Monitoring of Power Quality in Industry

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*Abstract-*The paper deals with power quality in the industry. A virtual instrument-power meter and power quality analyser is described. The instrument enables complete monitoring of all the powers and power quality parameters, as well as simultaneous measurements of voltages and currents and application for Motor Current Signature Analysis (MCSA) and technical diagnostics. The results of measurements of different industrial plants are shown and their influence on the power quality is evaluated and discussed. The complete and continual measurements of the powers and power quality characteristics give basis for consideration of the technical and economical aspects of planning and contracting of the electrical power needs and characteristics.

I. Introduction

The implementation of the new renewable power sources in the power system, on the one hand, and the usage of the power by the different nonlinear loads in the industry, on the other hand, generates harmonics and other disturbances in the power system. A lot of negative effects produced by the harmonics in the power system are known, starting with increased losses, malfunctions of the electrical protection devices; overheating and losses in transformers, switchgear, and power cables; overheating, vibration, and losses in ac motors, etc [1, 2]. The dealing with these negative effects demands previous complete monitoring of the powers and power quality characteristics. The methods and procedures for compensation i.e. undertaking technical and economic measures, suppose previous monitoring. A lot of different instruments for power quality monitoring are available on the market [3-5]. However, the measurement results delivered by particular instruments frequently vary depending on the algorithms and definitions used by them which are unknown to the users [6-10]. Because of that and with the aim to have possibility of usage of different models and definitions, a virtual instrument-power meter and power quality analyser is developed. In the following section a description of the instrument is given. The instrument was used for monitoring of the powers and power quality parameters in different industries, which is presented in the section III of this contribution.

II. Design of the instrument for power quality monitoring

A. Description of the hardware

The instrument has two modules for analog inputs:

- 3-channel 300 V rms analog input module with 50 kS/s per channel simultaneous inputs for phase voltages measurement,
- 4-channel current input, 5 A rms measurement, 50 kS/s per channel simultaneous inputs and
- built–in antialias filters.

The modules use a compact DAQ, 4 slot chassis with USB connection. The chassis runs the analog input modules simultaneously. The chassis has four built-in general purpose 32 bit counter/timers. The Delta-Sigma ADCs are with 24 bits. The internal master time-base is f_M=12,8 MHz. The accuracy is ±0,23 % of the read value, ±0,05 % of the range (for temperature range from -40 °C to 70 °C).

B. Software of the power monitoring instrument

The LabVIEW™ graphical programming language was used for creation of the virtual instrument for

measurement of the power quality characteristics. The virtual instrument beside the measurement of the phase voltages, phase and neutral currents, contains software modules running in parallel: power monitor, EN 50160 voltage monitor, FFT analyser, vector analyser, and flicker analyzer. In Figure 1 the source code for subroutine POWER is shown.
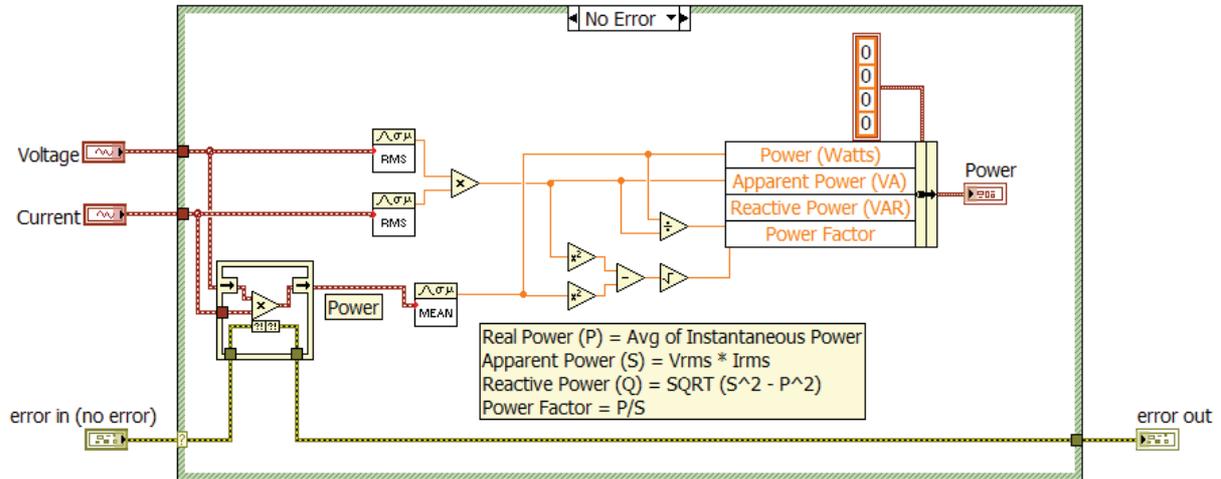

Figure 1. Block diagram-source code of the subroutine POWER

C. Calibration of the instrument

The calibration and verification of the instrument was performed using a procedure based on the direct measurement of value of the standard. For calibration of the virtual instrument, the laboratory calibrator FLUKE 5500A was used. The calibrator is a multifunction programmable source which generates reference values of DC voltage and current, AC sine wave and nonsinewave voltage and current, DC and AC power, voltage and current distorted with harmonics, with sinusoidal form at different frequencies. The errors and the drift with the time and temperature for all the listed quantities, outputs of the calibrator FLUKE 5500A, are given in the calibrator specifications and calibration certificate. Metrological traceability to the national standards is achieved by calibration of the FLUKE 5500 at the National Bureau of Metrology of R. Macedonia. The virtual instrument was calibrated for all measuring quantities by programming the calibrator outputs and measurement under the condition of repeatability. A part of calibration results are given in Tables I and II and in Figure 2.

Table I. – Voltage calibration

U_{ref} [V]	U_{meas} [V]	THD [%]	ξ [%]
1	0.99973	0.012	-0.027
10	9.9974	0.008	-0.026
100	99.976	0.010	-0.024
200	199.95	0.012	-0.025
230	229.95	0.012	-0.022
250	249.95	0.013	-0.020

Table II. – Power calibration

U_{ref} [V]	I_{ref} [A]	P [W]	PF	P_{meas} [V]	ξ [%]
230	0.5	115	1.00000	115.13	0.113
230	1	230	1.00000	230.08	0.035
230	2	460	1.00000	459.97	-0.007
230	3	690	1.00000	690.96	0.139
230	4	920	1.00000	920.85	0.092
230	5	1150	1.00000	1150.7	0.061

The complete calibration results of all the measurement quantities and all the ranges have shown that the virtual instrument for measurement of power quality is very accurate and precise instrument.
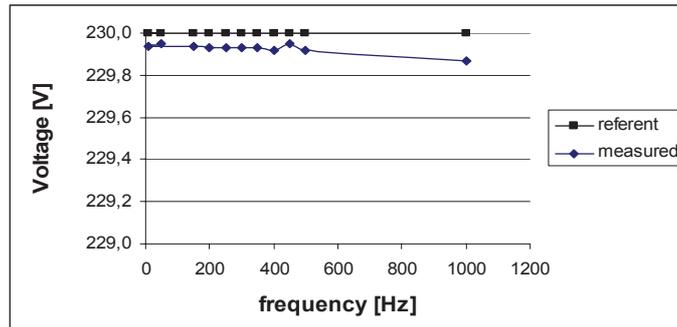

Figure 2. Voltage frequency characteristic

D. Measurement uncertainty

Measurement uncertainty is estimated according the ISO/IEC Guide of the Expression of Uncertainty in Measurement [11], mainstream procedure. Four independent sources of uncertainty were considered for modelling the measurement error of the virtual instrument: the repeatability of the instrument, the resolution of the instrument, the uncertainty of the value of the standard, and the drift of the standard. The model of the measurement error is:

$$E_X = X_I \pm \Delta X_I - X_S - \Delta X_S \qquad (1)$$

where: X_I –the instrument reading, ΔX_I- correction due to the resolution of the instrument, X_S- the value of the standard, and ΔX_S -the drift of the standard.

The calibration measurement result X_i is characterized by the mean $\overline{X}$, standard deviation σ and the student probability distribution function (pdf). The correction due to the resolution of instrument is characterized by the resolution value, standard deviation and the rectangular pdf. The value of the standard is characterized by nominal value, standard uncertainty and normal pdf. The correction due to the drift of the standard is characterized by ΔX_S, the standard deviation and rectangular pdf. The combined uncertainty of the measurement error is:

$$u_c^2(E_x) = \sqrt{u^2(X_I) + u^2(\Delta X_I) + u^2(X_S) + u^2(\Delta X_S)} \qquad (2)$$

Table III. - Measurement Uncertainty

	Voltage	Current	*THD$_I$*	P
Combined Uncertainty [ppm]	504	2814	3980	3320

III. Monitoring Results

The monitoring of power quality in order to study how the industry is influencing power quality level is realized near a plastic production plant, textile factory, marble production plant, and a still production plant. As an example of a device with variable speed drive the measurement of an inverter type air-conditioner are made. The measurements were also used for practical testing and verification of the developed instrument performances and use of the instrument for Motor Current Signature Analysis (MCSA). A short presentation of some of the monitoring results is given in the following part of the paper.

A. Monitoring of power quality near plastic production plant

The plastic production plant has many variable speed drives which cause high harmonic currents. The measurements were done at medium voltage level in the point of connection of the plant to the power system. The total harmonic distortion of the voltage THD_u (%) was 3.3 %. The most present harmonic voltages are 5th, 7th and 11th harmonic, drown by the integral action of the plant variable speed drives. The highest permitted level of THD_u is 8 %. Despite the THD_u is not high, the reduction of the harmonics by filtering will reduce the number of negative effects on the power system.

B. Monitoring of power quality near marble production facility

The marble production plant regularly draws high currents from the power system which mainly cause flicker. The measurements were done at low voltage side at the transformer where the point of connection of the plant to the power system is. The flicker level *Plt* was measured to be ≤ 0.5, during the measurement time of 7 days. The highest permitted level of *Plt* is ≤ 1, during 95% of time. Despite the *Plt* is not high, the reduction of the flicker may be realised by better grid topology at the plant location.

C. Device with variable speed drive

The inverter type air-conditioner is a significant source of harmonics. The rated data of the tested device, inverter air conditioner, are the following: 230 V, 50 Hz, cooling power 3.20 kW, heating power 4.50 kW, and energy efficiency class "A".

In Figures 3 and 4 the forms of the voltage and current in cooling regime of this device are displayed.
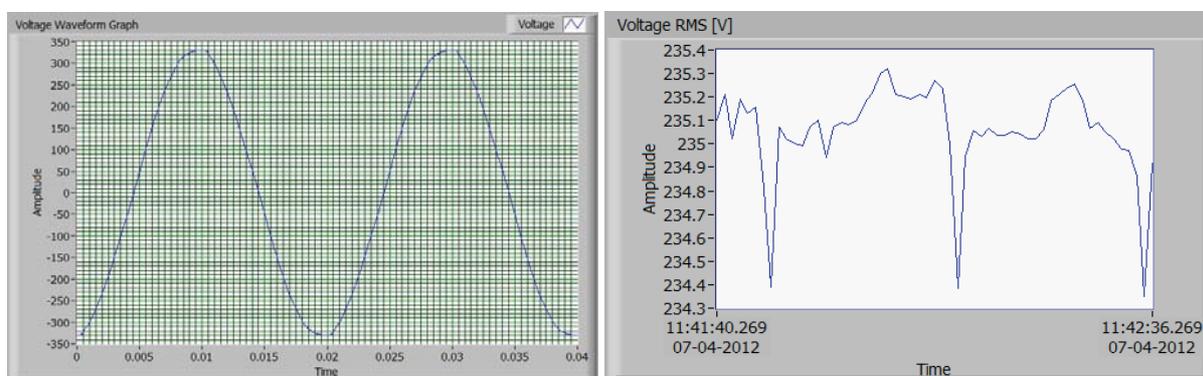
a) Voltage form   b) Voltage RMS
Figure 3. Voltage form and RMS changes (Line voltage RMS: 235,14 V, *THDV*=1,126 %)
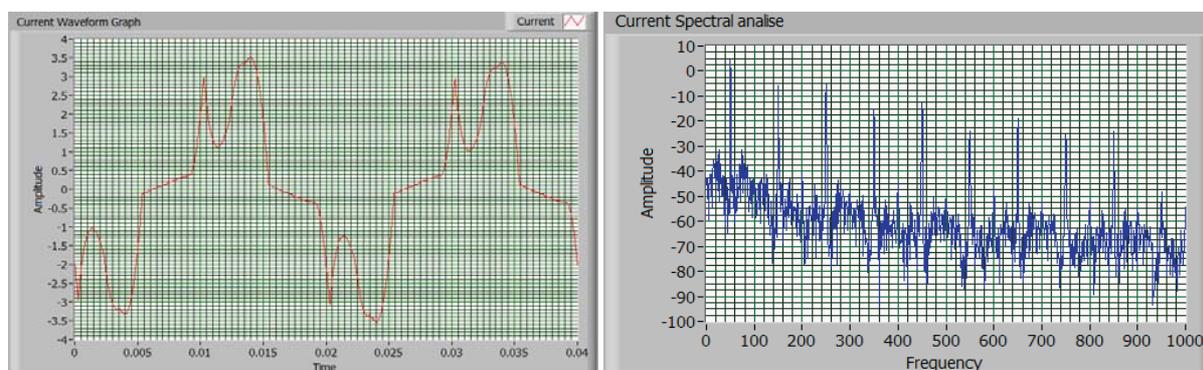
a) Current form   b) Current spectrum
Figure 4. Current form and spectral analysis (Load current RMS: 1,817 A, *THDI*=49,9 %)

Harmonics generated internally, which flow back to the utility power grid, can have an adverse effect on other customers. The quality of electrical power directly impacts the performance of the rotating equipment in terms of efficiency, vibration, sound power levels and expected life. High levels of harmonics result in erratic and sometimes subtle malfunctions of the equipment, having serious consequences in some cases.

The simultaneous measurements of voltages and currents enable application of the developed virtual instrument for Motor Current Signature Analysis (MCSA) and technical diagnostics of problems connected to control, connections, stator, rotor, air gap, bearings, vibrations, alignment and load of an electrical motor, [12].

D. Discussion

The industry plays an important role in disturbing the power quality. Industrial non linear loads, as well as high currents, cause in the power system harmonic voltages, voltage dips, flicker, voltage variations, unbalance, asymmetry etc. The consequences are numerous: transformer overheating and failures, overheating of metal enclosures, neutral conductor and terminal failures, motor failures and overheating, fuses blowing, electronic equipment failures, computer malfunction and failures, blinking of lights, power factor correction capacitors failure, circuit breakers tripping, conductor failure of heating…

The measurement near different industrial plants has shown that particular industries have specific influence on the power quality, depending of the production process and used equipment. Despite the measured power quality parameters do not exceed the limits stated in the regulation, the measures for improvement would be recommended, with very positive effects on power system reliability and economics.

IV. Conclusions

A virtual instrument-power meter and power quality analyser was developed and described in the paper. The instrument is based on analog input modules, data acquisition board, personal computer and software in LabVIEW™ .The instrument enables complete monitoring of all the powers and power quality parameters. The calibration results and the uncertainty estimation of all the measurement quantities and all the ranges have shown that the virtual instrument is very accurate and precise instrument for measurement of power quality. The instrument can be used for the MCSA diagnostics of electrical motors.

The results of measurements of different industrial plants have shown that the industry plays important role in disturbing the power quality. Despite the measured power quality parameters do not exceed the limits stated in the regulation, the measures for improvement would be recommended, with very positive effects on power system reliability and economics. Further on, the complete and continual measurements of the powers and power quality characteristics give basis for consideration of the technical and economical aspects of planning and contracting of the electrical power needs and characteristics

References

[1] M. H. J. Bollen, Understanding Power Quality Problems: Voltage Sags and Interruptions, Wiley-IEEE Press, New Jersey (1999)
[2] J. Mindykowski, T. Tarasiuk "Dsp-Based Instrument for Power Quality Monitoring on Ships", *in Proc. XIX IMEKO World Congress*, Lisbon, Portugal pp. 923-927, 2009.
[3] D. Gallo, C. Landi, M. Luiso "Characterization Issue of Power Quality Instruments", *in Proc. XIX IMEKO World Congress*, Lisbon, Portugal, pp. 928-933, 2009.
[4] J. Mindykowski, T. Tarasiuk "DSP-Based Instrument for Power Quality Monitoring on Ships", *in Proc. XIX IMEKO World Congress*, Lisbon, Portugal pp. 923-927, 2009
[5] R. Bátorfi "Electrical Power Quality and Efficiency Diagnostic System", *in Proc. XIX IMEKO World Congress*, Lisbon, Portugal pp. 749-752, 2009
[6] CEI EN 50160: 2010, Voltage characteristics of electricity supplied by public distribution systems.
[7] IEC 61000-4-7 ed2.1 Consol. with am1 (2009-10): Testing and measurement techniques–general guide on harmonics and interharmonics measurements for power supply systems and equipments connected thereto.
[8] C. Budeanu, *Reactive and fictitious powers*, Rumanian National Institute, No. 2, 1927.
[9] R. Arseneau, Y. Baghzouz, J. Belanger, K. Bowes, A. Braun, A. Chiaravallo, M. Cox, S. Crampton, A. Emanuel, P. Filipski, E. Gunther, A. Girgis, D. Hartmann, S.-D. He, G. Hensley, D. Iwanusiw, W. Kortebein, T. McComb, A. McEachern, T. Nelson, N. Oldham, D. Piehl, K. Srinivasan, R. Stevens, T. Unruh, and D. Williams, "Practical definitions for powers in systems with nonsinusoidal waveforms and unbalanced loads: a discussion," *IEEE Transactions on Power Delivery*, vol. 11, no. 1, pp. 79-101, 1996.
[10] IEEE Std 1459/2010, IEEE Standard Definitions for the Measurement of Electric Power Quantities under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions.
[11] Evaluation of measurement data — Guide to the expression of uncertainty in measurement (GUM), JCGM 100 with member organizations (BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP and OIML), 2008
[12] H. Penrose "The Multi-Technology Approach to Motor Diagnostics", *for All-TEST Pro, http://www.alltestpro.com/fileadmin/user_upload/PDFs/The_Multi_technology_approach.pdf*