Reference Waveforms Using the Control Software Applicationi in the Labview Environment

Milan Simic[1], Goran Miljkovic[2], Dragan Živanovic[3], Dragan Denic[4], Zivko Kokolanski[5]
[1,2,3,4]The University of Niš, Faculty of Electronic
Engineering Aleksandra Medvedeva 14, 18000 Niš, Serbia
{milan.simic@elfak.ni.ac.rs} {goran.miljkovic@elfak.ni.ac.rs}
{dragan.denic@elfak.ni.ac.rs} {dragan.zivanovic@elfak.ni.ac.rs}

[5]The SS. Cyril and Methodius University
Faculty of Electrical Engineering and Information Technologies
1000 Skopje, Macedonia
kokolanski@feit.ukim.edu.mk

ABSTRACT: *We have outlined the software-based evaluation of electrical power quality parameters in the Wireless Sensor Network settings. The proposed components include the reference waveforms, a software application for the measurement of standard PQ parameters and two microcontroller-based wireless sensor modules for transmission. The quality parameters are used to reference functions with the control software application in the Lab environment. We have used the IEEE standard 802.15.4 protocol for transmission. According to the Guide to the Expression of Uncertainty in Measurement, the procedure for calculating Type A, Type B, combined and expanded measurement uncertainty, is supported using professional instrumentation with high accuracy levels. Metrological evaluation of a supported experimental system based on wireless sensor network (WSN), applicable in the measurement of electrical power quality (PQ) parameters and disturbances, is presented in this paper. The system includes a based generator of reference waveforms, a software application for measuring standard PQ parameters and two microcontroller-based wireless sensor modules for transmitting and receiving measurement results. Measures of basic quality parameters for reference waveforms are performed using the control software application in the LabVIEW environment. Wireless sensor networks are based on the communication standard IEEE 802.15.4 (Zigbee). Metrological assessment includes calculating measurement uncertainty components and the final presentation of measurement uncertainty budget. The procedure for calculation of Type A, Type B, combined and expanded measurement uncertainty, according to the Guide to the Expression of Uncertainty in Measurement, is supported using professional instrumentation with high accuracy levels.*

Keywords: Measurement Uncertainty, Wireless Sensor Network, Power Quality Measurement, Virtual Instrumentation

Received: 19 March 2023, Revised 12 June 2023, Accepted 24 June 2023

DOI: 10.6025/jnt/2023/14/3/61-67

1. Introduction

Having in mind the challenges of the modern smart grids and great importance of PQ problems, in the recent years special attention is given to development of microprocessor based sophisticated measurement systems for PQ monitoring**.** In the last decade especially attractive are virtual instruments, which are well suited for development of flexible computer supported measurement systems. Virtual instruments can be successfully used for research and scientific purposes [1-3]. In order to satisfy the specified level of the measurement uncertainty and characteristics, devices for measurement of PQ parameters must be followed by appropriate metrological evaluation. Measurement instruments can be used as single devices at specific points in power distribution network. Alternatively, number of separated devices can be combined in distributed measurement system, for permanent monitoring and analysis of quality in power distribution networks.

Advances in wireless communications and electronics lead to development of wireless sensor networks (WSN), as low cost, low power and multifunctional sensors. These WSN sensor nodes are small and able to sense various data, process this data and communicate with each other or with central base station. Basic advantages of WSN systems are: self organizing capabilities, short range broadcast applications, changing of network topology in order to avoid fading and potential failures, including significant savings in energy consumption, transmission and computing capabilities [4].

WSN based networks can be used in various military applications, environmental measurements of various physical quantities, home intelligence, prevention of many disasters, surveillance, medical care purposes and others [5], [6].

Significant segment in real-time implementation of WSN for various measurement purposes is metrological assessment. Procedure for analysis of measurement uncertainty shown in this paper includes calculation of measurement uncertainty components and presentation of total uncertainty budget in accordance with relevant document - Guide to the Expression of Uncertainty in Measurement [7], defined by International Organization for Standardization - ISO. For this purpose are used reference PQ signal generator for simulation of typical network disturbances and experimental WSN based system for measurement of standard PQ parameters, presented and described in the previously published papers [8], [9].

2. Configuration of Experimental System for WSN Based PQ Measurement

Hardware configuration of experimental system, developed for WSN communication based measurement of standard PQ parameters and disturbances, is presented in Figure 1. Software supported generator of reference PQ waveforms is applied for generation of reference three-phase voltage waveforms. This generator is presented and described in previously published paper [8]. It can generate long time and short time reference waveforms, including special functions for simulation of various network disturbances, typical for real electrical power distribution networks. Procedure includes computer with the LabVIEW control application and data acquisition board PCIe NI 6343, supported with standard connection block SCB-68A. Control software application implemented on PC platform performs acquisition, measurements, recordings and graphical presentations of measurement data (RMS voltage values, signal frequency values and levels of high-order harmonics).

WSN communication for transmission of measurement results includes two WSN modules (transmitter and receiver), with Cortex M3 architecture, called the SPaRCMosquito v.2.

Communication and transferring of the measurement results between application software for PQ measurement and WSN module on transmitter side of experimental system is provided using standard USB interface. WSN base module is supported with communication standard IEEE 802.15.4, also known as Zigbee. On receiver side of experimental measurement system VISA drivers from LabVIEW software are used for providing USB communication and transferring of results from receiver WSN module to laptop computer for further data analysis.

Basic functions enabled using software supported PQ signal generator are: definition of nominal amplitude and frequency values, definition of signal sample rate and duration of final test sequence, generation of noise with Gaussian distributed amplitude, variations of nominal signal frequency value, slow variations of signal amplitude value with defined frequency of variations, definitions of DC offset, voltage swell and voltage sag and possibilities for generation of high-order harmonic components [8]. Definition of reference waveforms, with specified levels of signal disturbances, can be performed directly inside the control front panel and block diagram of software application. Each category of signal disturbances can be defined and generated by separate functional segments. Individual disturbances can be combined and unified in form of final complex sequence, according to basic requirements of relevant European PQ standard EN 50160 [10].

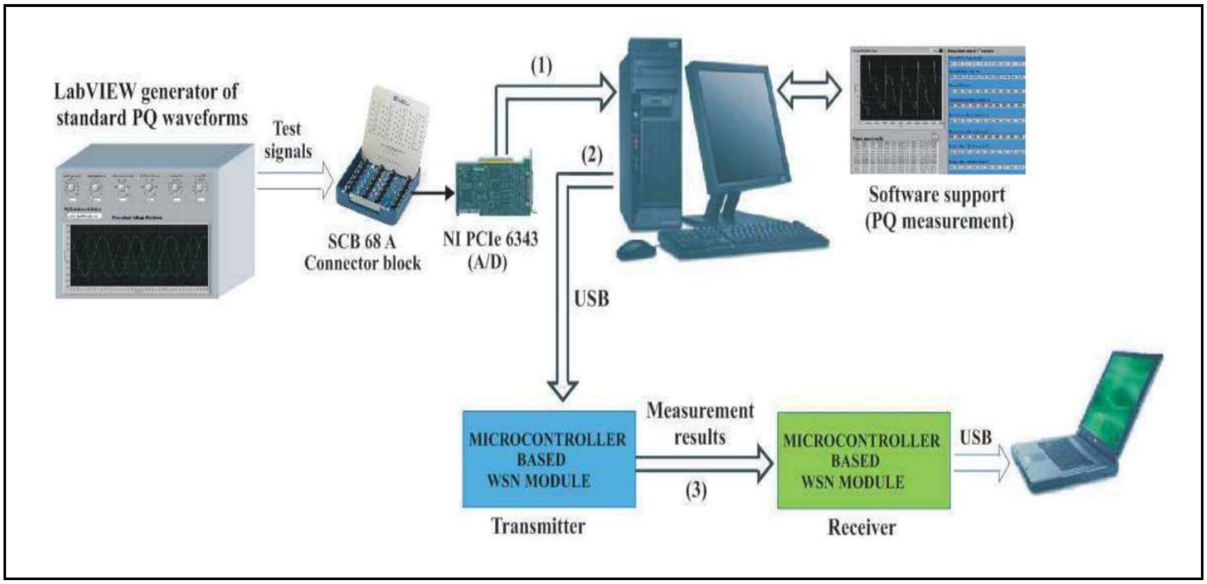

Figure 1. Hardware configuration of experimental system for WSN communication based electrical power quality measurement

Separated segment of control functions is used for selection and variation of amplitude levels related to individual highorder harmonics. Front panel of LabVIEW virtual instrument, for presentation and measurement of basic parameters related to voltage test waveform generated with certain level of signal harmonic components, is presented in Figure 2. Specific voltage waveforms are generated with nominal frequency value of 50 Hz and normalized RMS voltage value of 1 V. Shown control software is implemented on transmitter side of experimental system. This application enables simultaneous presentation of voltage waveform, tables with obtained measurement results and write box with chronologically measured values of quality parameters: RMS voltage values, frequency values, THD - Total Harmonic Distortion factor values and individual highorder harmonics. Measurement is performed in cycles. Time interval for each PQ measurement cycle is set on 1 second.

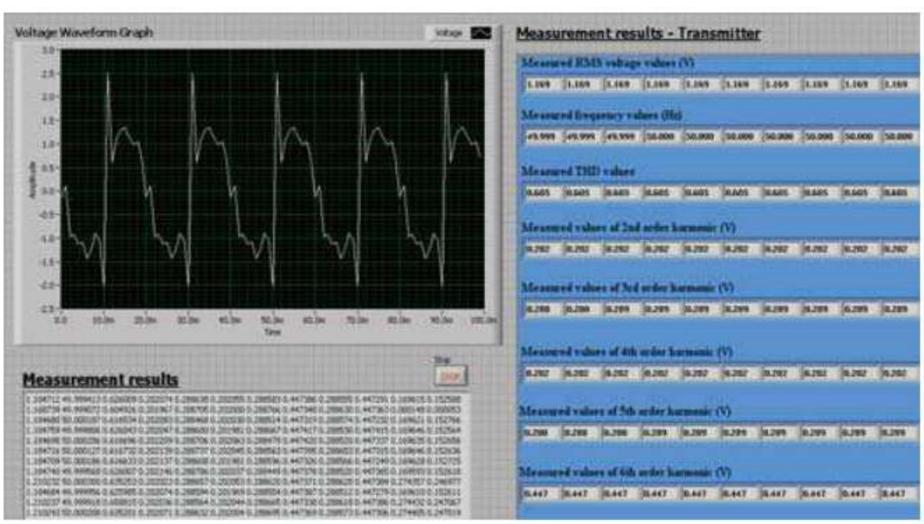

Figure 2. Software application for data acquisition, measurement of PQ parameters and presentation of measurement results - transmitter

The WSN based network communication is applied for transferring of obtained measurement results to the receiver side of presented experimental system. LabVIEW software application implemented on the receiver side of experimental system, for presentation of received voltage waveform and received measurement results, is shown in previous Figure 3.

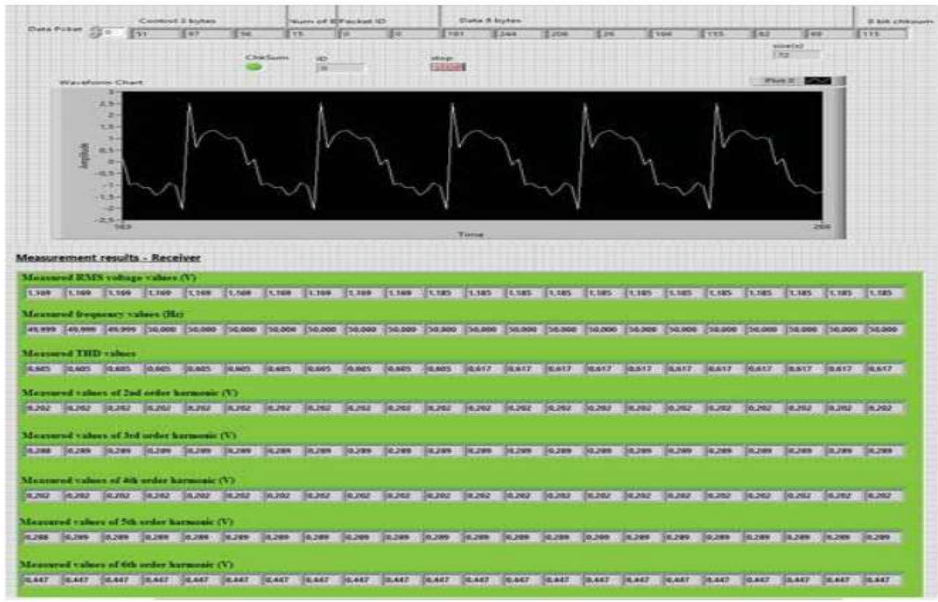

Figure 3. Software application for presentation of received voltage signal and measurement results – receiver side

3. Calculation of Standard Measurement Uncertainty Components

Most important segment in metrological assessment of experimental system for the WSN based PQ measurement is calculation of measurement uncertainty components and final presentation of measurement uncertainty budget related to the PQ signal generator, applied as the source of reference voltage signals. Calculation of uncertainty is performed according to the standard document Guide to the Expression of Uncertainty in Measurement [7]. Voltage signal generated using the virtual instrument is physically reproduced by the data acquisition (DAQ) card containing the digital to analog (D/A) converter. Voltage signal generated on D/A converter output is usually standardized to reference voltage level, typically about ±10 V.

Procedure for uncertainty calculation is applied for each of measured signal quality parameters. In this paper is presented and analyzed method used for calculation of uncertainty in measurement of standard RMS voltage values. Measurement system applied for calculation of generator uncertainty is consisting of computer with DAQ card PCIe NI 6343 [11] for generation of reference voltage waveforms and 6 ½ digital multimeter Fluke 8846A [12] for measurement of DAQ card output RMS voltage values. Nominal RMS voltage value of the analog signals generated by DAQ card was set to 5V. Measurement of generator output voltage is performed for two values of signal frequency, 50 Hz and 1 kHz. In order to calculate Type A measurement uncertainty, 10 measurement cycles for each input signal frequency are performed. Interval between two successive measurement cycles is set to 5 min. RMS voltage values measured on the DAQ card output and calculated standard deviations, for two signal frequency values, 50 Hz and 1 kHz, are presented in Table 1. Overall measurement uncertainty budget, including the calculations of standard, combined and expanded measurement uncertainty of applied PQ signal generator is presented in Table 2.

Calculation of standard measurement uncertainty involves Type A uncertainty components (standard deviation of the mean values for measurement results) and Type B uncertainty components, including the multimeter uncertainty, multimeter resolution, DAQ card uncertainty and DAQ card resolution.

Standard deviation of the mean (Type A measurement uncertainty) is calculated according to the statistical methods applied on measurement results, using following equation:

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

Type *B* standard measurement uncertainties are calculated on the basis of data and measurement accuracies provided by specifications of instruments Fluke 8846A and DAQ card.

No.of measurements	50 Hz	1 kHz
	$V_{RMS}\,[V]$	$V_{RMS}\,[V]$
1	4.99308	4.99381
2	4.99298	4.99378
3	4.99318	4.99379
4	4.99311	4.99378
5	4.99305	4.99376
6	4.99318	4.99376
7	4.993	4.99381
8	4.99309	4.99378
9	4.99297	4.99376
10	4.99315	4.99376
St.Deviation	0.00007	0.00002
St.Dev/$\sqrt{n}$	0.00002	0.00001
$V_{AVERAGE}(V)$	4.99308	4.99378

Table 1. Measurement results and calculated standard deviations for measured RMS output voltage values

According to instrument specifications [12], the multimeter absolute voltage uncertainty is ΔV_{MUL} = ± (0.06 % of output value + 0.03 % of range value). Multimeter voltage resolution is $V_{MUL\text{-}RES}$ = 10μV. Then, corresponding value of multimeter Type B uncertainty (u_{BMUL}) is calculated using equation:

$$u_{BMUL}{}^2\,(V) = u^2_{B1} + u^2_{B2} = \left(\frac{\Delta V_{MUL}}{2.58}\right) + \left(\frac{1}{2}\,\frac{V_{MUL\text{-}RES}}{\sqrt{3}}\right)^2 \quad (2)$$

According to DAQ card PCIe NI 6343 specifications [11], DAQ card voltage absolute uncertainty value at full scale is V_{DAQ} = 3.271 μV. Voltage resolution value of DAQ card is $V_{DAQ\text{-}RES}$ = 305 μV. Then, corresponding DAQ card Type B uncertainty (u_{BDAQ}) is calculated using the following equation:

$$u_{BDAQ}^{2}(V) = u^{2}_{B3} + u^{2}_{B4} = \left(\frac{\Delta V_{DAQ}}{2.58}\right) + \left(\frac{1}{2}\,\frac{V_{DAQ\text{-}RES}}{\sqrt{3}}\right) \tag{3}$$

Calculation of combined voltage measurement uncertainty value (u_{CDAQ}) is based on the previously calculated individual Type A and Type B measurement uncertainty values, using (1), (2) and (3), with following equation:

$$u_{CDAQ}(V) = \sqrt{u^{2}_{A} + u^{2}_{BMUL} + u^{2}_{BDAQ}} \tag{4}$$

Finally, expanded measurement uncertainty value (u_{EXP}) is calculated for desired confidence probability level of 95% (value of coverage factor k is 1.96). Using the previously calculated value of the combined measurement uncertainty, expanded measurement uncertainty value is calculated as:

$$u_{EXP}(V) = ku_{CDAQ}(V) = 1.96u_{CDAQ}(V) \tag{5}$$

The results presented in Table 2 suggest that expanded voltage measurement uncertainty values are ± 0.00456 V, for the both signal frequency values of 50 Hz and 1 kHz.

Uncertainty source	Type	Notation	Uncertainty for 50Hz [V]	Uncertainty for 1kHz [V]	Probability distribution	Coverage factor	Standard uncertainty for 50 Hz [V]	Standard uncertainty for 1 kHz [V]
Standard deviation	A	u_A	0.0000235	0.0000059	Normal	1	0.0000235	0.0000059
Multimeter uncertainty	B	u_{B1}	0.005995847	0.005996267	Normal	2.58	0.002323972	0.002324135
Multimeter resolution	B	u_{B2}	5.00E-06	5.00E-06	Uniform	1.732050808	2.88675E-06	2.88675E-06
DAQ card uncertainty	B	u_{B3}	3.27E-06	3.27E-06	Normal	2.58	1.26783E-06	1.26783E-06
DAQ card resolution	B	u_{B4}	0.000152588	0.000152588	Uniform	1.732050808	8.80967E-05	8.80967E-05
						Combined	0.00233	0.00233
						Expanded $k = 1.96$	0.00456	0.00456

Table 2. Overall measurement uncertainty budget - standard, combined and expanded voltage uncertainty calculations

4. Conclusion

Procedure for detailed metrological assessment of WSN based measurement of standard PQ parameters is described in the paper. This software oriented method includes calculation of standard, combined and expanded uncertainty components and presentation of overall measurement uncertainty budget. Evaluation of standard measurement uncertainty involves Type A uncertainty components (standard deviation of the measurement results) and Type B uncertainty components, including the specified instrument uncertainty and resolution values. Most important component in metrological assessment chain is PQ signal generator, including computer and data acquisition card, applied as the source of reference voltage waveforms. Metrological performances of WSN based PQ measurement system are evaluated for two signal frequency values, 50 Hz and 1 kHz. This solution can be implemented in distributed systems for electrical power distribution monitoring, with a number of remotely controlled measurement stations.

Acknowledgement

This work was supported by national scientific project, with reference number TR 32019, sponsored by Serbian Ministry of Education, Science and Technological Development.

References

[1] de la Rosa, J. G., Pérez, A. A., Salas, J. C., Fernández, J. M., and Muñoz, A. M. (2012). A Novel Virtual Instrument for Power Quality Surveillance based on Higher-Order Statistics and Case-based Reasoning. *Measurement*, 45(7), 1824–1835.

[2] Montenegro, D., Hernandez, M. E., and Ramos, G. A. (2014). A Realistic Generator of Power Quality Disturbances for Practicing in Courses of Electrical Engineering. *Computer Applications in Engineering Education*, 23(3), 391-402.

[3] Zhu, W., Ma, W. Y., Gui, Y., and Zhang, H. F. (2013). Modelling and Simulation of PQ Disturbance based on Matlab. *International Journal of Smart Grid and Clean Energy*, 2 (1), 18–24.

[4] Lim, Y., Kim, H. M., and Kang, S. (2010). A Design of Wireless Sensor Networks for a Power Quality Monitoring System. *Sensors*, 10(11), 9712-9725.

[5] Akyildiz, I. F., and Vuran, M. C. (2010). *Wireless Sensor Networks*. John Wiley & Sons.

[6] Mahgoub, I., and Ilyas, M. (2006). *Smart Dust: Sensor Network Applications, Architecture and Design*. CRC Press, Taylor & Francis Group.

[7] ISO. (1993). *Guide to the Expression of Uncertainty in Measurement*. International Standard Organization, Geneva.

[8] Simic, M., Kokolanski, Z., Denic, D., Dimcev, V., Živanovic, D., and Taskovski, D. (2017). Design and Evaluation of Computer-based Electrical Power Quality Signal Generator. *Measurement*, 107, 77-88.

[9] Simic, M., Planinšiè, P., Denic, D., Gleich, D., Živanovic, D., and Malajner, M. (2017). Software based Experimental System for Electrical Power Quality Measurement using the Wireless Sensor Network Modules. *Facta Universitatis - Series Automatic Control and Robotics*, 16 (2), 131-141.

[10] Copper Development Association. (2004). *Power Quality Application Guide, Voltage Disturbances, PQ Standard EN 50160*.

[11] National Instruments Corporation. (2014). *PCIe NI 6343 Multifunction Data Acquisition Card DAQ - Specifications*.

[12] Fluke Corporation. (2006). *Fluke 8845A/8846A Digital Multimeter – Users Manual*, Rev. 3, 3/11, July 2006.