Software Based Procedure for Estimation of Measurement Uncertainty Applied to Power Quality Measurement

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Abstract – **Software supported procedure for calculation and analysis of standard measurement uncertainty components, used for electrical power quality measurements, is presented in this paper. Experimental measurement system is functionally based on the virtual instrumentation concept. Reference measurement signals are provided by means of LabVIEW based generator of standard three-phase voltage waveforms, including simulation of typical power quality disturbances, which is already described in previously published paper [1]. Device used for measurement of three-phase voltage basic parameters is standard power quality analyzer - Fluke 435 Series II. Developed software application controls measurement, recording, graphical presentation and statistical processing of obtained measurement results, regarding to basic parameters of reference three-phase voltage waveforms. Statistical processing of obtained measurement results includes possibility for graphical presentation of recorded time diagrams and histograms of measured voltage parameters. Estimations of standard measurement uncertainty components are performed according to basic demands of relevant international documents for estimation and expression of uncertainty in measurements.**

Keywords – **Measurement uncertainty estimation, Electrical power quality measurement, Virtual instrumentation software.**

I. Introduction

The primary goal of electrical power suppliers is to fulfill basic demands of their final customers under all possible conditions and environments. Consistently, in order to avoid the high cost of equipment failures, all customers have to make sure that they obtain an electrical power supply of satisfactory quality. Also, customer electrical equipment and devices must be capable of functioning as required, even in cases when small level network disturbances are present. This can be provided only if limit values of specific power quality parameters are exactly specified. These limit values can be defined by specific demands of individual customers in the power supply quality contract with suppliers, or generally by national and international electrical power quality (PQ) standards, such as European quality standard EN 50160 [2,3].

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Previous documents define the main characteristics in low and medium voltage networks under normal operating conditions. For example, according to EN 50160, a customer is allowed to complain, if the voltage quality at the supply delivery point does not satisfy standard demands and requirements. As a consequence, standard PQ parameters should be constantly monitored, processed and analyzed. These procedures must be performed by means of advanced measurement instruments and equipment. Instruments for measurement and analysis of basic PQ parameters, such as Fluke 435 or Chauvin Arnoux C.A. 8334, based on complex digital processing functions, are capable to allow continuous power supply quality monitoring and control. It have been designed to measure relevant quality parameters and to perform software based statistical activities on single phase or three-phase power distribution networks, in order to verify compliance with relevant quality standards. Such instruments can be used as single units at selected points in the network, or alternatively several separated units can be combined in complete distributed measurement system, for monitoring and analysis of power distribution networks [4].

In order to satisfy specified parameters and measurement accuracy level, these measurement devices must be followed by the satisfactory metrological traceability. Verification and testing of such instruments must be performed in appropriate metrological laboratories. Reference devices, such as voltage and current calibrators, are available in various functional and constructive solutions. Calibrators generate reference signals with high accuracy levels, which correspond to the secondary standards, laboratory and industrial standards in metrological traceability assurance chain. There are calibration instruments for some specific types of PQ analyzers, such as solutions of multifunctional calibrators Fluke 5520A and Fluke 6100B [5].

Experimental software supported system for measurement and analysis of basic PQ parameters, presented in this paper, can be applied for estimation of measurement uncertainty components defined by the ISO Guide to the Expression of Uncertainty in Measurement. Procedure is functionally based on virtual instrumentation software. Standard PQ analyzer Fluke 435 Series II is applied for measurement of reference voltage parameters, provided by LabVIEW based generator of standard three-phase voltage waveforms defined according to requirements of European PQ standard EN 50160. Control software application enables statistical analysis and graphical presentation of obtained experimental measurement results.

II. Configuration of Experimental Measurement System

Hardware block configuration of experimental acquisition system, for measurement and software supported processing of standard PQ parameters, is presented in Fig. 1. Three-phase

Fig. 1. Block configuration of experimental system for measurement and software processing of standard PQ parameters

reference voltage waveforms, with nominal standard 230V RMS voltage values and 50Hz frequency, are provided using LabVIEW based generator of PQ waveforms and network disturbances. This signal generator is presented and described in the previously published paper [1]. It can generate various three-phase voltage test waveforms, including some special functions for simulation of typical PQ network disturbances characteristic for real power distribution networks. Voltage test waveforms and PQ disturbances can be defined according to the criteria of European quality standard EN 50160 [3].

Basic control front panel for generation and presentation of reference three-phase voltage waveforms is shown in Fig. 2. Each type of standard disturbances, for example voltage swell, voltage sag and high-order harmonic components, can be individually defined and generated using separate functional segments. Individual signal disturbances can be combined and unified in the form of final complex test waveforms. Shown front panel of signal generator includes primary control switch for selection of specific disturbance categories, such as: slow voltage variations, voltage swells, voltage sags, interruptions, voltage transients, high-order harmonics, voltage swells with harmonics and voltage sags with high-order harmonics [1].

Presented solution of signal generator provides definition and adjustment of basic signal parameters. These functions are enabled by number of control buttons and knobs, implemented on front panel of signal generator. In this specific example are presented six control knobs for definition of signal frequency, amplitude levels, disturbance start and stop times, maximum levels of voltage swell and voltage sag. Reference three-phase waveforms are generated with standard nominal frequency of 50Hz, signal phase differences of $2\pi/3$ rad and nominal RMS voltage values of 230V. Separate segment of control knobs on generator front panel is used for selection and adjustments of amplitude levels related to individual high-order harmonic components. Content of specific high-order harmonic can be precisely defined by number of control knobs for regulation of amplitude levels, from third to eleventh high-order harmonics.

Developed signal generator can be used for generation of reference waveforms applicable in testing of instruments for measurement and analysis of standard PQ parameters and network disturbances. As an example, in this specific case are tested three-phase PQ analyzer Fluke 435 Series II, previously shown in Fig. 1. Reference three-phase voltage waveforms must be sent directly to voltage inputs of tested instrument

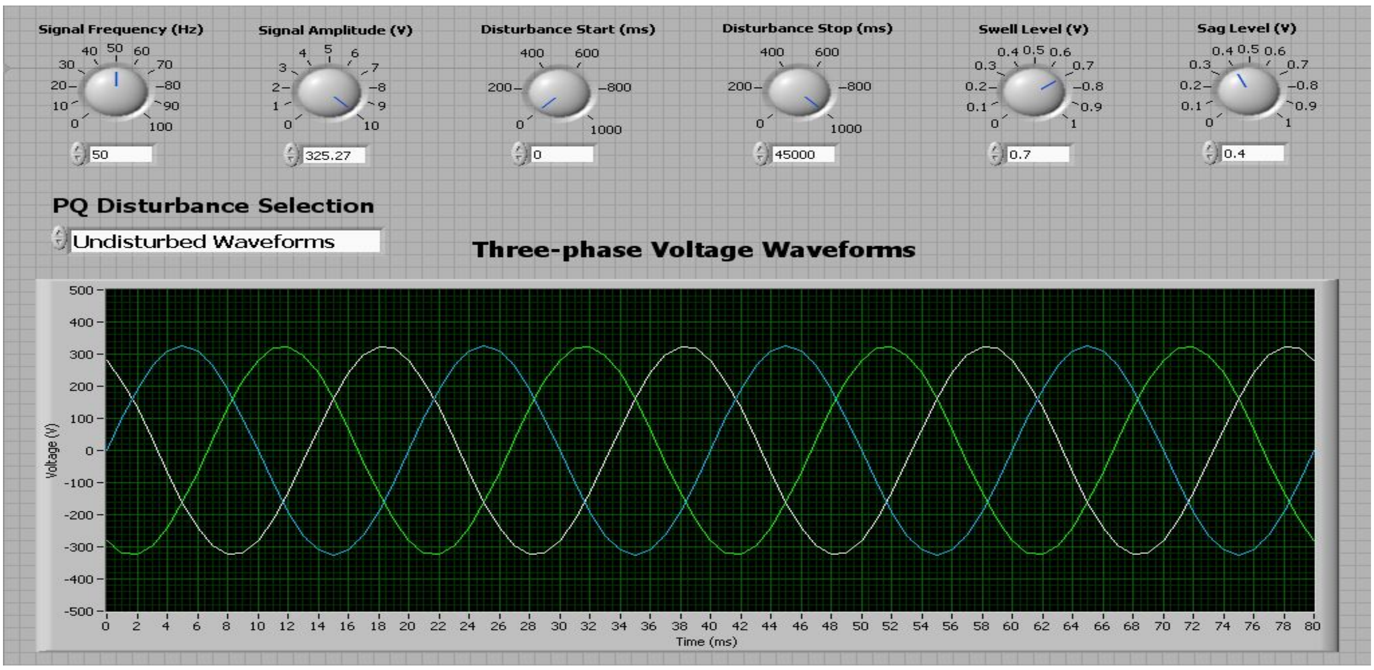

Fig. 2. LabVIEW control front panel of signal generator for presentation of standard three-phase voltage waveforms

Fluke 435. Direct two-way communication between tested instrument outputs and control computer is provided using standard USB interface. Measurement results obtained from instrument outputs can be simply transferred directly to the computer, recorded into system database and processed for graphical presentation. Some of characteristic experimental measurement results are shown in following paper segment.

III. Presentation and Software Analysis of Measurement Results

Experimental measurement system previously presented in Fig. 1 is software controlled using the virtual instrumentation concept. Application software, implemented in the control computer system, performs acquisition, recording, graphical presentation and statistical analysis of experimental results, previously obtained by measurement instrument Fluke 435.

Front panel of control software application, developed in LabVIEW environment, for graphical presentation of recorded time diagrams regarding to measured RMS voltage values per three phases of reference waveforms, is presented in Fig. 3. Beside recorded time diagrams of measurement data, control software application shows individual RMS voltage values, measured for three phases of reference voltage waveforms.

Software supported procedure for statistical processing and analysis of measured RMS voltage values is shown in Fig. 4. Specific statistical analysis includes two functional segments. First segment involves recording and presentation of statistical histograms for measured voltage values per phases. Second part of statistical analysis is calculation and presentation of standard measurement uncertainty components, defined by relevant international standards. Therefore, virtual instrument in Fig. 4 presents corresponding statistical histograms and estimated values of type A measurement uncertainty, type B measurement uncertainty and standard combined uncertainty per phases. Also, analysis includes detection and indication of minimum, maximum and average measured voltage values.

Presented average measured voltage values per phases are calculated as arithmetical means of individual measurement results per three phases, as is shown in a following equation:

$$V_{average} = \frac{1}{n}\sum_{i=1}^{n} V_i \tag{1}$$

Statistical procedure applied for estimation of individual measurement uncertainty components is performed according to the recommendations of document Guide to the Expression of Uncertainty in Measurement [6], defined by International Organization for Standardization – ISO. Estimation of type A measurement uncertainty is performed according to statistical methods applied on obtained measurement results. Type A uncertainties are calculated by following square root equation for statistical standard deviation of measured voltage values:

$$u_A(V) = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}\left(V_i - V_{average}\right)^2} \tag{2}$$

Type B standard measurement uncertainties are estimated on the basis of maximum absolute errors, calculated from obtained measurement results per phases. In this specific case, considering maximum measured voltage values and nominal reference values of 230V, for type B standard measurement uncertainty values per phases are obtained following results:

$$u_{B1}(V) = \frac{V_{\max 1} - V_{nom}}{\sqrt{3}} = \frac{230.075 - 230}{\sqrt{3}} = 0.043V \tag{3}$$

$$u_{B2}(V) = \frac{V_{\max 2} - V_{nom}}{\sqrt{3}} = \frac{230.060 - 230}{\sqrt{3}} = 0.034V \tag{4}$$

$$u_{B3}(V) = \frac{V_{\max 3} - V_{nom}}{\sqrt{3}} = \frac{230.067 - 230}{\sqrt{3}} = 0.039V \tag{5}$$

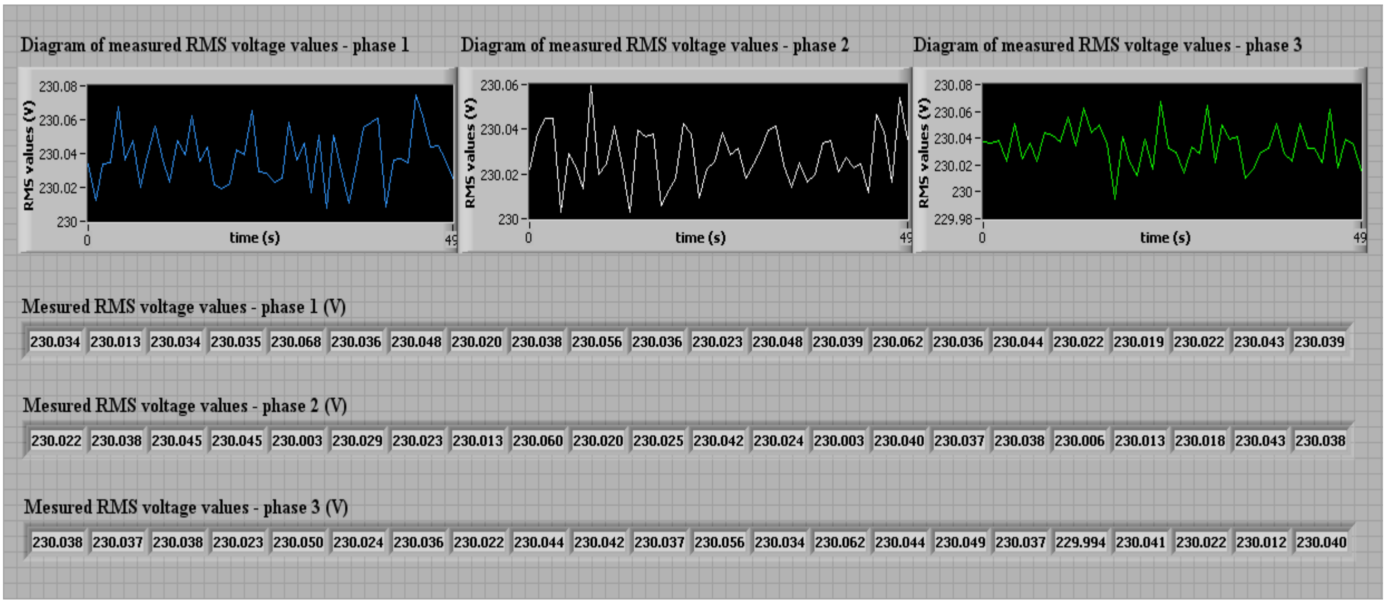

Fig. 3. Front panel of software application for presentation of time diagrams and measured RMS voltage values per phases

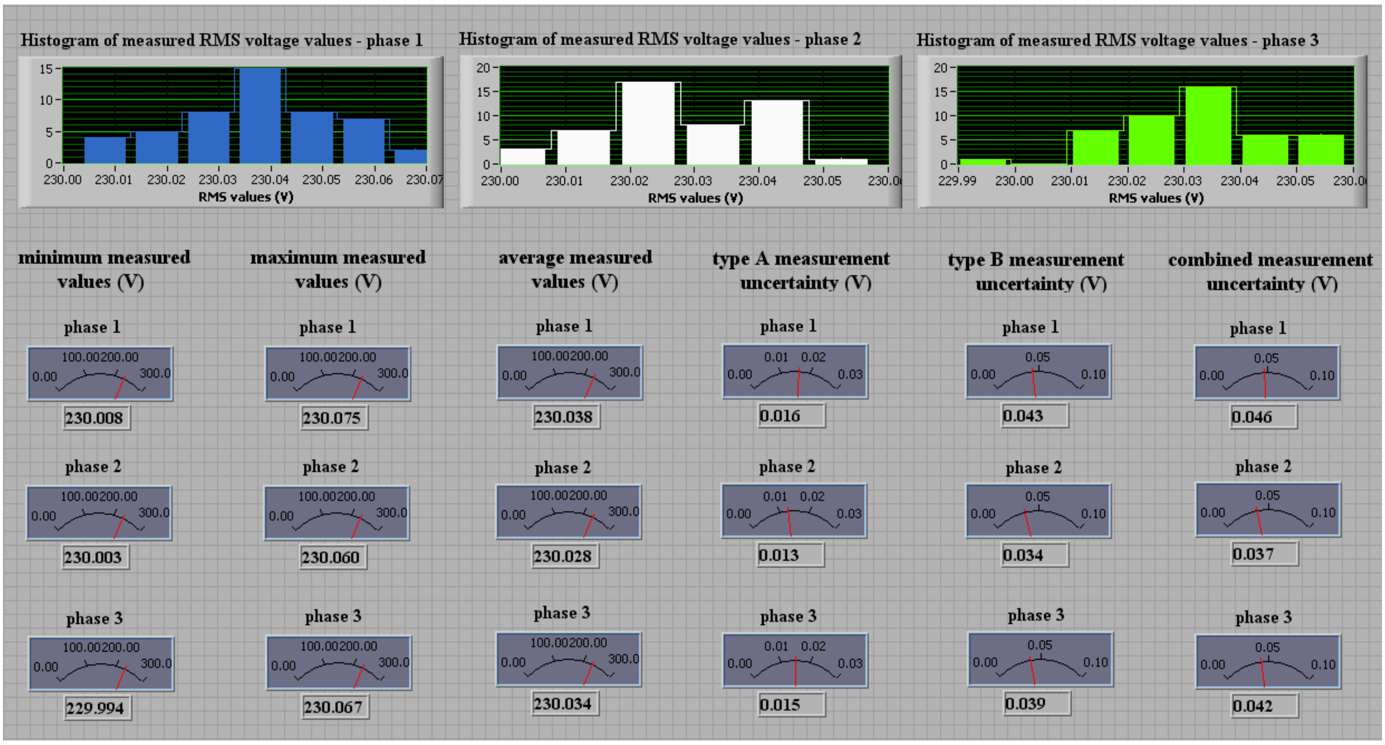

Fig. 4. Statistical processing and analysis of obtained measurement results performed in LabVIEW software environment

On the basis of previously estimated individual values of type A and type B measurement uncertainties, calculation of standard combined measurement uncertainties per phases is performed using the following square root equations [6]:

$$u_{C1}(V) = \sqrt{u_{A1}^2 + u_{B1}^2} = 0.046\,V \quad (6)$$

$$u_{C2}(V) = \sqrt{u_{A2}^2 + u_{B2}^2} = 0.037\,V \quad (7)$$

$$u_{C3}(V) = \sqrt{u_{A3}^2 + u_{B3}^2} = 0.042\,V \quad (8)$$

Similar procedure for software analysis of measurement results and estimation of standard uncertainty values can be applied for others important PQ parameters, such as: signal frequency, signal phases, high-order harmonic components, power factor and others parameters. Some of characteristic measurement results will be presented in following papers.

IV. Conclusion

Possibility of using the virtual instrumentation software in procedure for statistical processing of PQ measurement results and estimation of standard measurement uncertainty values is described in this paper. Measurement of basic parameters for three-phase voltage waveforms are performed by standard PQ analyzer Fluke 435 Series II. Reference three-phase voltage waveforms, with standard parameters, are generated using the generator of PQ waveforms based on virtual instrumentation concept. Experimental measurement system is controlled by developed software application, which performs presentation of measurement results, presentation of recorded statistical histograms, indication of minimum and maximum measured voltage values, calculation of average measured values and standard measurement uncertainties. Calculations of type A measurement uncertainty, type B measurement uncertainty and combined uncertainty values are performed in accordance with recommendations of relevant document Guide to the Expression of Uncertainty in Measurement, prescribed by International Organization for Standardization – ISO.

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