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Personal computer-based electrical power quality signal generator

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Abstract **– Electrical power quality signal generator, capable of reproducing power quality disturbances in accordance with European quality standard EN50160, is presented in this paper. Signal generator is divided in two parts: LabVIEW based virtual instrumentation software for defining the disturbance parameters and hardware electronics for signal generation (data acquisition card and power amplifier). The paper focus is on the design of power amplifier for scaling the data acquisition card output voltage level to the nominal power line voltage (230 V). Developed signal generator can be used for generation of reference signals useful for testing of power quality measuring instruments and various algorithms for power quality disturbance detection. In such manner, this PC based signal generator can be used as very good and cost effective alternative to very expensive instruments for testing of power qulity meters and analyzers.**

Keywords **– Electrical power quality, Signal generator, Power amplifier, LabVIEW software.**

I. INTRODUCTION

Degradation of the optimal power quality (PQ) can be caused by various problems and disturbances in electrical power distribution networks. Signal disturbances, present in form of RMS voltage variations or high-order signal harmonics, directly affect on the energy efficiency decreasing in electrical power production, distribution and consumption. Increased concern for PQ problems, indicated in the recent years, primarily is caused by the limitations of natural resources necessary for power production, followed by widespread using of alternative energy resources [1,2]. Considering these facts, PQ problems are became very important and significant topic. For purpose of customer protection, optimal quality level is defined according to the relevant international standards and regulations [3]. European quality standard EN 50160 defines voltage characteristics of electricity supplied using the public distribution systems, for normal operating conditions. Required quality level is determined by reference nominal values and acceptable limits of standard quality parameters and network disturbances. Relevant information, necessary for quality assessment, can be provided by measurement and processing of PQ parameters at specific locations in distribution network.

Having in mind the challenges of the modern smart grids and great importance of PQ topic, special attention is paid to development of sophisticated and reliable microprocessor-based measurement systems for PQ monitoring. In the last decade especially attractive are so called “virtual instruments”, which are well suited for development of flexible computer-based measurement and control systems. Generally, virtual instruments can be successfully used in research and scientific purposes. Many scientific papers on virtual instrumentation for PQ analysis (both for measurement or signal generation) have being published [4-9]. However, usually less attention is paid to signal amplification, which is very important for practical implementation of virtual PQ signal generators.

In order to satisfy the specified level of measurement accuracy and characteristics, devices for PQ measurement must be followed by appropriate metrological traceability chain. Reference instruments, such as voltage and current calibrators, are available in the various functional and constructive solutions. Such calibration instruments are relatively expensive and therefore unavailable to many scientific researchers. Significant limitation of these instruments is closed functional architecture, developed according to the relevant quality standards. Due to this limitation, such instruments are not flexible and hardly adaptable to some specific problems. Virtual instrument, presented in this paper, is capable of reproducing the PQ disturbances in accordance with the European quality standard EN50160. This solution is easily adaptable to various practical researcher requirements, for example logging of measurement results, generation of PQ disturbance random sequence and upgrading of some recently defined standard network disturbances [10].

II. VIRTUAL INSTRUMENT FOR GENERATION OF STANDARD PQ DISTURBANCES

Generator of sinusoidal voltage signals with standard PQ disturbances is based on virtual instrumentation concept, including LabVIEW software platform and data acquisition board NI PCIe 6343. Virtual instrument (VI) is divided in two segments: a graphical user interface (front panel) and program code (block diagram), both strongly interlinked between each other. Basic purpose is generation of reference waveforms with special functions for simulation of the standard network disturbances [11]. Generally, this virtual instrument enables generation of three-phase voltage signals. Currently, signal amplifier is developed for amplification of one-phase voltage signal, but this solution can be simply multiplied in simetrical manner for other two channels of voltage waveforms.

Some basic functions provided by developed virtual instrument for PQ signal generation are:

- definition of nominal amplitude and frequency values,
- definition of signal sample rate and duration of final test sequence,
- generation of noise (Gaussian distributed amplitude),
- variation of nominal signal frequency value and slow amplitude fluctuations,
- slow variation of signal amplitude value with defined frequency of variation,
- definition of DC offset, voltage swell and voltage sag,
- definition of high-order signal harmonic components with up to 50 individual defined harmonics,
- generation of some special types of disturbances (flicker, burst transients, short voltage oscillation).

LabVIEW front panel of signal generator for graphic presentation of reference voltage waveform, with four different examples, is presented in Fig. 1. Definition and simulation of voltage waveforms, with specified levels of standard PQ disturbances, can be performed directly in control front panel and block diagram of LabVIEW virtual instrument. Each type of signal disturbances, for example voltage swell, voltage sag and high-order signal harmonics, can be defined and generated using separate functional segments. Individual signal disturbances can be combined and unified in the form of final complex sequence, according to the requirements of European PQ standard EN 50160 [3]. Presented front panel of signal generator includes primary control buttons for selection of individual PQ disturbances, such as: voltage swells, voltage sags,signal DC offset,frequency variations, slow amplitude fluctuations and percentage noise level.

Separated segment of control functions on LabVIEW virtual instrument is used for selection and variation of specific amplitude levels related to individual high-order harmonic components. Content of specific high-order signal harmonics can be precisely determined by number of control knobs for regulation of harmonic amplitude levels. Specifically, in Fig. 1. are presented four examples of sinusoidal voltage waveform, generated with various levels of high-order harmonic components. Presented voltage waveforms are generated with nominal signal frequency value of 50Hz and normalized RMS voltage value of 5.5 V. In order to be more realistic in generation of voltage waveforms, for specific quality disturbances is enabled separate definition of start time, stop time, rising time and falling time of generated signal disturbances. Some additional classes of network disturbances can be

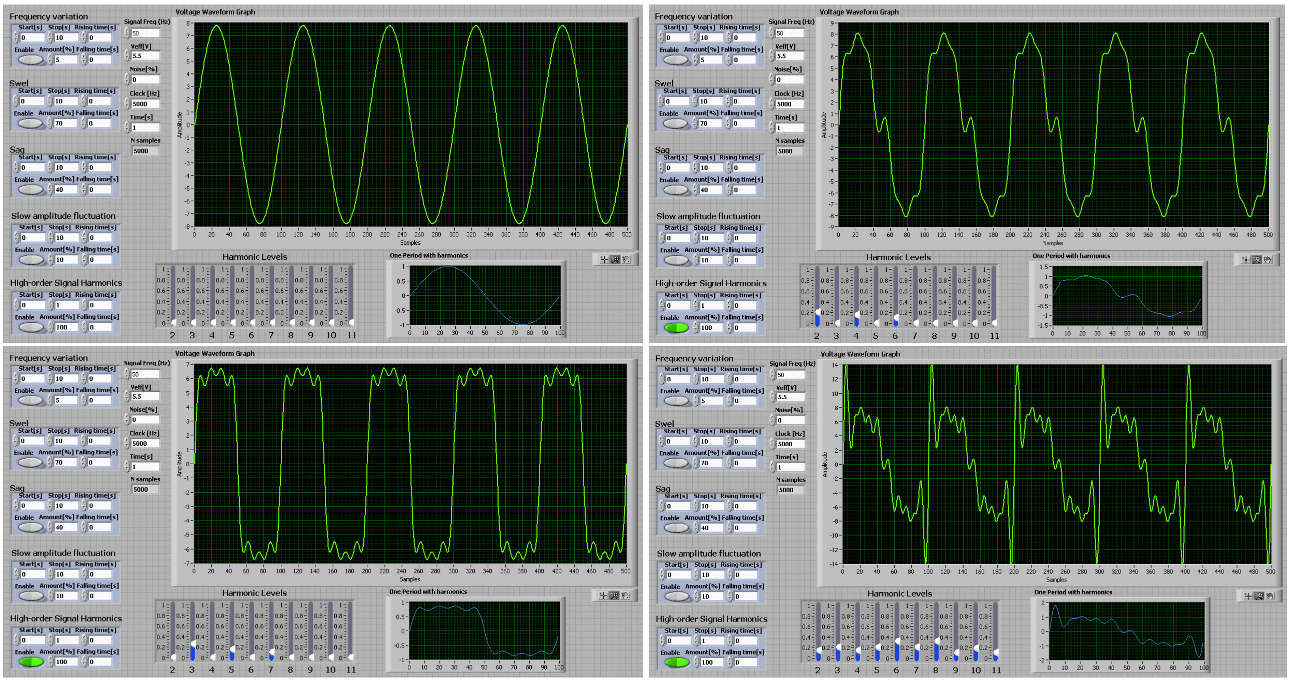

Fig. 1. Front panel of LabVIEW signal generator (voltage waveforms with various levels of high-order signal harmonics)

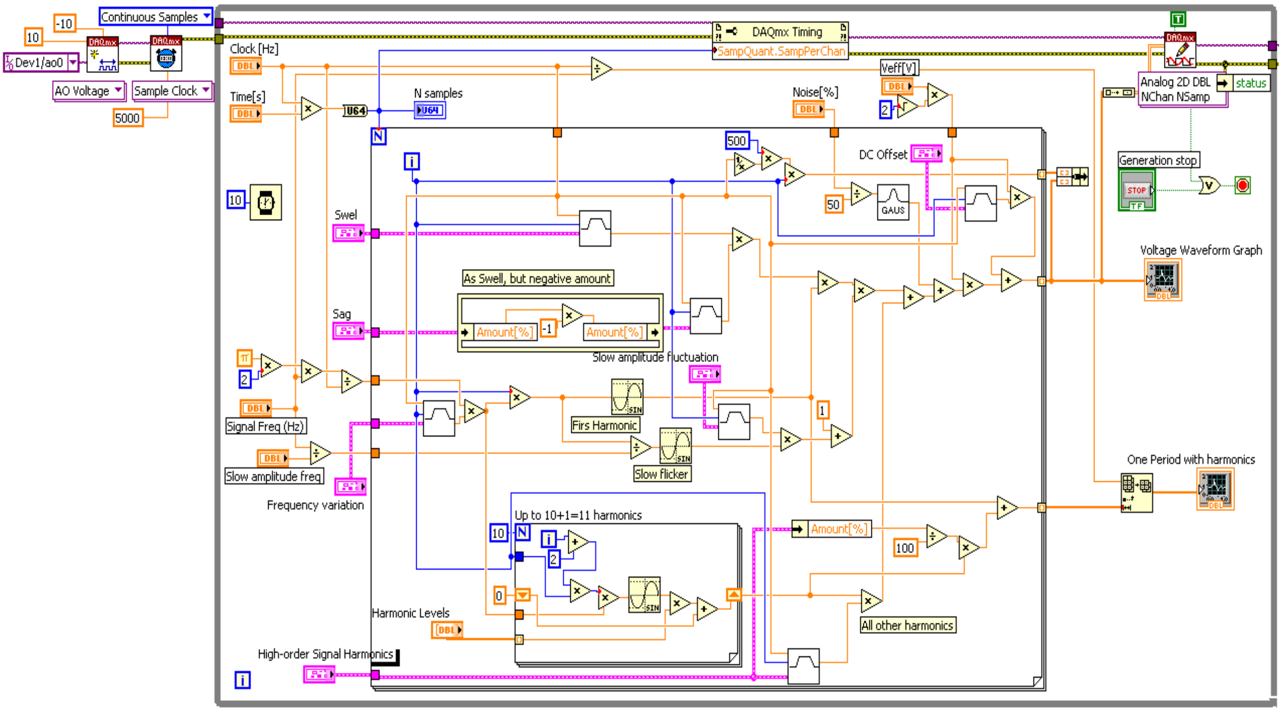

Fig. 2. Block diagram in LabVIEW environment (executive software code) – virtual instrument for generation of PQ disturbances

also generated by the described signal generator. These characteristic disturbances are: flicker generated as slow variation of signal amplitude level, voltage interruption that can be defined as one special type of voltage sag, burst transients and short voltage oscillation caused by the presence and influence of higher signal harmonics.

Block diagram in LabVIEW environment (software code), corresponding to virtual instrument for generation of standard PQ disturbances, is presented in Fig. 2.

III. POWER AMPLIFIER DESIGN

The signal generated (simulated) by the virtual instrument is usually physically reproduced by using a PC-based data acquisition (DAQ) card, containing a digital to analog (D/A) converter. The D/A converter output signal is usually standardized to a given voltage level, typically up to ±10V. Such voltage levels are not directly applicable to test power quality meters and have to be amplified to the nominal power line voltage of 230V (or 110V) prior the measurements.A dedicated data acquisition cards with the “high voltage”outputs are also available, but they are usually too expensive. The aim of this paper is to address the key parameters in the design phase in order to implement a low-cost and full-performance PQ signal generator.

The block diagram of the realized PQ signal power amplifier is given in Fig. 3.

The simulated signal with the LabVIEW software can be reproduced by any standard DAQ card with analog output channels. However, the DAQ card should meet

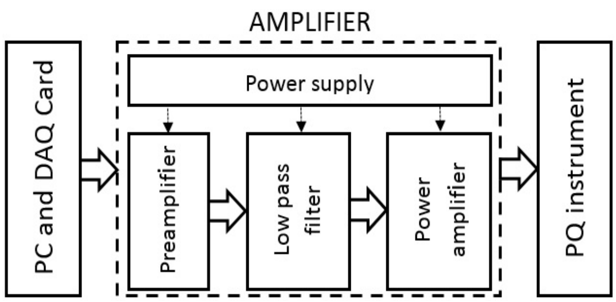

Fig. 3. Block diagram of the PQ signal power amplifier

some implementation related requirements. Namely, it must have good-enough resolution (which is defined by the required output signal uncertainty), and support high-enough sampling frequency. Theoretically, the sampling frequency has to be at least twice higher than the maximal harmonic that needs to be generated. According to the PQ standard EN50160 [3] (up to 50th harmonic), the minimum sampling frequency is 5 kHz. However, in practice the sampling frequency should be higher to maintain the accuracy of the higher harmonics.

The generated signal with the DAQ card is amplified by an amplifier (given in Fig. 3.), which amplifies the signal to the nominal power line level of 230 V. To do so, several analog signal processing modules are used: preamplifier (to amplify the input signal to a given reference level and limit the input voltage level), low pass filter (to restrict the input signal bandwidth and eliminate noise), power amplifier (to amplify the signal to nominal power line level and increase the load current capability).

A. Preamplifier

In the proposed solution, preamplifier has a double role: to amplify the input signal (comming from the PC-DAQ card) to a standardized refference level, and to limit the input voltage level. Usually, commercial DAQ cards have a standardized analog output voltage, e.g: ± 2.5 V, ± 5 V, or ± 10 V. The idea is to design an amplifier capable of reproducing the power line voltage with any standard DAQ card with the voltage levels such as mentioned above. To do so, the refference output voltage of the preamplifier was taken as ± 10 V. This means that preamplifier must have variable amplification (4, 2, and 1 times), regarding the input voltage level (± 2.5 V, ± 5 V, and ± 10 V), respectively. Such solution can be easilly implemented with a clasical operational amplifier-based preamplifiers in inverting or non-inverting configuration and with an amplification selector switch. In practice, the preamplifier was realized by using a low-noise and low-offset precision operational amplifiers OP07 [12], in inverting configuration.

The voltage limiter is also an important part of the preamplifier stage because it prevents generation of a high voltage spikes and saturation of the PQ amplifier. While there are a lot of possible implementations of a voltage limiters, the simplest realization is by using a Zener diodes. On the other hand, when using a Zener diode limiters, a low-pass filter at the output of the diodes must be used. The voltage limiter was realized with two Zener diodes with breakdown voltages of 10 V, wired in an oposite direction. While this is a very simple solution, the Zener diodes can generate a significant amount of noise. Therefore, a passive low-pass RC filter was designed at the output of the diodes. The cut-off frequency of the filter has to be well above the PQ generator pass-band (which is up to 50^{th} harmonic of the power line frequency). Therefore, a first order passive RC filter, with a cut-off frequency of 22.5 kHz, was realized

B. Lowpass antialiasing filter

The filters are characterized by several parameters: width of the pass band, attenuation in the stop band, cut-off frequency and filter order. Every filter type has its own unique properties. The Bessel filter has the most linear phase-frequency characteristics, Butterworth filter have maximally flat pass band and Chebyshev filter have the highest attenuation in the stop band but also ripples in the pass band. When designing an anti-aliasing filter it is necessary to consider the -3dB attenuation at the cut-off frequency. If this is not taken into account, the higher harmonics of the signal will be attenuated and the error caused by the filter at the cut-off frequency will be around 30%. Therefore, to control the errors caused by non-ideal shape of amplitude-frequency characteristics in [13], a CFM (Cutt-off Frequency Multiplier) parameter is defined. The CFM parameter defines a segment of the pass band where the errors caused by the difference between the real and ideal filter transfer characteristics are controlled on certain defined level (e.g 0,1%). It is important to note that the CFM value decreases with the filter order. However, the value of CFM stabilizes for a filter order higher that four and further increase carry benefit only in the attenuation in the stop band. Hence, if a Butterworth fourth order filter is designed, the value of the CFM parameter will be 2.18. This means that the filter cut-off frequency should be 2.18 times higher than frequency of the highest harmonic in the signal spectrum. Therefore, a fourth order Butterworth low-pass filter in a Sallen-key configuration (realized as a cascade of two two-pole filters) [14] was designed. Considering that 50^{th} voltage harmonic (f_{50} = 2.5 kHz) has to be analyzed, the cut-off frequency of the filter is 5.45 kHz.

C. Power amplifier

The power amplifier has to amplify the input signal (standardized to a ±10 V) to the power line voltage levels. However, in order to be able to generate voltage swells, the power line voltage level should be placed near the middle of the DAQ card analog output voltage range. The power amplifier was designed by using APEX PA97 [15] high voltage operation amplifier. The amplifier is capable of delivering 10 mA at 500 V (or power of 5 W), which is sufficent to test PQ meters. The amplifier was designed in an inverting configuration with amplification of 40 times. A special attention has to be paid to the power supply of the power amplifier. In the current realization, a classical zener-diode based power supply of ±430 V was designed.

D. Experimental verification of PQ signal generator

Developed signal generator is experimentally verified by using the PQ analyzer Fluke 435. Reference voltage waveforms, generated by PC based signal generator with various level of harmonic disturbances, are sent directly to the voltage inputs of quality analyzer Fluke 435. Photo of experimental system including PQ signal generator and reference instrument Fluke 435 is presented in Fig. 4.

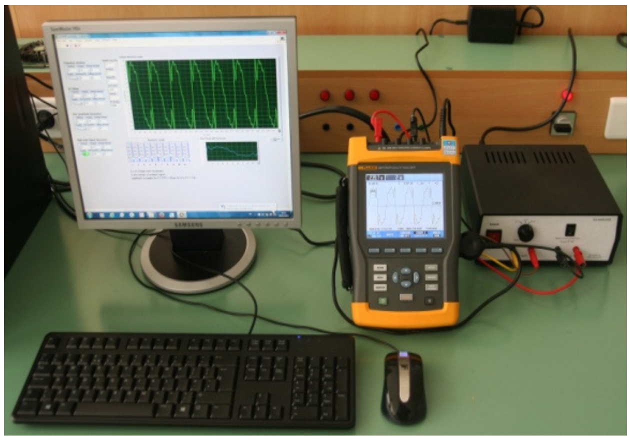

Fig. 4. Experimental system for verification of PC-based PQ signal generator

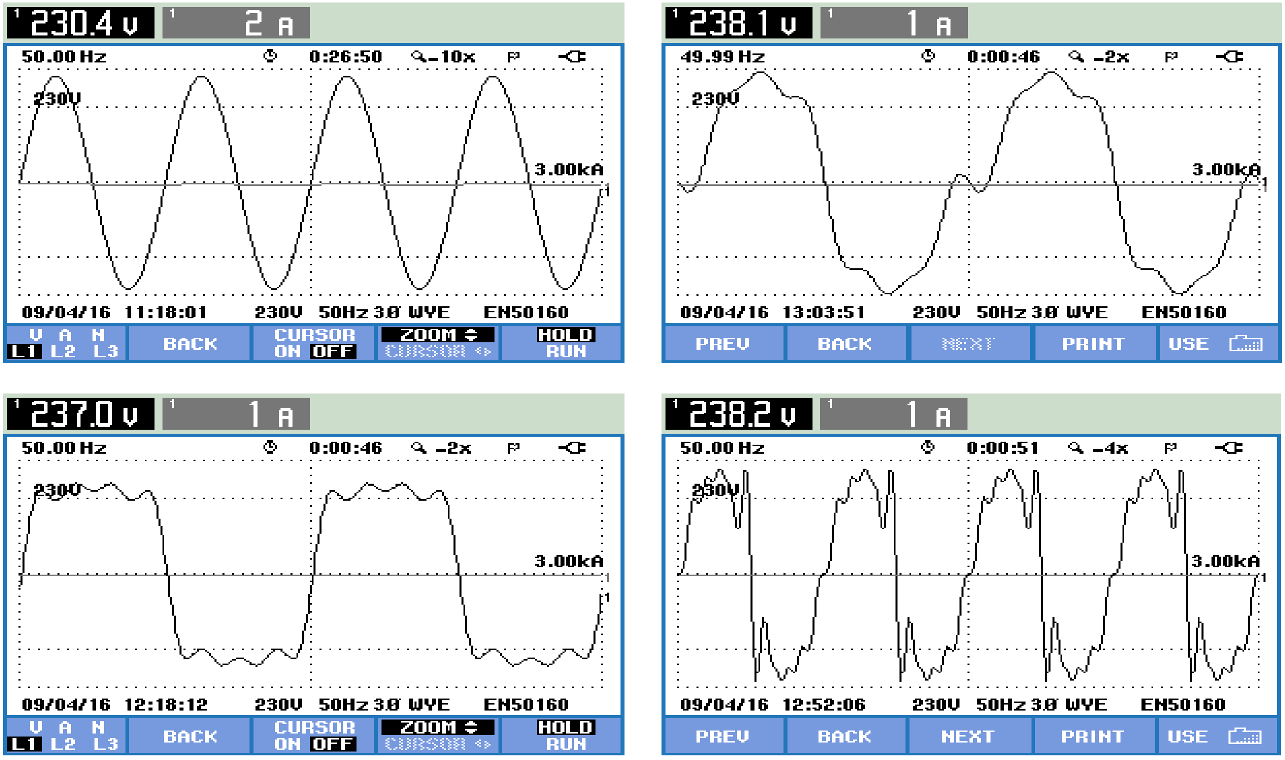

Fig. 5. Voltage signals with harmonic disturbances recorded on display of reference instrument - PQ analyzer Fluke 435

Standard USB communication interface enables direct communication between instrument Fluke 435 and PC computer, therefore measurement results can be easily transferred to computer, recorded and processed. Four examples of voltage waveforms from PQ signal generator with various level of harmonic disturbances, recorded on graphical display of reference instrument Fluke 435, are shown in Fig. 5. Specific waveforms are corresponding to voltage signals generated by LabVIEW virtual instrument and previously presented in Fig. 1.

IV. CONCLUSIONS

Implementation of personal computer-based electrical power quality signal generation is presented in this paper. Definition of basic parameters for signal generation is enabled by virtual instrument developed in LabVIEW software environment. Paper is focused on designing of PQ signal amplifier, including preamplifier, limiter, low pass antialiasing filter and power amplifier. It is very important to perform proper determination of antialiasing filter cut-off frequency by using a cut-off frequency multiplier (CFM). The use of CFM parameter eliminates the necessity of filter amplitude-frequency characteristic compensation. If the attenuation at the cut-off frequency is not taken into account, then it will introduce errors of around 30% for the harmonics near this frequency. This PQ signal generator is experimentally verified by using the reference instrument - PQ analyzer Fluke 435.

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