ANALYSIS OF MEASUREMENT UNCERTAINTY BUDGET FOR ELECTRICAL POWER QUALITY SIGNAL GENERATOR

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Abstract

Procedure for metrological evaluation of signal generator developed for testing the electrical power quality meters is described in this paper. This work is focused on specific power quality (PQ) signal generator, described and analyzed in some previously published scientific papers [1-3]. Described method includes the estimation of individual measurement uncertainty components and presentation of overall measurement uncertainty budget. Calculations of standard, combined and expanded measurement uncertainty values, performed in accordance with the Guide to the Expression of Uncertainty in Measurement, are supported by professional instrumentation with the nominal high accuracy levels. Performed analysis of obtained measurement results and calculated uncertainty values shows that total measurement uncertainty of PQ signal generator is slightly increased with the rising of nominal RMS voltage value on the generator outputs.

Keywords: software analysis, measurement uncertainty budget, PQ signal generator, test procedure

INTRODUCTION

In order to significantly reduce possibility of various problems and disturbances during the delivery of electricity in distribution networks, continuous monitoring of transmission and consumption of electrical power is required. Among other things, this preventive activity must include the measurement and analysis of basic electrical power quality (PQ) parameters and disturbances, defined by the national and international quality standards [4]. Reliable monitoring of electrical power quality implies application of modern measurement systems and instruments. Such control instruments are available in various forms from simple devices to very sophisticated devices that can measure quality parameters and register all phenomena that disrupt the quality level of electrical power delivered to final consumers. In order to obtain valid measurement data, these devices must be adequately tested and verified.

The experimental procedure described in this paper was applied in order to analyze the measurement uncertainty of reference signal generator for testing devices for measurement of standard PQ parameters. This software based signal generator is already described in previously published scientific papers [1-3]. In this paper emphasis is placed on evaluation and analysis of total measurement uncertainty budget for this PQ signal generator. Procedure includes calculation of standard measurement uncertainties type A and type B, combined and expanded generator measurement uncertainty. In order to properly verify and calculate the components of measurement uncertainty, an experimental system for calibration of signal generator was developed. This system includes the reference calibrator Fluke 5500A [5] and digital multimeter Keithley 2010 [6].

LABORATIORY MEASUREMENT SYSTEM FOR UNCERTAINTY BUDGET EVALUATION

The most important part in the metrological verification of signal generator is evaluation of standard measurement uncertainty components including the total uncertainty budget. Specific voltage uncertainty is calculated according to the requirements of Guide to the Expression of Uncertainty in Measurement [7]. Procedure for generation of reference voltage waveforms with real PQ problems is shown in the Fig. 1. System is based on the virtual instrumentation concept, with LabVIEW software, acquisition card NI PCIe 6343 for output signal generation and external power amplifier for providing the nominal RMS output voltage value of 230 V [1-3]. Graphical illustration of real laboratory experimental system is presented in the Fig. 2. Digital multimeter - Keithley 2010 is applied for measurement of output signal parameters.

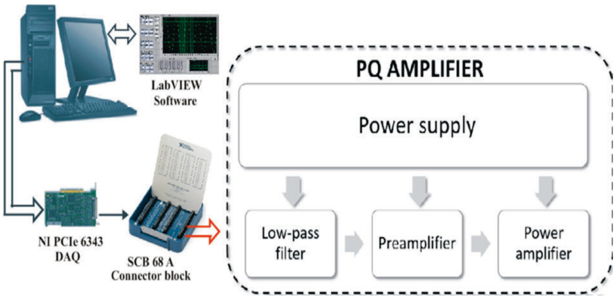

Fig. 1. *Basic configuration of software supported PQ signal generator*

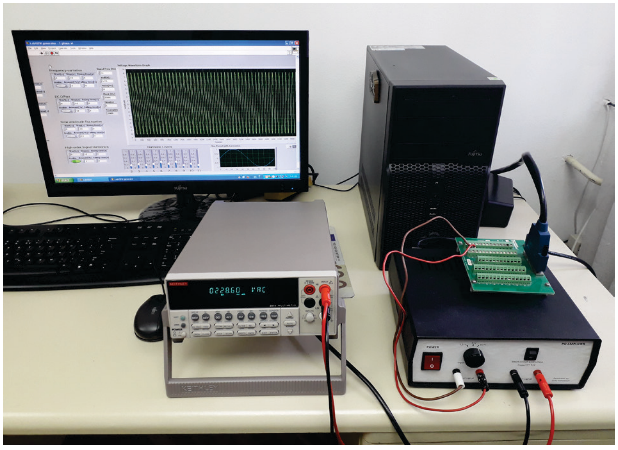

Fig. 2. *Presentation of laboratory experimental system*

Software application enables selection and definition of basic parameters and disturbances for output generation. Based on defined signal parameters, LabVIEW software successively calculates signal samples for the NI PCIe 6343 acquisition card buffer. Some basic functions are: selection of test sequence duration, signal amplitude and frequency definition, phase shift selection, DC addition offset and noise, as well as defining the amplitude and frequency of the flicker. Nominal parameters can be changed automatically during the generation procedure, according to predefined testing algorithms. In general, the signals generated at the output of data acquisition card are in range of ± 10 V. In order for these signals to be used in the testing of PQ instruments, they should be amplified to the reference voltage level of 230 V. Signal amplifier contains three basic segments: a low pass filter to limit the signal frequency range and noise, preamplifier to amplify the input signal to the appropriate reference level, and power amplifier for signal amplification to the standard RMS voltage level of 230 V [1,2].

The complete procedure includes two basic segments: the calculation of the measurement uncertainty of the signal amplifier and the calculation of the measurement uncertainty of the applied acquisition card. In this paper, the analysis of signal amplifier as the dominant source of RMS voltage uncertainty budget is presented with more details. A similar analysis can be performed for measurement of some other signal quality parameters. Experimental calibration system for PQ signal amplifier is presented in the Fig. 3. This system includes a high-precision Fluke 5500A calibrator [5] used as a source of voltage test signals for amplifier input, as well as a digital multimeter Keithley 2010 [6] used for real time measurements of output voltage parameters and disturbances.

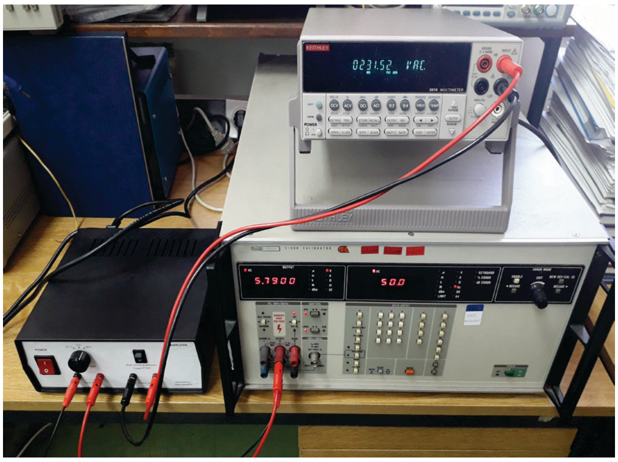

Fig. 3. *Experimental measurement system for calibration of PQ signal amplifier*

Constant effective RMS value of 2,902 V defined on the calibrator output provides the nominal amplified value on the PQ amplifier output of 230 V. Measurement is performed for nominal signal frequency value of 50 Hz, with 10 measurement cycles. The time interval between two consecutive measurement cycles is set to 5 min. Total measurement uncertainty budget of the amplifier output voltage includes the calculation of type A and type B standard measurement uncertainty values, the combined measurement uncertainty value and expanded measurement uncertainty value.

The total measurement uncertainty budget includes calculation of type A measurement uncertainty (standard deviation of the mean value for obtained measurement results), type B measurement uncertainty (uncertainty and resolution of calibrator and digital multimeter), calculation of combined uncertainty value and finally calculation of expanded measurement uncertainty value for coverage factor k = 1.96. Standard deviation of the mean value for the measurement results (type A uncertainty) is calculated according to the statistical methods applied on the obtained measurement results, using the following equation:

$$u_A(V) = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}\left(V_{RMSi} - V_{SR}\right)^2} \qquad (1)$$

Type B standard measurement uncertainty is calculated using the measurement accuracies provided by specifications of calibrator Fluke 5500A and digital multimeter Keithley 2010. According to the manufacturer specifications [5], the calibrator absolute voltage uncertainty is defined as: $\Delta V_{CAL} = \pm$ (0.03 % of output value + 60 μV). Calibrator voltage resolution is $V_{CAL\text{-}RES}$ = 10 μV. Corresponding value of calibrator Type B measurement uncertainty (u_{BCAL}) is calculated using the equation:

$$u_{BCAL}{}^2(V) = u^2{}_{B1} + u^2{}_{B2} = \left(\frac{\Delta V_{CAL}}{2.58}\right)^2 + \left(\frac{1}{2}\frac{V_{CAL-RES}}{\sqrt{3}}\right)^2 \qquad (2)$$

The absolute voltage uncertainty of digital multimeter (normal probability distribution), based on the specifications of Keithley 2010 measurement instrument, can be calculated as: $\Delta V_{MUL} = \pm$ (0.06 % of output value + 0.03 % of range value). Multimeter voltage resolution is $V_{MUL\text{-}RES}$ = 1 mV. Corresponding value of multimeter Type B measurement uncertainty (u_{BMUL}) is calculated using the equation:

$$u_{BMUL}{}^2(V) = u^2{}_{B3} + u^2{}_{B4} = \left(\frac{\Delta V_{MUL}}{2.58}\right)^2 + \left(\frac{1}{2}\frac{V_{MUL-RES}}{\sqrt{3}}\right)^2 \qquad (3)$$

The combined measurement uncertainty of PQ signal amplifier can be determined using the values of previously calculated individual measurement uncertainties of type A and type B, using the following relation:

$$u_{CAMP}(V) = \sqrt{u_A^2 + u_{BCAL}^2 + u_{BMUL}^2} \qquad (4)$$

The expanded measurement uncertainty of PQ signal amplifier is determined for required confidence level of 95%, which corresponds to the value of coverage factor k = 1.96. Using the amount of estimated combined uncertainty, the extended measurement uncertainty value is determined as:

$$u_{EXP-AMP}(V) = ku_{CAMP}(V) = 1.96u_{CAMP}(V) \qquad (5)$$

Previous calculations and obtained results show that expanded measurement uncertainty value of PQ signal amplifier is ± 0.282 V, for the nominal signal frequency value of 50 Hz, in the case of undisturbed test signal.

The calculation of measurement uncertainty of data acquisition DAQ card is described in previously published paper [1]. The previously calculated values of corresponding combined and extended measurement uncertainties of the DAQ card are: u_{CDAQ} = 0.00233 V i $u_{EXP\text{-}DAQ}$ = 0.00456 V.

Finally, expanded measurement uncertainty of entire PQ signal generator, for the required confidence level of 95%, was calculated based on the previously estimated values of amplifier and acquisition card combined measurement uncertainty, using the following relation:

$$u_{EXP-PQ}(V) = 1.96\sqrt{u_{CAMP}^2 + u_{CDAQ}^2} \qquad (6)$$

Total summary of standard measurement uncertainty budget for PQ signal generator is presented in Table 1. This summary includes all voltage uncertainty sources and calculated uncertainty values for all individual types of standard measurement uncertainty. In the case of undisturbed voltage waveform generated on PQ generator outputs, the calculated expanded measurement uncertainty value is ± 0.282 V, for nominal signal frequency value of 50 Hz. Also, further analysis of experimental results and calculations shows that total measurement uncertainty value of PQ signal generator is slightly increased with the rising of nominal RMS output voltage value.

CONCLUSION

Experimental laboratory system applied for evaluation of measurement uncertainty budget of PQ signal generator is presented in the paper. Performed analysis includes the evaluation of individual standard measurement uncertainty components in accordance with the document Guide to the Expression of Uncertainty in

Measurement. Presented experimental system includes the reference instrument Fluke 5500A that provides signals for generator calibration,

Voltage uncertainty source	Uncertainty value [V]
Standard deviation of measurement results from amplifier	0.0020162
Calibrator uncertainty	0.0267748
Calibrator resolution	0.0000058
Multimeter uncertainty in amplifier range	0.1407124
Multimeter resolution in amplifier range	0.0002887
Combined uncertainty amplifier - u_{CAMP}	0.1432500
Expanded uncertainty amplifier - u_{EAMP}	0.2807700
Standard deviation of measurement results from data acquisition card - DAQ	0.0000235
Multimeter uncertainty in DAQ range	0.0023240
Multimeter resolution in DAQ range	0.0000029
DAQ card uncertainty	0.0000013
DAQ card resolution	0.0000881
Combined uncertainty for DAQ - u_{CDAQ}	0.0023300
Expanded uncertainty for DAQ - u_{EDAQ}	0.0045600
Combined uncertainty - signal generator	0.1432690
Expanded voltage uncertainty of signal generator - u_{EGEN}	0.28 V

Table 1. *Final summary of PQ signal amplifier measurement uncertainty budget - uncertainty sources and calculated measurement uncertainty values*

and digital multimeter Keithley 2010, used to measure basic signal parameters at generator outputs. Total measurement uncertainty budget of PQ signal generator includes the calculation of the standard measurement uncertainties of type A and type B, combined uncertainty and expanded measurement uncertainty value. The calculated expanded measurement uncertainty value on signal generator outputs is ± 0.282 V.

ACKNOWLEDGMENT

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