Power Quality Monitoring and Power Measurements by Using Virtual Instrumentation

Z. Kokolanski, M. Srbinovska, A. Simevski, C. Gavrovski and V. Dimcev

Abstract—The presented paper describes a virtual instrument used for monitoring and analysis of the relevant power quality parameters and power measurements.

The metrological support block is realized in LabVIEW environment which uses advanced methods for measurement and recording of the power quality parameters in accordance with the European quality standards. In that way, a suitable hardware solution for signal conditioning and load control is proposed. The most important parameters (voltage, current, power) are recorded into text files which are further used for measurement data analyses. The measurement results are obtained by using waveform simulator METREL.

Index Terms—**Power Quality, Data Acquisition, Virtual Instrumentation.**

I. Introduction

THE electric power is essential for running industrial production processes, for commercial use, for transport and other purposes. In the last years this dependency has increased and all these processes relay on the quality of electricity supply, namely power quality [1]. The detection of the disturbances affecting the line voltages is one of the most qualifying points in the estimation of the "voltage quality" or "supply quality". The correct assessment of the quality of the supplied voltage has become one of the key issues in the deregulated electricity market. Ensuring a "high quality" of the supply voltage is the main requirement for ensuring a high "power quality".

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Great attention is therefore paid to the definition of suitable indexes of voltage quality and the definition of suitable measurement procedure to evaluate these indexes. A large number of power quality disturbances have been reported in the literature-some of them being transient in nature and others being related to periodic, steady – state operation. Some of the more common disturbances are: voltage and current harmonics [2,3], voltage dips, electric noise, impulses, notches and flicker.

Because of these disturbances measurement of the electric quantities, such as voltage, current and power by using equipment commonly used for measurement of sinusoidal signals can result in errors. In this way, inclusion of the digital signal processing techniques can be much more adequate. Anyway, a suitable digital signal processing approach must be provided.

In the recent years adoption of personal computers (PCs) in the field of the measurement technique offers great progress and flexibility. Step ahead for development of modern measurement systems is achieved by adopting the concept of Virtual Instrumentation. It is a methodology for realization of measurement instruments by using standard PC's, hardware data acquisition components for signal conversions and specialized program platforms for processing and recording of the measurement results.

In this paper a Virtual Instrument for power quality monitoring is proposed.

II. Power Quality Parameters

The ideal supply voltage is pure sinusoidal voltage with nominal frequency and nominal amplitude. Any variation from this is considered as a power quality event or a disturbance. One important aspect in the field of power quality is monitoring and control of the qualitative parameters of the electrical energy according to today's standards [4]. In that way, a big attention is paid to define the disturbances and determination of procedures for their measurement. A large number of power quality disturbances have been reported in the literature. In general, the parameters could be divided in two groups - voltage amplitude variations and wave-form distortion. A short classification of power quality parameters is given in Table I.

TABLE I
POWER QUALITY PARAMETERS

Variation of	Parameter
Frequency	Variation of power frequency
Voltage	Variation of magnitude of supplied voltage
	Rapid voltage changes
	Supply voltage dips and swells
	Voltage interruptions
	Flicker
	Supply voltage unbalance
Waveform	Transient overvoltages
	Voltage harmonics
	Voltage interharmonics
	Mains signaling voltage on the supply voltage
	Notching
	Noise

In the following section some theoretical analyses relied on the signal processing are reported.

III. SIGNAL PROCESSING ANALYZES

Analyzing a periodic signal *u(t)* with angular frequency ω and having in mind the Nyquist criteria, the signal limited with it's *N*th harmonic can be represented by 2*N*+1 samples over the period *T*.

The active power value of the voltage *u(t)* and current *i(t)* is represented with the equation:

$$P = \frac{1}{T}\int_0^T u(t)i(t)dt \quad (1)$$

Analyzing (1), measurement of the active power demands estimation of two time dependent components.

The p(t) spectrum is given by:

$$P(\omega) = U(\omega) * I(\omega) \quad (2)$$

According to relation (2) the spectrum of *p(t)* is wider than that of *u(t)* and *i(t)* and is limited to its 2*N*th harmonic. From this analysis it can be clearly seen that if the moment value and the spectrum of the power is required, *u(t)* and *i(t)* must be sampled with frequency twice than the sampling theorem criteria. Theoretically, it is possible to acquire only 2*N*+1 samples for the voltage and current, but in practice the sampling frequency must be significantly increased [5].

The same considerations can be applied for evaluation of the RMS value of *u(t)* which is expressed by the relation:

$$U = \sqrt{\frac{1}{T}\int_0^T u^2(t)dt} \quad (3)$$

The appropriate evaluation of (1) and (3) also demands for proper definition of the observation interval. The observation interval needs to be an integer multiply of the signal period *T* in order to minimize the leakage errors in the frequency domain. Otherwise under non-synchronous sampling conditions an interpolation algorithm must be employed.

IV. HARDWARE SOLUTION

The hardware is realized by using National Instruments multifunctional data acquisition (DAQ) card containing 32 analog input channels with resolution of 16 bits, programmable input range (±10V) and sampling rate up to 250kS/s. Two hardware boards for voltage and current signal conditioning are realized using six analog input channels, and three digital channels for load switching. The current measurement signals are obtained by using three electronic transducers incorporating current transformers and the load switching is realized by three relay switches controlled by the DAQ card. The voltage measurement signals from the power lines are obtained with precise resistive dividers. Block diagram of the hardware solution is shown in Fig.1

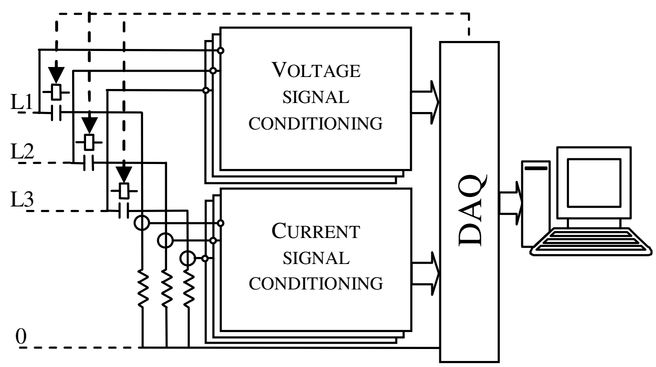

Fig. 1. Hardware block diagram

The signal conditioning circuits should provide few functions like: galvanic isolation from supply network, attenuation or amplification of the measured signals, protection of DAQ card and noise suppression. The main role of the signal conditioning circuit is to adjust the sensor's output signal span to match the analog-to-digital converter (ADC) input range.

The block diagram of the signal conditioning circuits is shown on Fig.2.

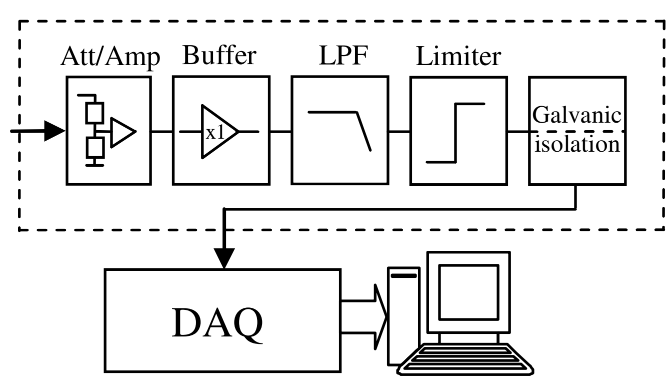

Fig. 2. Signal conditioning circuits block diagram

In the absence of proper signal conditioning the signal can exceed the ADC input range and cause saturation of its output. The signal is first attenuated or amplified and DC level shifted with the input attenuator/amplifier. The next block is a unity gain buffer with very high input impedance which is used for adaptation of the impedances of the attenuator and the filter. Sixth order active anti-aliasing filter has been designed with cut-off frequency of 6 kHz and near flat amplitude-frequency and phase-frequency characteristics. The filter is used before a signal sampler to restrict the signal's bandwidth and to satisfy the sampling theorem. Fast circuits for limiting the input voltage to the ADC input range have been designed. These circuits allow signals below a specified input level to pass unaffected while attenuating the peaks of stronger signals that exceed this level. The used data acquisition card is with galvanic isolated inputs. The galvanic separation eliminates all forms of operating disturbances such as ground loop and potential separation.

V. LabVIEW Based Virtual Instrument

LabView is a National Instrument development software that allows rapidly and cost-effectively interface with measurement and control hardware, data analyzes, share results, and distribute systems. It is based on graphical programming techniques that allow programming with visual expressions, spatial arrangements of text and graphic symbols [6].

The software is based on a block diagram (intended for graphical program development) and front panel (graphic interface formed by switches and panels intended for user interaction).The Virtual Instrument described in this paper consists of two parts:

1) power line voltage analyzes
2) current and power analyzes

Fig.3 represents the voltage analyzes block diagram. This block is identical for all three power lines.

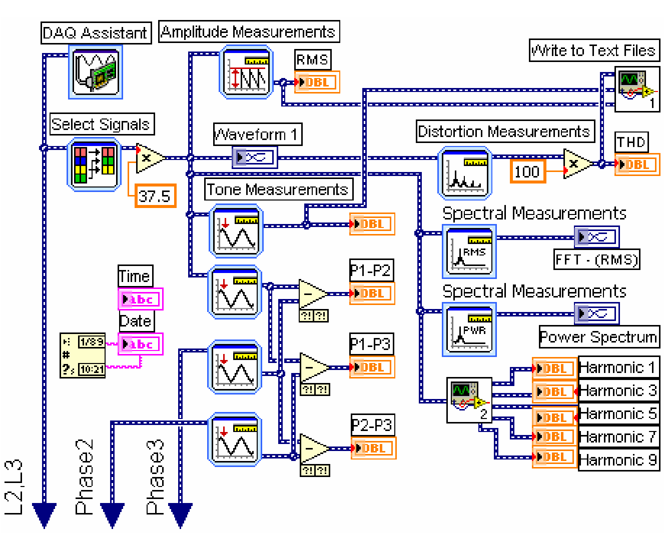

Fig. 3. Signal conditioning circuits block diagram

Samples from three analog channels are successively taken with sampling frequency of 2kHz per channel for sampling interval of 100ms and are fed to a signal selection block. Every sample is multiplied by a constant factor which indeed is the attenuation coefficient of the signal conditioning circuits. The obtained signal is further processed and used for measurement of the RMS, total harmonic distortion (THD), frequency and phase difference of the input signal.

The virtual instrument contains two sub-virtual blocks for filtration of the spectral components and data recording. The filtration block contains sixth order Chebyshev band pass IIR filters with central frequency at the odd spectral components and the data recording sub-virtual block stores the results for RMS, frequency and THD of the input signal in interval of 100ms.

The programming points are implemented as follows:

- Sample gathering;
- Voltage RMS calculation, equation (3);
- Frequency measurement;
- Phase difference calculation;
- Analyzes of the Total Harmonic Distortion, relation (4);

$$THD[\%] = \sqrt{\frac{\sum_{n} U_n^2}{U_1^2}} \cdot 100, n = 2,3..N \qquad (4)$$

- Analyze amplitude spectrum by using Amplitude spectrum VI, equation (5);

$$AmplitudeSpectrum = \frac{FFT(\,signal\,)}{N} \qquad (5)$$

- Analyze signal power spectrum using Auto Power spectrum VI, equation (6);

$$PowSpec = \frac{FFT^{*}(\,signal\,) \times FFT(\,signal\,)}{N^2} \qquad (6)$$

where * is a complex conjugate.

- Display the signal waveform, amplitude and power spectrum on a waveform graph;
- Filtration and measurement of RMS for 5 odd spectral components;

For this purpose a sixth order Chebyshev band pass IIR filters are used with central frequency at the odd spectral components. The pass band of the filters is 20Hz.

- Write the amplitude RMS, signal frequency and THD into text files;

All measurement data with time and date of recording are recorded into separate text files. These data can be further used for data storage and analysis by using some graphical presentation software such as DIAdem or MS Excel.

Fig.4 represents the front panel of the virtual instrument

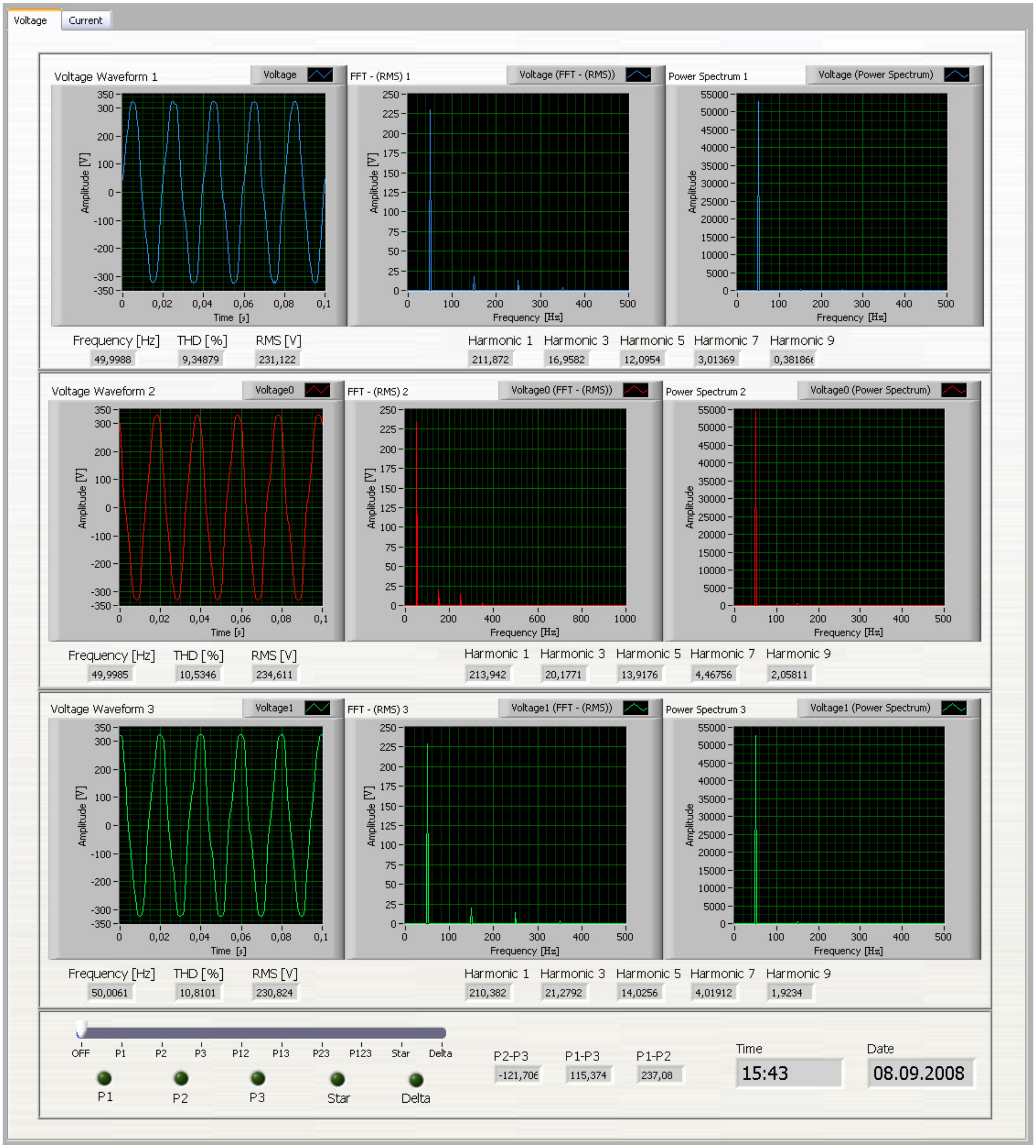

Fig. 4. Front panel of the virtual instrument

VI. Current and Power Analyzes

Three current channels are sampled with frequency of 2kHz per channel and a sampling interval of 100ms. Every sample is multiplied by constant factor corresponding to the transducer attenuation. The obtained signal is further processed and used for measurement of the RMS, total harmonic distortion (THD), and the active and reactive power of the input signal [7].

Fig.5 shows the LabView programming block diagram for current and power measurements for one measurement channel.

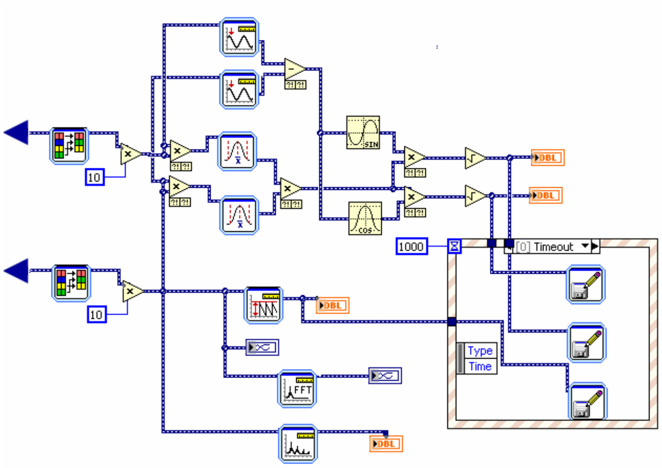

Fig. 5. Current and power measurements block diagram

The programming points are implemented as follows:

- Sample gathering;
- Current RMS calculation;
- Analyzes of the Total Harmonic Distortion;
- Analyze amplitude spectrum;
- Current phase measurement and current-voltage phase difference calculation;
- Active (7) and reactive (8) power calculation;

$$P = \sqrt{\sum_{i=0}^{N} U_i^2 \cdot \sum_{i=0}^{N} I_i^2 \cos^2 \varphi_i} \quad (7)$$

$$Q = \sqrt{\sum_{i=0}^{N} U_i^2 \cdot \sum_{i=0}^{N} I_i^2 \sin^2 \varphi_i} \quad (8)$$

- Display the signal waveform and amplitude spectrum on a waveform graph;
- Write the current RMS, active and reactive power into a text file;

The front panel corresponding to the LabView programming sequence is shown in (in) Fig.6

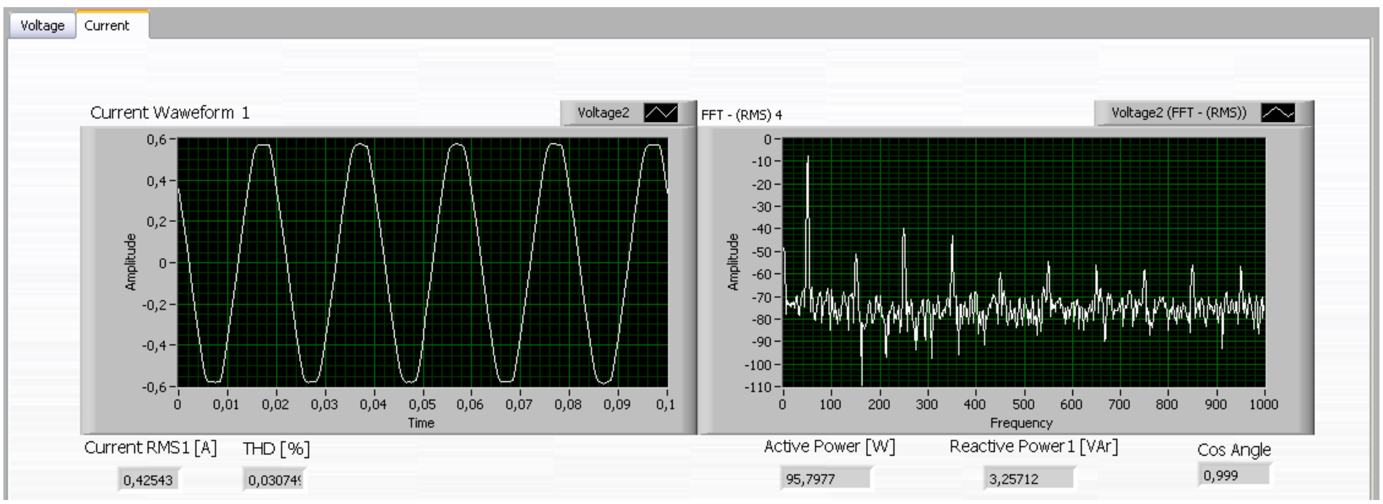

Fig. 6. Front panel of the virtual instrument for current and power measurements

VII. Measurement Results

Measurement of the power quality is usually defined as a measurement of low frequency conducted disturbance with the addition of transient phenomena. The ideal single phase supply voltage is a pure sine wave with nominal frequency and voltage amplitude. Any variation of this is considered as a power quality disturbance.

The following parameters of supply voltage are influenced by disturbances:

- Frequency
- Voltage level
- Wave shape
- Symmetry of three phase system

In the experimental tests one phase power simulator Metrel MI 2191 is used [8]. The instrument is able to simulate typical voltage and current shapes, such as voltage and current harmonics [2], flickers[9], transients[10], voltage interruptions [9] etc. Three examples for measurement of transients, flickers and harmonics are shown in the results.

- Transient is a term for short, highly damped momentary voltage or current disturbance Fig.7 and Fig.8;
- Flicker is a visual sense caused by unsteadiness of a light. The level of the sense depends on the frequency and magnitude of a light change and the observer itself Fig.9;
- Harmonics [3,4] are any periodic deviation of a pure sinusoidal voltage Fig.10;

Fig.11.a, Fig.11.b and Fig.11.c represent the recorded values for the RMS voltage, frequency and THD during 10 hour interval by using the text files from the virtual instrument. In the second experiment measurement of current and power of a 100W light is presented (Fig.6). Switching of the light is controlled by the DAQ card.

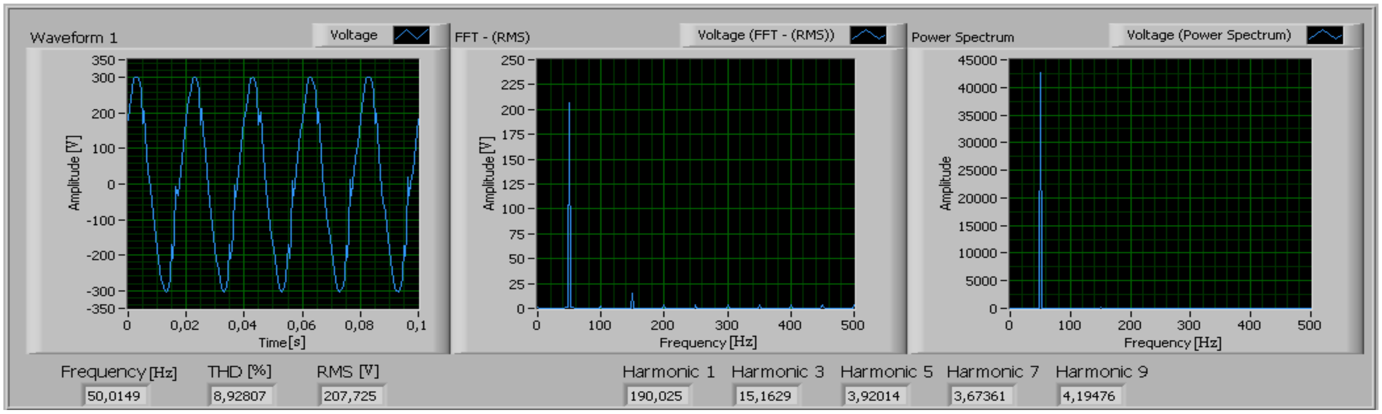

Fig. 7. Transients caused by SRC switching

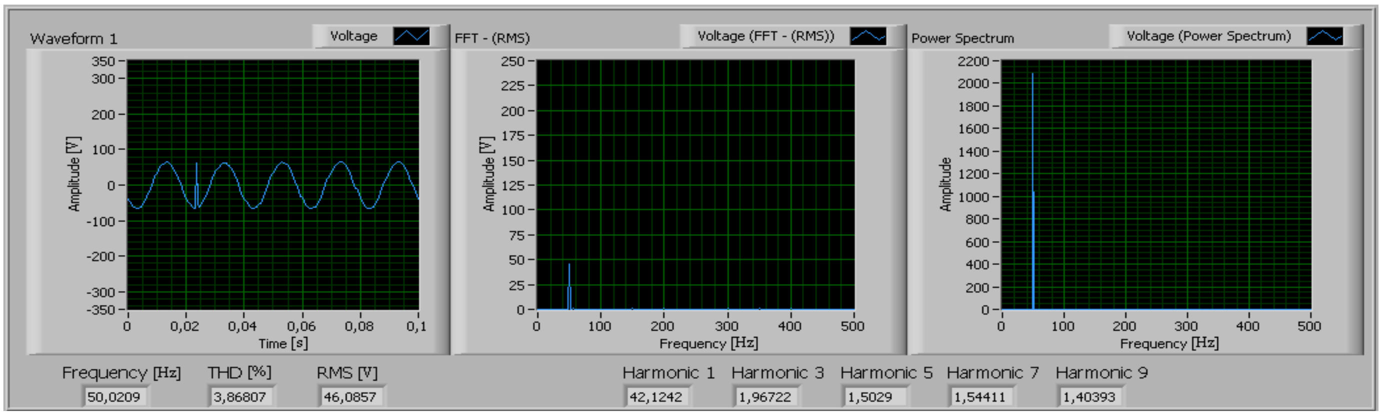

Fig. 8. High transient pulse caused by lightning

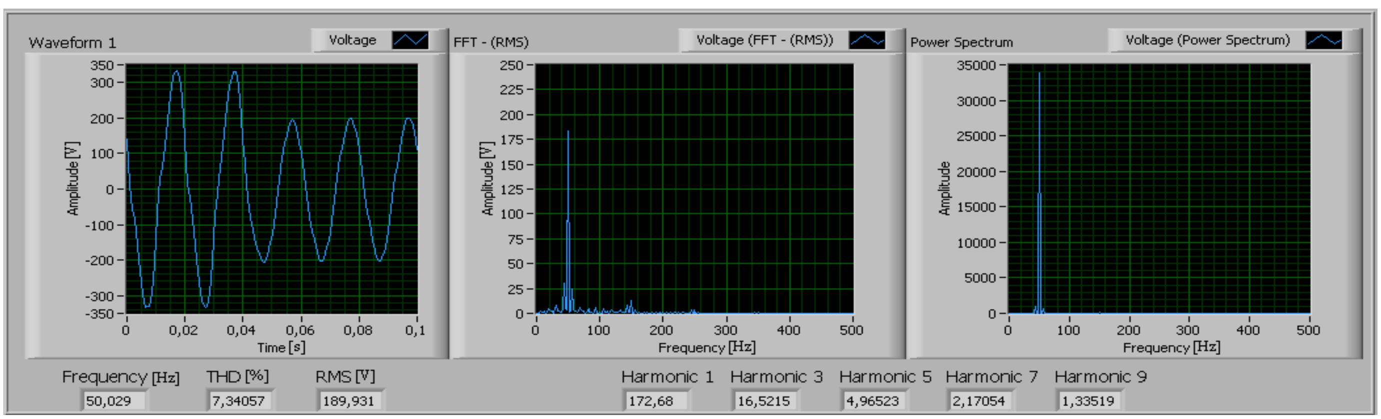

Fig. 9. Flicker with square distribution

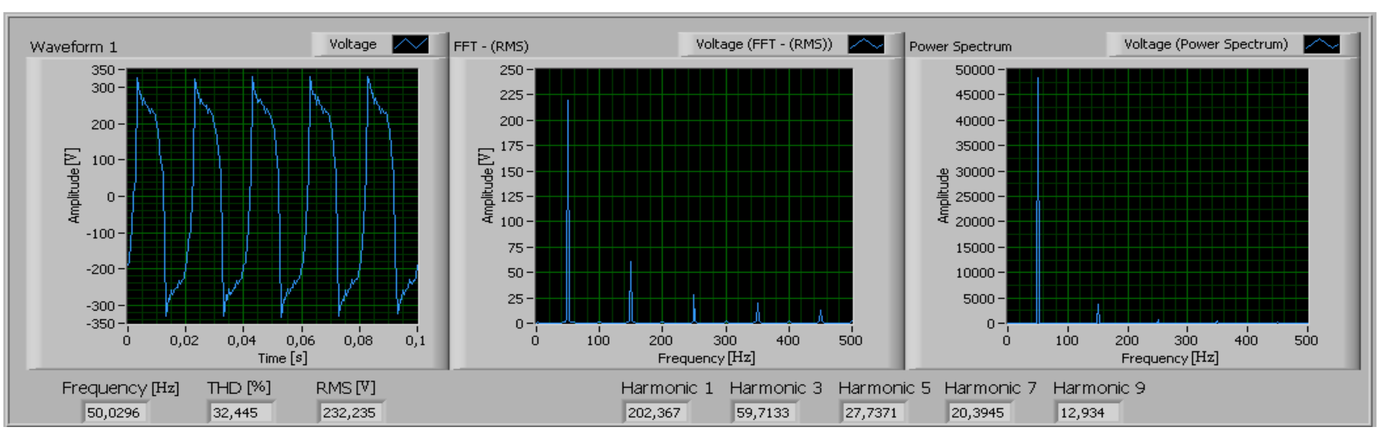

Fig. 10. Highly distorted signal of a simple chopper voltage converter

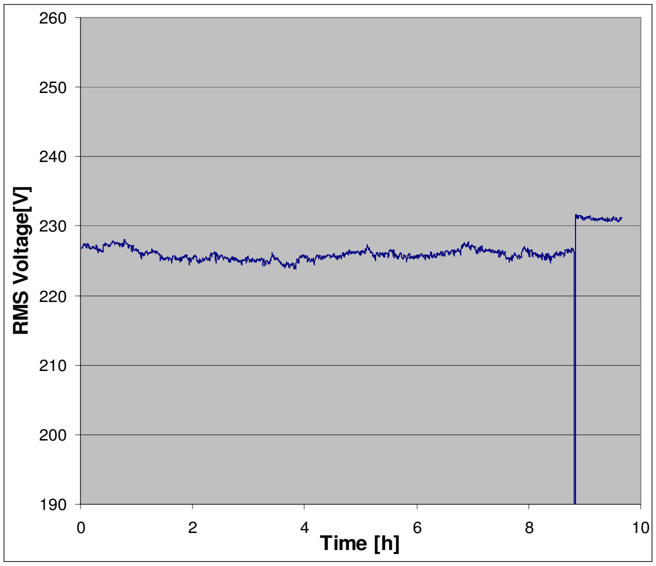

Fig. 11.a Current and power measurements block diagram

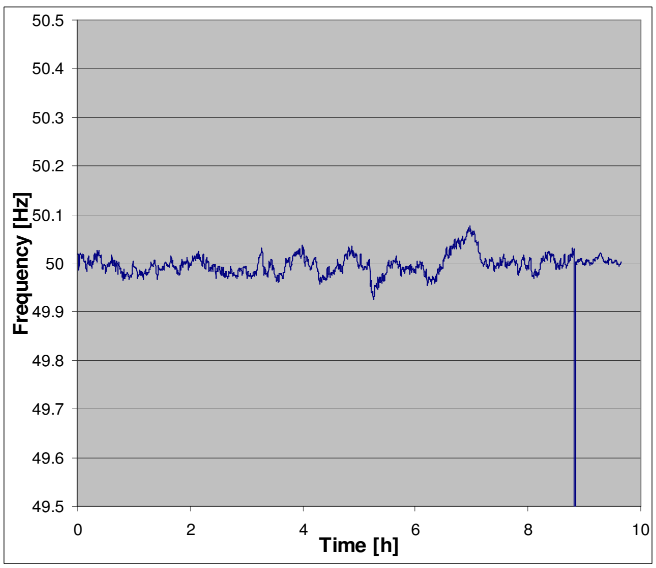

Fig. 11.b. Current and power measurements block diagram

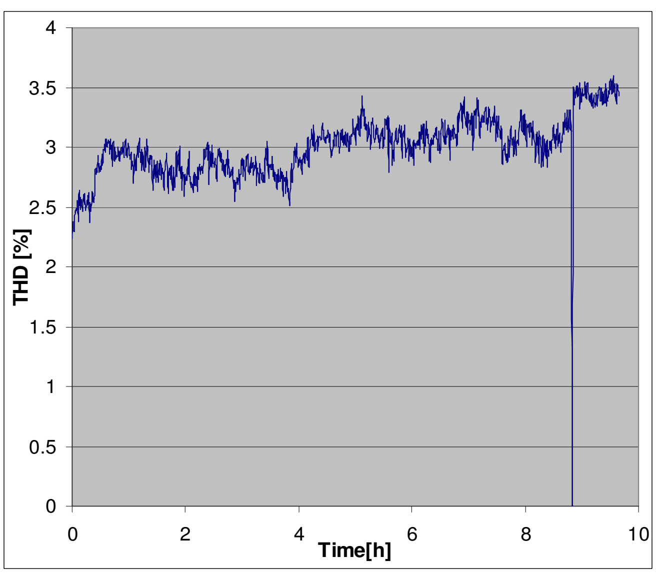

Fig. 11.c. Current and power measurements block diagram

In Fig.11.a, Fig.11.b and Fig.11.c recorded values for the RMS voltage, frequency and THD during 10 hour interval are presented. The graphs are obtained by using the data records from text files presented in MS Excel. The virtual instrument detected appearance of short voltage interruption, as it can be seen from the results.

VIII. CONCLUSIONS

This paper has summarizes theoretical and practical facts concerning the monitoring and analysis of power quality parameters. One possible hardware solution for signal conditioning in combination with DAQ card is implemented. This system is used for measurement and analyzes of different power quality disturbances. The signal conditioning module is developed in a way so it can be used for measurement of all power quality parameters. The voltage, current and power analyses are completely developed using virtual instrumentation techniques implemented in LabView software. Measurement data are recorded in text files for further analysis by using some graphical presentation software such as DIAdem or MS Excel. The performance of the proposed equipment is good enough for an effective application to test the power quality parameters.

The implemented system worked correctly in real time and detected and stored different types of disturbances.

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