Experimental Verification of Metrological Properties of Power Quality Analyser

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Abstract. *Electrical power quality assessment is a complex measurement task, requiring the usage of a system with suitable metrological properties. The parameters dedicated to assess the power quality are measured and registered with the use of measurement devices called power quality analysers. Examples of the results of testing a selected power quality analyser in a designed measuring system are presented in the paper. The measurement results were completed with a presentation of the uncertainty budget.*

Keywords: Power quality analyser, Harmonics, Fourier series, Uncertainty budget

1. Introduction

To assess the power quality, we use a set of standard and complementary quantities contained in documents [1] and [2]. Among them, there are two measures of harmonic content: amplitude spectrum, i.e. a set of values of particular harmonics as well as Total Harmonic Distortion (THD). These values, as well as other quantities used in power quality assessment, are measured with power quality analysers. The measurement results, registered with those devices, make it possible to diagnose the state of power network, e.g., through detecting disturbing loads. The discussion of these topics can be found, among others, in scientific papers [3] and [4]. Currently, there are a number of various power quality analysers on the market. The estimation of the uncertainty of measurement results obtained with the use of the investigated analyser is a very important issue. This paper presents the research results on a selected power quality analyser PQ-Box 100.

2. Measuring System for Testing Power Quality Analyser

The selected analyser PQ-Box 100 was tested in a measuring system presented in Fig. 1.

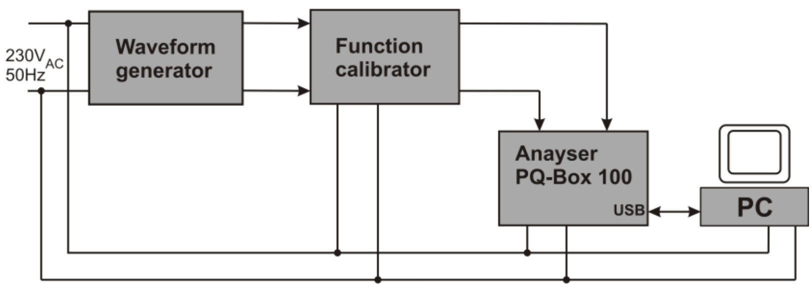

Fig. 1. Diagram of the measuring system for testing the power quality analyser PQ-Box 100

In the measuring system presented in Fig.1, waveform generator is designed to generate a given waveform and controls the operation of function calibrator. The calibrator generates a signal formed by the generator, with given rms values. The waveform generator was calibrated in the Central Office of Measures, where its accuracy was verified. The value of the limiting error of frequency reproduction, given in the calibration certificate, together with the uncertainty of its determination, for triangular wave is equal to $(198 \pm 68) \cdot 10^{-6}$ Hz. The

function calibrator generated a voltage signal with a form generated by the function generator. The value of limiting error for the considered signal values is equal to $\Delta = (0.042\%\, W_w + 0.005\%\, W_z)$, where W_w denotes the indicated value, and W_z denotes the value of measurement range. The signal generated in that way is then given to the tested analyser. Because the testing process is time-consuming, only selected values were verified: the voltage rms value and the distribution of harmonic components.
One of the test functions was a periodic signal that can be presented as a Fourier series. Such signal $u(t)$ can be shown in the form of trigonometric Fourier series, according to generally known dependencies. The representation of signal $u(t)$ in the form of a Fourier series refers to an infinitely great number of components. In practice, it is impossible. Therefore, a finite number of components are used. In practical measurement of power systems the first dozens of components are usually used. In the case considered, the measurements were limited to a harmonic of the 50th order. All the measurements were carried out in laboratory conditions, for the values of ambient temperature in a range of (22.5 ÷ 23.8) °C, and relative humidity in a range of (37.3 ÷ 46.7) %. Voltages were measured in all three phases, but given the result repeatability, the results were presented for a selected phase L_1. In all the measurements, measurement errors were determined as a difference between the measurement result and the value of reference quantity.

3. Experimental Research

Different test signals were used to verify the accuracy of measuring the rms value of voltage and harmonic content with selected power quality analysers. The investigated power quality analysers are calibrated in a two-phase process. The first phase consists in calibrating a meter with a distorted signal with a given rms value. The other phase consists in calibrating a meter with a sinusoidal signal with the same rms value as the distorted signal. During the tests two types of distorted waveforms were used:

a) Triangle wave – its expansion into Fourier series was presented with dependence (1):

$$u(t) = \frac{8U_m}{\pi^2}\left(\sin\omega_0 t - \frac{1}{3^2}\sin 3\omega_0 t + \frac{1}{5^2}\sin 5\omega_0 t - \cdots\right) \tag{1}$$

where: U_m denotes signal amplitude, $\omega_0 = \frac{2\pi}{T}$, T – test signal period

b) Waveform composed of a sum of two signals: fundamental harmonic and selected higher harmonic.

Calibration of the meter with the sinusoidal signal with the expected value of harmonic content equal to zero was aimed to testing the so-called “zero” of the analyser. For a distorted waveform composed of a sum of two signals, fundamental harmonic and selected higher harmonic, the basic harmonic had rms value equal to 230 V, and higher harmonics – value of 18.4 V, which constitutes 8 % of the value of fundamental harmonic. The rms value of such test signal was equal to 230.7 V. Table 1 presents examples of the results of verifying the test signal distorted with one harmonic component. Similarly as for other input signals, due to their repeatability, the results presented correspond to L_1 phase of the analyser. Because the publication size is limited, the results of experimental research concerning other test signals, triangle and sinusoidal signals, will be presented during the conference. All the measurements were repeated many times, at least 10 times, in order to determine the dispersion of measurement results and to eliminate possible gross error.

In order to determine the uncertainty value of a measurement result, it is necessary to correctly determine the measurement equation, which would take into consideration all the results affecting the final measurement result. In case of calibrating the analyser with distorted signal, with a given rms value, the equation for measurement error $\Delta_{THD\,dst}$ was presented with dependence (2):

$$\Delta_{THD\ dst} = W_{zmTHD\ dst} - W_{odnTHD\ dst} + \delta\Delta_{r\ dst} - \delta D_{dst} \quad (2)$$

where: $W_{zmTHD\ dst}$ – the value of quantity measured by the tested analyser, $W_{odnTHD\ dst}$ – reference value for a distorted signal, $\delta\Delta_{r\ dst}$ – value connected with the resolution of measuring device indications during the distorted signal measurement, δD_{dst} – value connected with limiting error of the reference standard during the distorted signal measurement.

Table 1. Summary of measurement results for signal with one harmonic component

Harmonic order	Measurement of THD Distorted signal with one harmonic component			
	Measurement result	Reference quantity value	Measurement error	Measurement uncertainty
	%	%	%	%
2	7.99	8.00	-0.01	0.19
3	7.99	8.00	-0.01	
4	7.99	8.00	-0.01	
5	7.99	8.00	-0.01	

To calibrate the analyser with sinusoidal signal with the same rms value as the distorted signal, the equation for measurement error $\Delta_{THD\ sin}$ is given with dependence (3):

$$\Delta_{THD\ sin} = W_{zmTHD\ sin} - W_{odnTHD\ sin} + \delta\Delta_{r\ sin} - \delta D_{sin} \quad (3)$$

where: $W_{zmTHD\ sin}$ – quantity value measured by the investigated analyser, $W_{odnTHD\ sin} = 0$ – reference value, $\delta\Delta_{r\ sin}$ – value connected with the resolution of measuring device indications during the sinusoidal signal measurement, δD_{sin} – value connected with limiting error of the reference standard during the sinusoidal signal measurement.

Combined standard measurement uncertainty $u_c(\Delta_{THD\ odk})$ of determining the analyser measurement error for distorted signals is given with dependence (4):

$$\begin{aligned} u_c^2(\Delta_{THD\ dst}) = {} & c_1^2 \cdot u^2(W_{zmTHD\ dst} - W_{odnTHD\ dst}) + c_2^2 u^2(\delta\Delta_{r\ dst}) \\ & + c_3^2 u^2(W_{zmTHD\ sin} - W_{odnTHD\ sin}) + c_4^2 u^2(\delta\Delta_{r\ sin}) \\ & + c_5^2 u^2(\delta D) \end{aligned} \quad (4)$$

where: $c_1 - c_5$ denote sensitivity coefficient, and δD denotes a value connected with limiting error of reference standard, which is determined as a geometric sum of values δD_{dst} and δD_{sin}.

When estimating the measurement uncertainty of the tested analyser, it is necessary to consider the following factors:

a) Standard uncertainty of measuring the difference of measurement results and reference value for distorted signal $W_{zmTHD\ dst} - W_{odnTHD\ dst}$,
b) Standard measurement uncertainty connected with the resolution of analyser indications during the measurement of distorted signal $\delta\Delta_{r\ dst}$,
c) Standard uncertainty of measuring the difference of the measurement result and reference value for sinusoidal signal $W_{zmTHD\ sin} - W_{odnTHD\ sin} = W_{zmTHD\ sin}$,

Because the expected value $W_{odnTHD\ sin}$ is equal to zero, randomization is done for random variable e_{THD} from measurement uncertainty $u(e_{THD})$. Standard measurement uncertainty, with normal distribution assumed, according to the uncertainty propagation law, is given with dependence (5):

$$u(e_{THD}) = \sqrt{\overline{(W_{zmTHD\ sin})}^2 + u^2(W_{zmTHD\ sin})}. \quad (5)$$

The uncertainty determined in that way is connected with the instability of indications of the tested analyser for sinusoidal signal. The complex standard uncertainty of measurement Δ_{THD} of distorted signal is expressed with dependence (6):

$$u_c^2(\Delta_{THD\ dst}) = u^2(W_{zmTHD\ dst} - W_{odnTHD\ dst}) + u^2(\delta\Delta_{r\ dst}) + u^2(e_{THD}) + u^2(\delta\Delta_{r\ sin}) + u^2(\delta D) \tag{6}$$

d) Standard measurement uncertainty connected with resolution of analyser indications during the measurement of sinusoidal signal $\delta\Delta_{r\ sin}$,
e) Standard uncertainty connected with limiting error of reference standard δD.

Standard uncertainties connected with the resolution of analyser indications, with rectangular distribution assumed, can be determined from formula (7):

$$u(\delta\Delta_r) = \frac{\Delta_r}{2\sqrt{3}} \tag{7}$$

where Δ_r denotes a value corresponding to the last indicated digit of the investigated analyser. All the components of expanded uncertainty mentioned above were determined and taken into consideration in the final uncertainty budget. Table 2 presents an example of uncertainty budget for the measurements contained in Table 1.

Table 2. Uncertainty budget for signal with a selected higher harmonic

Quantity symbol	Quantity estimate	Standard uncertainty $u(x_i)$		Probability distribution	Sensitivity coefficient c_i		Part of combined uncertainty	
W_{zm} - W_{odn}	-0.01	0.00019	V	Normal	1	V	0.00019	V
e_{THD}	0	0.08960	V	Normal	1	V	0.08960	V
$\delta\Delta_{r\ odk}$	0	0.00029	V	Rectangular	1	V	0.00029	V
$\delta\Delta_r sin$	0	0.00029	V	Rectangular	1	V	0.00029	V
δD	0	0.06731	V	Rectangular	-1	V	-0.06731	V
Δ_{THD}	-0.01	-		-	-		0.11207	V

4. Conclusions

A measuring system to assess the metrological properties of power quality analysers was presented in the paper. A number of tests on the voltage rms value and the Total Harmonic Distortion THD were carried out in this measuring system, with the use of selected test signals. The metrological analysis of the obtained measurement results let to final conclusions indicating that the determined values of uncertainty measurements of selected analyser are smaller than the uncertainty values declared by the manufacturer and defined in document [2].

References

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