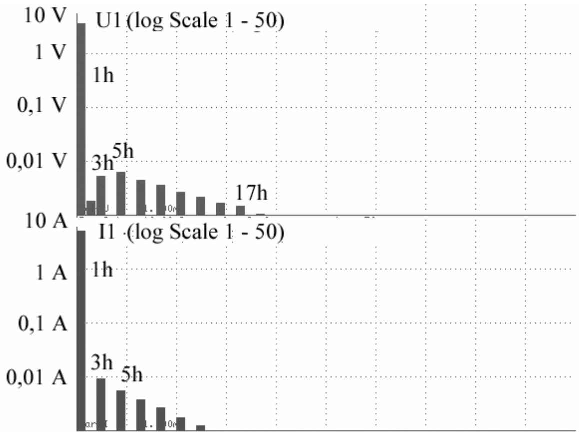

Figure 3. Current transformer current I_1 and voltage U_1 harmonics determined for frequency 50 Hz without conduced disturbances in supply voltage of the primary winding

The RMS values of the primary current and voltage harmonic (Fig. 3) does not exceed 0.01 A and 0.01 V. THD_{I1} factor in this conditions was equal about 0,23% while THD_{U1} factor was equal about 0,76%.

Figure 4 shows the results of the RMS values of current and voltage harmonics measurement on current transformer secondary side.

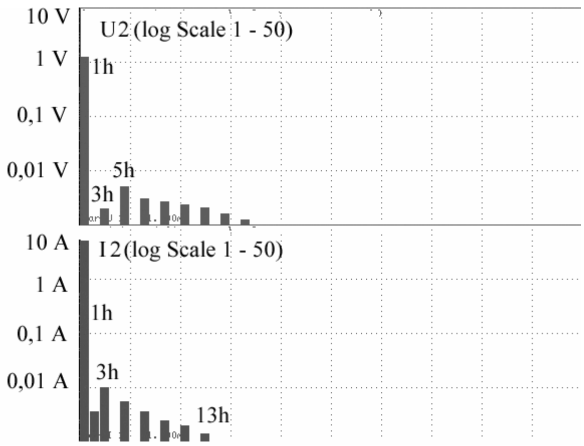

Figure 4. Current transformer current I_2 and voltage U_2 harmonics determined for frequency 50 Hz without conduced disturbances in supply voltage of the primary winding

The RMS values of the secondary current and voltage harmonics (Fig. 4) also did not exceed 0.01 A and 0.01 V. Is a noticeable decrease in the RMS value of the current harmonics in relation to their value in the primary side of the current transformer. In the case of secondary voltage harmonics a slight increase of their value in relation to the primary side of the current transformer is observed. THD_{I2} factor in this case is equal about 0,35% while THD_{U2} is equal about 0,61%.

The occurrence of 2nd harmonic in secondary current which RMS value is about 6 mA is caused by interferences in nonshilded measuring wires of digital power meter Yokogawa 1600. During all considerations harmonics which RMS value is smaller than 0,01 A or 0,01 V were not taken into account.

The next step was to study results of laboratory measurements in conditions when in the primary winding supply voltage additional conductive disturbances were generated. Given level of conductive disturbances was established by the total harmonic distortion value to THD_{UZ} equal 30%. Waveforms of currents and voltages on the primary and secondary sides of current transformer for this case are shown in Figure 5.

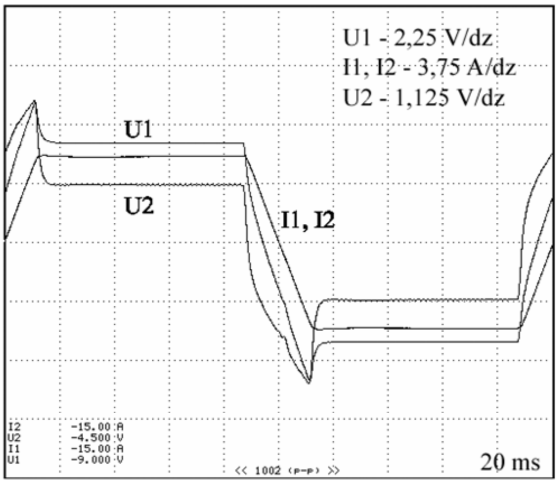

Figure 5. Current transformer primary and secondary sides voltages and currents waveforms for rated primary current RMS value 5A (50 Hz) and rated load of the secondary winding 5 VA with primary winding supply voltage THD_{UZ} = 30%

In the case of waveforms shown in Figure 5 a significant deformation is observed which is appropriate to the high value of these signals THD factor. Crest and form factors of current waveforms on secondary and primary sides of the current transformer have the same value equal 1,1 for the crest factor and 1,04 for the form factor. The value of the primary voltage crest factor is equal about 1.47 and form factor is equal about 1,04. On the secondary side voltage form factor is equal 1.06 while crest factor is equal 2.06. Significantly higher value of crest factor characterizing secondary voltage distortion is caused by higher value of overvoltage on the secondary side of the current transformer [4] [11]. The percentage difference in the RMS values of primary and secondary currents for distorted signals from Figure 5 is equal -0,24% and is significantly higher than for sinusoidal signals presented in Figure 2 (-0,14%).

Figure 6 presents the results of the RMS values of current and voltage harmonics measurement on current transformer primary side.

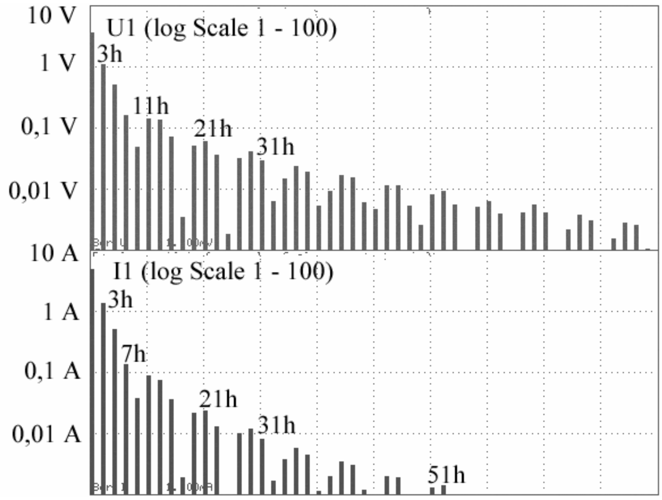

Figure 6. Current transformer current I_1 and voltage U_1 harmonics determined for frequency 50 Hz with primary winding supply voltage THD_{UZ} = 30%

THD_{I1} factor in this case is equal about 30% while THD_{U1} is equal about 105%. At the same time it should be noted that higher order harmonics than 40th (not included in the standard [17]) reached significant values.

Figure 7 presents the results of measuring the RMS values of current transformer secondary side current and voltage harmonics.

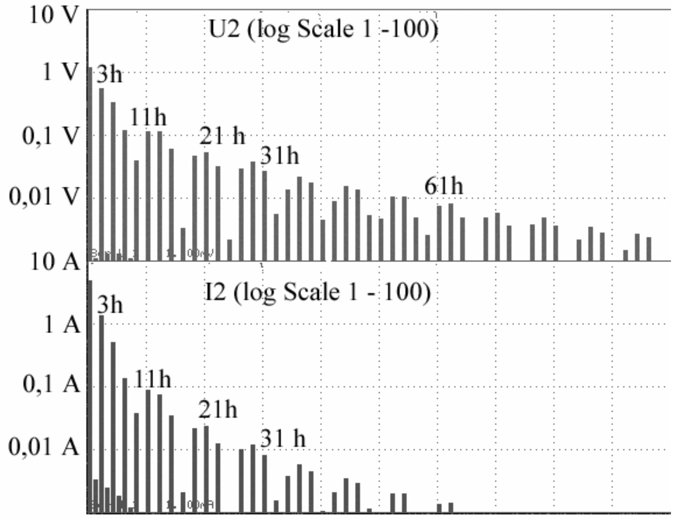

Figure 7. Current transformer current I_2 and voltage U_2 harmonics determined for frequency 50 Hz with primary winding supply voltage THD_{UZ} = 30%

In this case, like for current transformer primary side, there was also observed an increase in RMS values of the voltage and current particular harmonic due to the increase ratio of current transformer primary winding supply voltage THD_{UZ}. Secondary current total distortion factor in this case is equal about 28% and is 2% lower than on the primary side of the current transformer. The level of secondary voltage distortion is much higher then of the primary voltage which results in THD_{U2} factor value equal about 121%.

The next stage of laboratory tests was to determine the waveforms of primary current and voltage (I1, U1) as well as secondary current and voltage (I2, U2) of the voltage transformer for rated RMS value of its primary voltage equal 1000 V (50 Hz) without conductive disturbances and rated load of the secondary winding 25 VA (fig. 8).

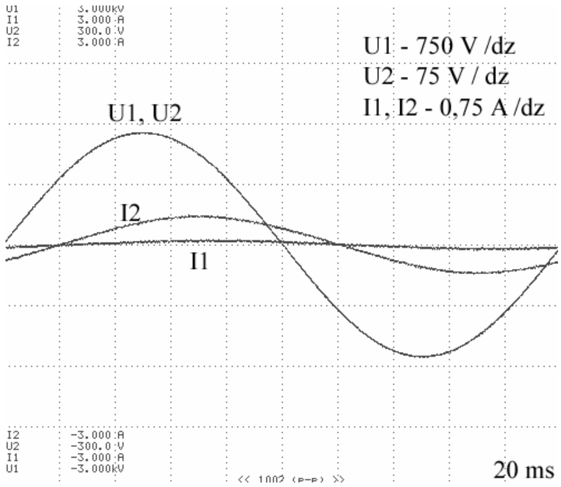

Figure 8. Voltage transformer primary and secondary sides voltages and currents waveforms for rated primary voltage RMS value 1000 V (50 Hz) without conduced disturbances for rated load of the secondary winding 25 VA

Crest and form factors of voltage transformer voltages waveforms (fig. 8) have characteristic values for sine waves, which are respectively 1,42 for crest factor and 1,11 for form factor. Crest factor of primary current is equal 1.51 while secondary current is equal 2. Form factors of both currents are equal 1.1.

Figure 9 presents RMS values of current and voltage harmonics on voltage transformer primary side.

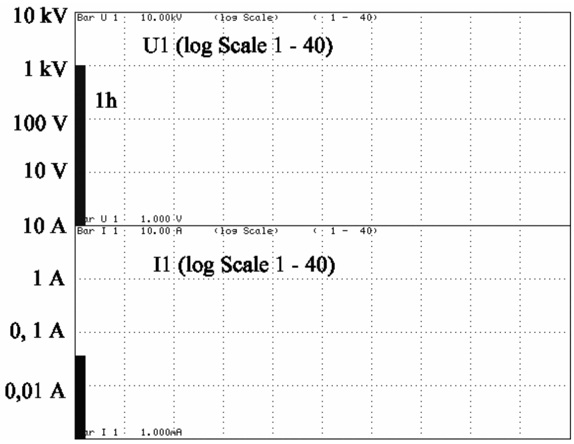

Figure 9. Voltage transformer current I_1 and voltage U_1 harmonics determined for frequency 50 Hz without conduced disturbances in supply voltage of the primary winding

Primary voltage and current only contain the first harmonic of frequency 50 Hz that is the reason why THD_{U1} factor is equal 0,15% while THD_{I1} is equal about 0,39%. The percentage difference in the RMS value of primary and secondary voltages is equal -0.48%. This value results from the voltage transformer accuracy determined for primary voltage frequency of 50 Hz in accordance with standard [18].

Figure 10 shows results of measuring the RMS values of voltage transformer secondary side current and voltage harmonics for waveforms from Figure 8.

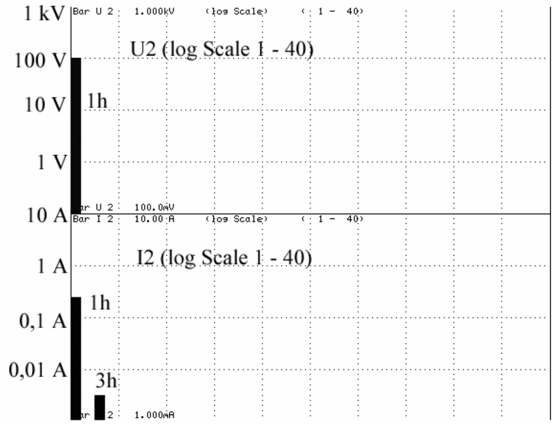

Figure 10. Voltage transformer current I_2 and voltage U_2 harmonics determined for frequency 50 Hz without conduced disturbances in supply voltage of the primary winding

Total harmonic distortion factor of voltages on both sides of voltage transformer have the same value equal about 0,15%. THD_{I2} factor is higher than on the primary side of the voltage transformer and reaches a value of 3,89%. This increase is caused by 3rd harmonic occurrence.

In the next phase of the research in the supply voltage of the voltage transformer primary winding additional conducted disturbances were generated. Their level was set, in accordance with the standard [17], by the value of the total harmonic distortion factor on 8% (fig. 11).

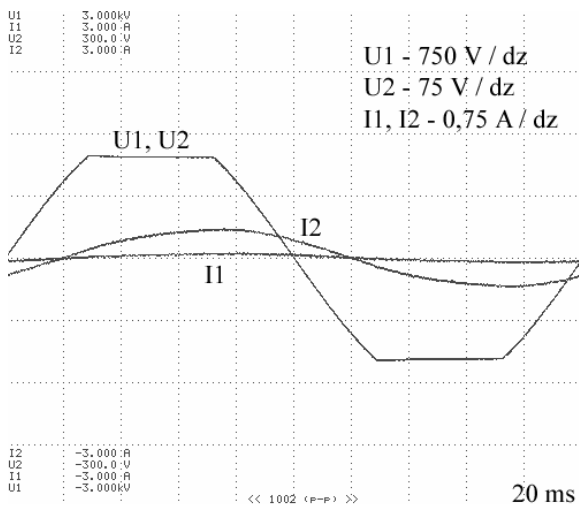

Figure 11. Voltage transformer primary and secondary sides voltages and currents waveforms for rated primary voltage RMS value 1000 V (50 Hz) and rated load of the secondary winding 25 VA with primary winding supply voltage THD_{UZ} = 8%

Figure 11 shows primary current and voltage (I1, U1) as well as secondary current and voltage (I2, U2) particular harmonics RMS values determined for conditions of rated supply voltage and load of tested voltage transformer. Waveforms are characterized by the increased value of THD which is shown as a smooth course of their tensions. Crest and form factors of voltages on primary and secondary sides of voltage transformer have same value equal 1,3 for the crest factor and 1,1 for the form factor. Crest and form factors of primary current are equal 2.12 and 1,1. On the secondary side of the voltage transformer current crest factor is equal 1.5 while form factor is equal 1.1.

Figure 12 shows results of the voltage transformer primary side current and voltage harmonics RMS values measurement for waveforms from Figure 11.

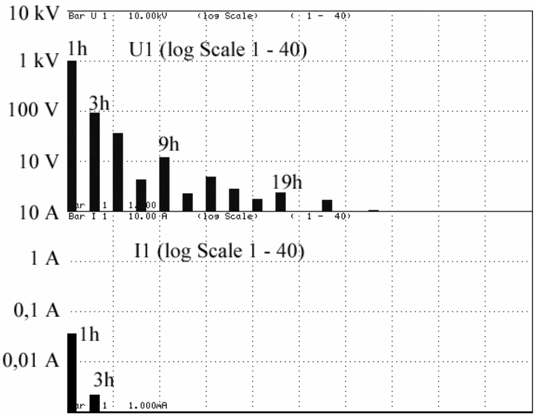

Figure 12. Voltage transformer current I_1 and voltage U_1 harmonics determined for frequency 50 Hz with primary winding supply voltage $THD_{UZ} = 8\%$

Total harmonic distortion factor THD_{U1} in this case is equal about 8% while THD_{I1} of primary current is equal about 4%.

Figure 13 presents the results of the RMS values measurements of signals on voltage transformer secondary side.

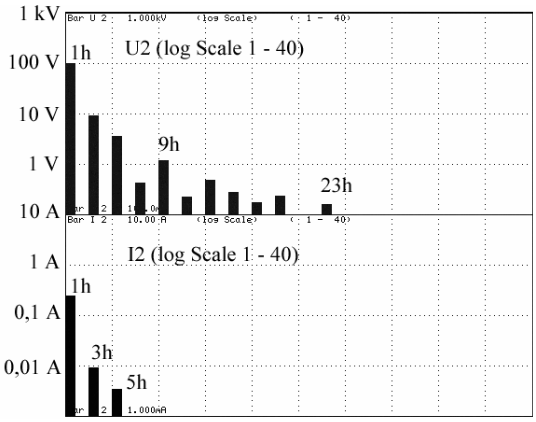

Figure 13. Voltage transformer current I_2 and voltage U_2 harmonics determined for frequency 50 Hz with primary winding supply voltage $THD_{UZ} = 8\%$

In this case THD_{U2} factor of the voltage is equal about 7,5%. Comparing the measurement system with the current and voltage transformers it should be noted that the error resulting from the application of voltage transformer is four times smaller than for the current transformer. Primary voltage (fig. 11) in order to smaller value of the THD factor regarding the primary current of the current transformer is characterized by smaller transferred waveform distortion and contains mainly harmonic which frequencies are closer to the primary signal frequency 50 Hz (U1 - fig. 12, harmonic 3., 5.). This harmonics are transferred more accurate [8] [9]. The percentage difference in the RMS values of primary and secondary voltages for distorted signals from Figure 11 is equal -0,53% and is higher than for sinusoidal signals presented in Figure 8 (-0,48%) [18].

IV. Conclusions

RMS and average values of distorted signals measured through current and voltage transformers are determined with the additional error than specified for sine waves (50 Hz). Decrease of the accuracy is proportional to the degree of transferred signal distortion.

Instrument transformer causes additional error in determining of the harmonic distortion factor.

Designated with a digital power analyzer values of the measured signals crest and form factors indicated no influence of the instrument transformer on this parameters.

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