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# Virtual Instrument for Power Quality Research

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***Abstract-*** In the paper a virtual instrument for power quality measurement and research is proposed. The instrument is divided in several modules which provide generation, measurement and recording of the typical power quality (PQ) disturbances such as: harmonics, voltage dips, interruptions, flicker, unbalance etc. The virtual instrument allows setting different measurement parameters which expands its capabilities for research work. To perform real-time monitoring a prototyped signal conditioning circuit has been developed.

## I. Introduction

The increased awareness of the power quality (PQ) problems in the last 10-15 years has contributed in the development of different analysers and monitoring equipment that can characterize disturbances and PQ variation. Today different kind of monitoring equipment exists on the market, and some of them are with sophisticated software for statistical analysis. The shortage of those instruments usually is the price, which is too high for academia, and the analysis software which is usually sold together with the instrument does not give possibility for deeper scientific work.

This paper proposes computer based data-acquisition system that provides real-time monitoring of voltages and currents in a three phase system. The hardware part of the developed instrument is signal conditioning module, data acquisition card and personal computer. The software platform for user interface and PQ events analysis has been developed in LabVIEW program. The software is foreseen as open platform where new modules for different analysis can be easily upgraded.

## II. Signal conditioning module

The input electronic circuits of the A/D converter units can process signals with given standardized voltage parameters. The input range of the commercial A/D converters is usually ±10V. Therefore, the power line signals, voltages and currents have to be attenuated to the input voltage range of the A/D converter. This can be achieved in two ways: by using instrument transformers, resistive voltage dividers or resistive shunts. Each approach has its own justifications and drawbacks. Thus, instrument transformers have worse amplitude-frequency and phase-frequency characteristics and higher price. On the other hand, instrument transformers provide galvanic isolation from the power grid and simplify the realization of the signal conditioning module. Generally, the instrument transformers are usually used for power quality measurement in the high voltage power grids. For PQ measurements in the low voltage grids, usually resistive voltage dividers and resistive shunts are used. The galvanic isolation from the power lines is of high importance while it provides protection of the electronic circuits in a case of transients or ground loops. Therefore, when passive resistive elements are used, it is necessary to include isolation amplifiers in the signal conditioning module.

The block diagram of developed signal conditioning circuitry is given in Fig. 1. The signal conditioning circuit should provide seven representative voltage signals which correspond to the A/D converter input characteristics. These signals represent the appropriate currents and voltages of the three phase power system. The realized signal conditioning module has the following characteristics: input voltage range of ±500 V; output voltage range ±5 V; voltage and current analysis to $50^{th}$ harmonic; current measurements by using resistive shunt or current measurement transformer; USB power supply.

The electrical circuit for two input channels (one voltage and one current) of the signal conditioning module is given in Fig. 2.a, and the realized prototype [1] is given in Fig.2.b. The attenuator in the voltage channel is realized by using resistive voltage divider with attenuation 101 times. The value of the serial equivalent resistance (R'+R'') should be as low as possible to reduce the thermal noise. On the other hand, lower resistance value results in higher resistor power. For realization of the attenuator in this case a resistor values of R'=1 MΩ and R''=100 kΩ and power 2 Ω were used.

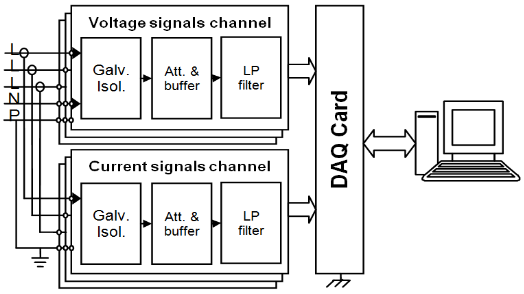


Figure 1. Block diagram of power line signal conditioning circuit

The output signal of the attenuator is galvanically isolated by using isolation amplifier ISO124. The isolation amplifier has maximal nonlinearity of 0.01% and temperature drift of 200µV/°C. The amplifier is supplied by two galvanically isolated DC/DC converters AM1D-0512D-N with input voltages of 5V and output voltages of ±12V. The input voltage of the DC/DC converters is provided by the USB port of a personal computer. To prevent aliasing, a fourth order Butterworth filter was designed. The value of the CFM (cut-off frequency multiplier) [2] parameter for this filter is 2.18.

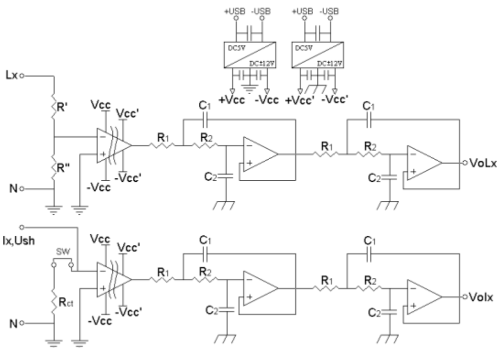


Figure 2.a. Electrical circuit of the signal conditioning module

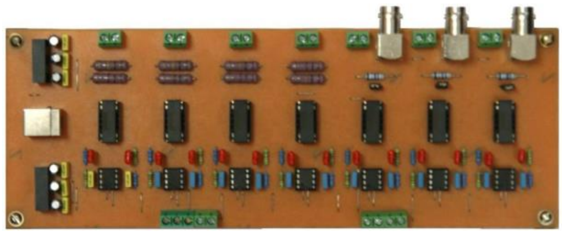

Figure 2.b. Realized prototype of the signal conditioning module

## III. Virtual flickermeter model

The developed model of virtual flickermeter is based on standard IEC 61000-4-15 and other solutions, [3], [4]. The functional block diagram is shown in Fig. 3. The model is divided in two parts:

- Input signal scaling and simulation of the response of the lamp-eye-brain chain, blocks 1 to 4, and
- Statistical evaluation of the flicker level, block 5.

Block 1 represents the signal conditioning module for filtering and attenuation of the input signal to an appropriate reference level and DAQ card, explained in the previous chapter. The blocks 2 to 4 represent the simulation of lamp-eye-brain response, programmed in LabVIEW. The block 2 represents a squaring demodulator for reconstruction of the envelope of the voltage fluctuations, and simulation of the lamp behavior. The block 3 is a cascade of two filters, band pass filter and weighting filter. The band pass filter is composed of: 3th order high pass filter which eliminates DC component with cut-off frequency of 0.05 Hz, and the 6th order low pass filter with cut-off frequency of 35 Hz for 230 V/50 Hz systems, [5]. The transfer characteristic of the band pass filter corresponds to the one of the human eye perception, [4]. The weighting filter of block 3 simulates the frequency response of a lamp and human visual system caused by voltage fluctuations. The weighting filter has maximum at 8.8 Hz since at this frequency the flicker perception is highest, [3]. The block 4 contains squaring multiplier and a first order low pass filter with cut-off frequency of 0.53 Hz. On the output of this filter the level of instantaneous flicker is obtained.

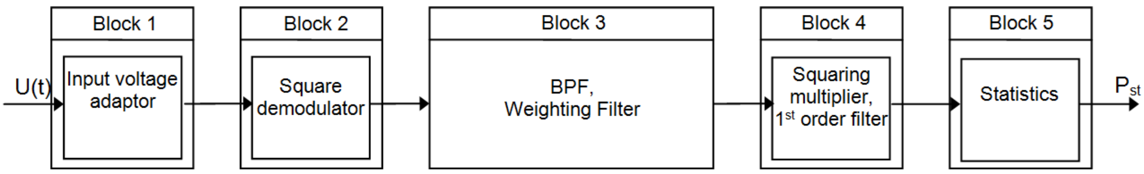


Figure 3. Virtual flickermeter model

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Statistical analyses of the measurement results over short period of 10 minutes are performed in block 5. The instantaneous flicker, which is time-varying function, is divided in 64 up to 1024 classes according the IEC standard. This classification is further used for obtaining the histogram of cumulative probability function (CPF) in percentiles, [5] and [4]. Percentiles are the levels of instantaneous flicker sensations which exceeded k% of the measurement time. Their evaluation is based on the cumulative probability function curve. The results of the statistical analyses are: 10-minute short-term flicker severity PST and two hours long-term flicker PLT. In the process of virtual instrument design it is very important to determine the appropriate sampling frequency of the input signal. Lower sampling frequency decreases the quality of the modulation signal envelope during the process of reconstruction. On the other hand, higher sampling frequency expands the calculation period.
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## IV. Virtual instrument for harmonic analysis

The Discrete Fourier Transform (DFT) is proposed in the IEC Standard 61000-4-7 [6] for the measurement of harmonics and inter-harmonics in power supply systems. Due to its cosine and sine basis functions DFT is a convenient way for spectral analysis of stationary and periodic signals. In practical situations, however, the voltage and current distortion levels as well as their fundamental components are varying in time, and the DFT can be inappropriate technique for signal analysis. If a signal is varying in a given time moment, the entire frequency spectrum can be affected. These time-variations of individual harmonics are analyzed by windowed Fourier transformations (or short-time Fourier transform), and each harmonic spectrum corresponds to each window section of the continuous signal. But, different windows sizes (i.e., number of cycles included in the DFT) give different harmonic spectra and the selection of the most adequate window size is a complex issue that is still being debated. In recent years, use of Discrete Wavelet Transform (DWT) as a powerful signal processing method is receiving increased attention for power quality (PQ) harmonic analysis. DWT is particularly useful for the analysis of non-stationary signals. The wavelet's dilation and translation property gives time and frequency information accurately. These unique properties are making DWT interesting for PQ analysis and research. However, the DWT coefficients cannot be used for harmonic analysis because the obtained output bands have non uniform frequency distribution. Wavelet packet transform (WPT) is the generalization of the conventional DWT and can be used for harmonics measurements. Many wavelet based algorithms for the harmonic analysis in power systems are proposed [7], [8]. Reported results are competitive with the results obtained using the harmonic-group concept proposed by the IEC for different measurement conditions, showing the potential of the wavelet analysis as an alternative processing tool for the harmonic estimation in power systems. The proposed virtual instrument serves as a good tool for harmonic analysis of the power supply and comparison of the performances of discrete Fourier transform (DFT) or wavelet packet transform (WPT) in different scenarios.
The proposed virtual instrument is divided into three main parts: setting the parameters of the input signal, recording and defining a wavelet type, Fig. 4. The virtual instrument allows input signal from several feeding sources like: simulated signal, signal from ASCII or COMTRADE data file or real signal from a data acquisition card. When the input signal is subject of simulation, the user can set the RMS value, offset and noise of each harmonic, etc. The user can also set the sampling frequency and the observation interval. By default, the observation interval is set to ten periods of the input signal, as in [7], but this rule can be disregarded. In a case of setting to low sampling frequency which doesn't satisfy the Nyquist theorem, it is automatically changed to its minimum allowed value.
In the "Wavelet" tab the user can select the wavelet type in two ways: choose some of the standard wavelet types implemented in LabVIEW (Daubaches, Symlet, Coiflet, Haar, etc.) or to import the filter coefficients from a file and create a custom wavelet. When importing the filter coefficients from a file, they are immediately displayed in an appropriate array indicator for inspection. In this section also a tree plot with node depth and position is displayed. The virtual instrument present the measurement results in the "Harmonics" tab. In the example shown in Fig.4, according the selected sampling frequency of 1600Hz, the virtual instrument measures the RMS of the first eight harmonics. This can be easily changed to measure higher harmonics by increasing the sampling frequency and wavelet depth.

The input signal, the wavelet approximation coefficients and the Fourier transform spectra are shown in graphical panels. The user can also choose particular wavelet approximation coefficient for a detailed view. The RMS results of the harmonics calculated both by wavelet or Fourier transform are automatically recorded into ASCII file format.

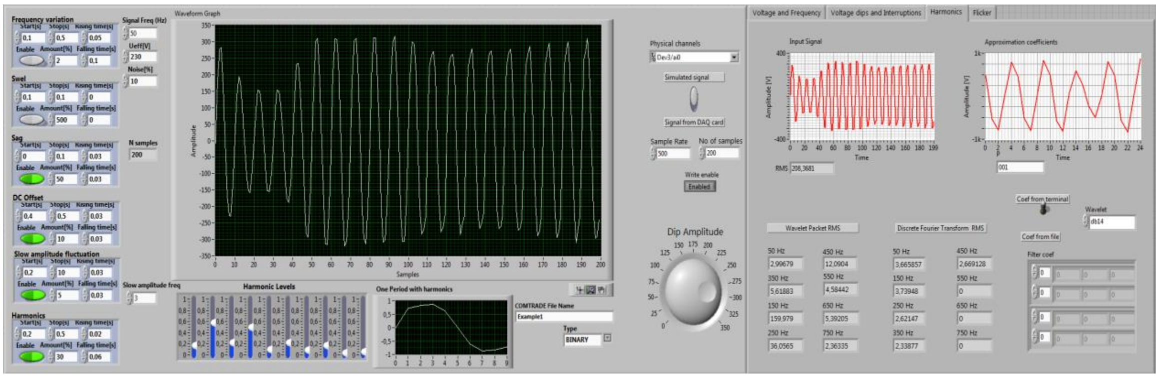


Figure 4. Front panel of the virtual instrument for harmonic analysis

## V. Voltage dips and interruptions detection

Typically, a voltage dip is visualized by plotting the RMS (Root Mean Square) voltage as a function of time, which is calculated or derived from the instantaneous voltage data. One-cycle RMS voltage values are used to quantify the reduction in voltage magnitude. The IEC power quality measurement standard [9] gives strict measurement-based definitions of the two main characteristics of voltage dips: the “residual voltage” and the “duration”. The residual voltage is the lowest RMS voltage in any of the channels during the event. The duration is the time during which the voltage is below the threshold in at least one of the channels where the threshold is defined, typically 90% of the nominal voltage. The detection and characterization of the voltage dips and interruptions according the standard has being implemented in the virtual instrument. The instrument has the possibility to change the voltage threshold and duration for classification of voltage dips and interruptions.

However, voltage dips are not fully described by residual voltage and duration and their shape is not always rectangular. In this context, measurements in three phase systems demonstrate various dip shapes. A dip due to motor starting is different from a dip due to line to line fault, which can also result in different types of dips. Such scenarios for detection and characterization of voltage dips can be investigated by using one of the coefficients of the Wavelet Packet Transform of the virtual instrument for harmonic measurements.

## VI. Conclusions

The paper presents data acquisition system for monitoring of power quality which is aimed for scientific research. The virtual instrument is divided into five main parts: power quality disturbances generator, voltages and currents parameters, harmonics, voltage dips and interruptions and flicker measurements.

For performing real-time monitoring a prototyped signal conditioning module has being developed. The conditioning module has an input voltage range of ±500V, output voltage of ±5V, USB power supply and possibility to analyze signals up to 50th harmonic.

In the developed virtual instrument the signal generator for all PQ disturbances is implemented. This module is significant for testing the other PQ analysis modules without the necessity of performing real-time measurements.Theoretical and practical facts concerning the monitoring and analysis of the light flicker according the standards have being elaborated and a LabVIEW based virtual instrument for measurement of light flicker was proposed. Virtual LabVIEW-based instrument for PQ harmonic analysis has being proposed. The virtual instrument performs harmonic RMS calculation by using DFT and WPT. The user can select the wavelet type in two ways: choose some of the standard wavelet types implemented in LabVIEW or to import the filter coefficients from a file and create a custom wavelet. Such instrument serves as a good tool for harmonic analysis of the power supply and comparison of the performances of DFT or WPT in different scenarios.

The advantage of such an instrument is that it can use the PC resources such as: memory, performance, communication interfaces, etc. In this way the developed instrument can be easily upgraded for performing distant distributed measurements over long period of time. The virtual instrument is designed as an open platform for power quality analysis and research. The user can easily change the working parameters used in the analysis and can implement new functions and different mathematical tools.

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