Computer Based Power Factor and Distortion Measuring for Small Loads

Marko Dimitrijević and Vančo Litovski

Abstract - Power factor and distortion measuring usually requires dedicated and expensive equipment. Computer-based acquisition modules and software provide for a possibility to create simple and non-expensive methods and instruments for power factor measurement and distortion characterization of small loads and bring all advantages of virtual instrumentation. A new approach to power quality characterization by measuring power factor, distortion and several other parameters of small electric loads (up to 0.5kW) will be described in this paper. Besides the low price maximum versatility and adaptability is provided without any loss in accuracy.

Keywords – Power factor, distortion, virtuall instrument

I. INTRODUCTION

Power quality is a relatively ambiguous concept, limited mostly to conversations among utility engineers and physicists, but as electronic appliances take over the home, it may become a residential issue as well [1].

According to a recent study [2], nowadays we are witnessing changes in the demand and energy use. In fact the new demand determines "new" load characteristics and trends while changes in the nature of the aggregate utility load happen. All of that is mostly due to the electronic plug-ins that became ubiquitous. Table 1 shows the typical household loads and their participation (in average) within the home power consumption.

TABLE I
THE STRUCTURE OF THE ENERGY NEEDS FOR ELECTRONIC
EQUIPMENT IN AVERAGE HOUSEHOLD

Type of consumption	Percentage
Entertainment	60
Information technology	31
Small appliances	5
Miscellaneous	4
Type of consumption	Percentage

Note that it is presumed that the overall household consumption for electronic appliances will rise with a rate of 6% per year so reaching 29% of the total household consumption in the year 2030. In the same time the household consumption is expected to reach 40% of the

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overall electricity demand.

Electronic loads are strongly related to the power quality thanks to the implementation of AC/DC convertors that in general draw current from the grid in bursts. In that way, while keeping the voltage waveform almost unattached, they impregnate pulses into the current so chopping it into seemingly arbitrary waveform and, consequently, producing harmonic distortions. The current voltage relationship of these loads, looking from the grid side, is nonlinear, hence nonlinear loads. The existence of harmonics gives rise to interference with other devices being powered from the same source and, having in mind the enormous rise of the number of such loads, the problem becomes serious with serious, sometimes damaging, consequences and has to be dealt width properly.

In linear circuits, consisting of linear loads, the currents and voltages are sinusoidal and the power factor effect arises only from the difference in phase between the current and voltage. In single phase system it is referred to as the displacement power factor or $\cos(\varphi)$. When nonlinear loads are present one should introduce new quantities in the calculations emanated by the harmonics and related power components [3]. Now the power factor can be generalized to a total or true power factor where the apparent power, involved in its calculations, includes all harmonic components. This is of importance in characterization and design of practical power systems which contain non-linear loads such as rectifiers, and especially, switched-mode power supplies [4].

Industry standards regulate the limits (minimum) of power factor. One of the most paradigmatic examples is personal computer that typically includes switched-mode power supply (SMPS) with output power ranging from 150W to 500W. SMPS with passive power correction factor (PFC) can achieve power factor of about 0.7–0.75, SMPS with active PFC—up to 0.99, while SMPS without any PFC has power factor of about 0.5–0.65 in the best. The current EU standard EN61000-3-2 imposes that all SMPS-es with output power more than 75W must include at least passive power factor correction [5].

Since the problem of distortion becomes ubiquitous one has to democratize the measurement of the properties of this kind of loads. There should be an opportunity to characterize every single product wherever convenient to a customer. Contemporary measurement of power factor and distortion, however, usually requires dedicated equipment.

For example, use of a classical ampermeter will return incorrect results when attempting to measure the AC

current drawn by a non-linear load and then calculate the power factor. A true RMS multimeter must be used to measure the actual RMS currents and voltages and apparent power. To measure the real power or reactive power, a wattmeter designed to properly work with non-sinusoidal currents must be also used. Accordingly, a set of measurement devices, some of them palm-held, are available on the market performing many measurements while offering connection to a computer. To our knowledge the price of such devices is considerably above the price of an average lap-top computer.

We are promoting here a new concept of measurement of the power quality parameters of small loads. The main idea is to perform the measurement in two phases that impose partitioning both the hardware and software subsystems in two. The parts will be referred to here as the Power Factor and Distortion Measurement Device (PFDMD) and the computer. The former is a "sampling" device while the other is the processing device. In that way only minor activities (sampling and A/D conversion of the current and voltage) are performed within the sampling subsystem the computer taking the main role in data processing of all kind. In this way we introduce a robust and versatile system with practically unlimited possibilities. The price of the system is defined by the sampling device to be incomparably lower than the palm-held devices now available on the market, and the price of the software, that, in our opinion, may be easily written so lowering the total price of the overall measurement system. We will demonstrate in the next that practically every conceivable quantity related to power measurement may be obtained.

The practical implementation of the new system was based on two broadly available components: the National Instruments NI USB-9215A acquisition module and the LabVIEW software platform.

In the next we will first introduce the basic definitions that are expressing how the measured quantities are calculated from the current and voltage waveforms. Then, the hardware and software components of the system will be described briefly. Finally, measurement results will be given to demonstrate the method and to give some information to the public about the properties (quality) of some small loads now available on the market.

II. THE DEFINITIONS OF THE FUNDAMENTAL QUANTITIES

Traditional power system quantities such as effective value, power (active, reactive, aparent), and power factor are defined for pure sinusoidal condition. In the presence of nonlinear loads, however, the system no longer operates in sinusoidal condition and use of fundamental frequency analysis does not apply any more. They will be numerically calculated from sampled voltage and current sequences [6]. In the next we will first introduce definitions that were used

as basis to the development of the new measurement tool and for characterization of the measured quantities.

Power factor is simply defined as the ratio of real power to apparent power, or:

$$TPF = \frac{P}{S} \tag{1}$$

The real power, P, is the average, over a cycle, of the instantaneous product of current and voltage:

$$P = \frac{1}{T} \int_{t_0}^{t_0+T} v(t) \cdot i(t) \cdot dt \tag{2}$$

where t_0 is arbitrary time (constant) after equilibrium, and T is the period (20 ms in European and 1/60 s in American system, respectively). The apparent power is the product of the root mean square value of current times the root mean square value of voltage:

$$S = V_{RMS} I_{RMS}. \tag{3}$$

The RMS value is calculated according to the well known formula:

$$X_{rms} = \sqrt{\frac{1}{T} \int_{t_0}^{t_0+T} (x(t))^2 \, dt}. \tag{4}$$

According to that definition for the RMS values of the voltage and current one may produce the following

$$V_{rms} = \sqrt{\sum_{i=1}^{m} V_{rms\,i}^2} \tag{5}$$

and

$$I_{rms} = \sqrt{\sum_{i=1}^{m} I_{rms\,i}^2}, \tag{6}$$

where $V_{RMS\,i}$ and $I_{RMS\,i}$ are the RMS values of the ith harmonic of the voltage and current, respectively, while m represents the number of harmonics taken into account.

For a pure sinusoidal case, i.e. when $v(t) = V_m \cdot \cos(\omega \cdot t + \alpha)$ and $i(t) = I_m \cdot \cos(\omega \cdot t + \beta)$, where V_m and I_m are the amplitudes, and α and β the phase angles of the voltage and current, respectively, the power factor is readily obtained to be $PF=\cos(\alpha-\beta)=\cos(\varphi)$. If harmonics are present the *power factor relates only the main (first) harmonics* of the current and voltage and will be referred to as the displacement power factor. New quantity is introduced to express the influence of the harmonics to the power losses. It was referred to as the distortion power factor. In the next we will first introduce its definition.

The total harmonic distortions, *THD*, are calculated from the following formula:

$$THD = \sqrt{\frac{1}{y_1}\sum_{i=2}^{m} y_i} \qquad (7)$$

where y_i, $i=1, 2, \ldots, m$ stands for the ith harmonic of the current or voltage. One usually computes the current *THD* from:

$$THD_I = \frac{1}{I_{rms\,1}}\sqrt{\sum_{i=2}^{m} I_{rms\,i}^2}, \qquad (8)$$

and the voltage THD from

$$THD_V = \frac{1}{V_{rms\,1}}\sqrt{\sum_{i=2}^{m} V_{rms\,i}^2}. \qquad (9)$$

The above definition of the *THD* may lead to values that are higher than 100%. That is the reason why in some proceedings an alternative definition is used:

$$THD_I^* = \sqrt{\frac{I_{rms}^2 - I_{rms\,1}^2}{I_{rms}^2}} = \sqrt{1 - \frac{I_{rms1}^2}{I_{rms}^2}} \qquad (10)$$

We define the distortion power factor as the quantity

$$DPF = I_{rms\,1}/I_{rms} \qquad (11)$$

and introducing (6) and (8) we obtain

$$DPF = \frac{1}{\sqrt{1 + THD_I^2}}. \qquad (12)$$

The total power factor defined by (1) is obtained as a product of the displacement power factor and the distortion power factor as

$$TPF = DPF \cdot \cos(\varphi). \qquad (13)$$

where φ represents phase difference between first harmonics of voltage and current. $\cos(\varphi)$ is displacement power factor; in case of linear load, total power factor is equal to displacement power factor.

Two more quantities are of interest for more complete characterization of the waveforms encountered. The direct component of the current defined as

$$I_{DC} = \frac{1}{T}\int_{t_0}^{t_0+T} i(t) \cdot dt, \qquad (14)$$

and the CREST factor. The later is defined as the ratio of the peak value and the RMS value in a given time slot:

$$CF = V_{peak}/V_{RMS}. \qquad (15).$$

III. SYSTEM IMPLEMENTATION

A. Hardware implementation

The measurement of the quantities mentioned in the previous paragraph is performed by a system whose components are depicted in Fig. 1. The Power Factor and Distortion Measurement Device (PFDMD) is connected to the grid from one side, and transfers the power to the device under test (load) while sampling the values of the current and voltage waveforms of the load. The sampled values are appropriately conditioned and coded, and then directly delivered to the computer via USB terminal. All computations are performed by the software implemented in the computer. For example, the frequency of the measured waveform is easily extracted by post processing of the signals. In the same time the computer is used as an oscilloscope enabling display of the measured and derived waveforms, as an interactive monitor allowing different quantities to be displayed, as a data storage device creating measurement logs and databases, and a communication means enabling remote control of the measurement and on-line delivery of the results.
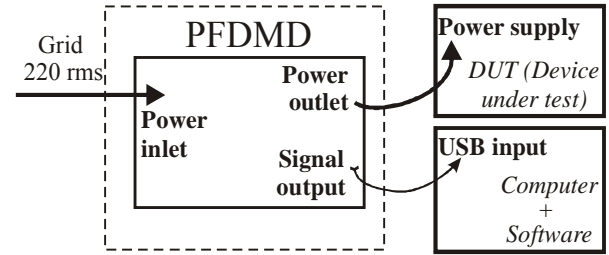

Fig. 1. The PFDMD and its surroundings

Data acquisition within the PFDMD is performed using an acquisition module. It is based on National Instruments NI USB-9215A acquisition module (DAQ) [7]. The data acquisition module has four channels of simultaneously sampled voltage inputs with 16-bit accuracy, 100kS per channel sampling rate and $250V_{RMS}$ channel-to-earth isolation, suitable for voltage measurements up to 40th harmonic (2kHz). It also provides for portability and hot-plug connectivity via USB interface.

Two channels are used: for voltage and current measurement. The analogue inputs of acquisition module are connected using differential measurement method [8] due to better noise rejection and channel-to-earth isolation.
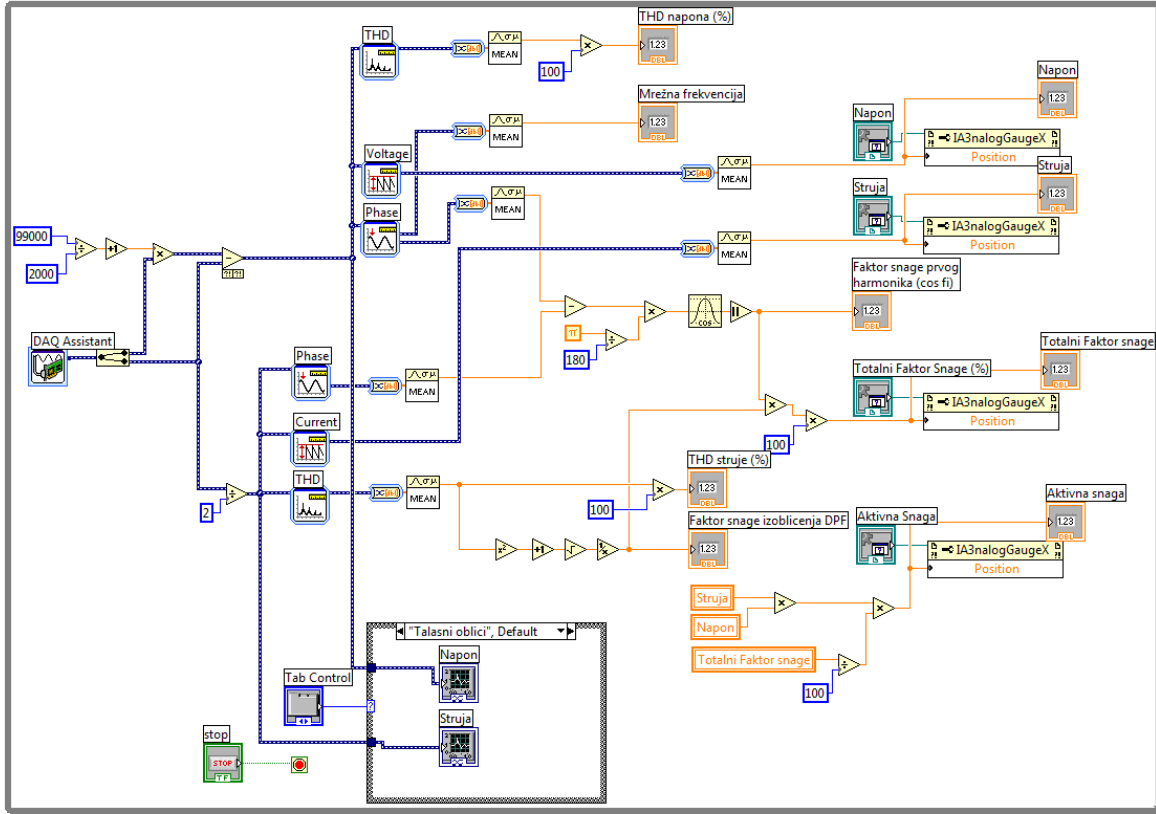
Fig 2. Main thread of application

B. Software implementation

The Software part of the power factor and distortion measuring system is implemented in *National Instruments* LabVIEW developing package (Fig. 2.), which provides simple creation of virtual instruments [9]. Virtual instruments consist of interface to acquisition module and application with graphic user interface.

Interface to acquisition module is implemented as device driver. USB-9215A module is supported by NIDAQmx drivers. All the measurements are performed using virtual channels. A virtual channel is collection of property settings that can include name, a physical channel, input terminal connections, the type of measurement or generation, and scaling information. A physical channel is a terminal or pin at which an analogue signal can be measured or generated. Virtual channels can be configured globally at the operating system level, or using application interface in the program. Every physical channel on a device has a unique name.

For better performance, the main application has been separated into two threads. The first thread has functions for file manipulation and saving measured values (Fig. 4.). All measured values will be saved in HTML file format.

The user interface of the virtual instrument consists of visual indicators. It provides basic functions for measurement. The indicators — gauges and graphs — show measured values. All measured values are placed in a table, and after the measurement process in appropriate file. User interface also provides controls for data manipulation and saving measured values.

IV. CONCLUSION AND MEASUREMENTS

The main research goal of this paper was to present a simple and non expensive method and instrument for power factor measurement and distortion characterization of small electric loads. The measured values of current and voltage THD, DPF, TPF and other parameters are shown in virtual instrument screenshots (Fig. 3). Virtual instrument shows current and voltage spectra as well as their waveforms in real time.

Virtual instrument is capable for real-time sampling and measuring voltage and current of DUT, providing possibility for transient analysis in time and frequency
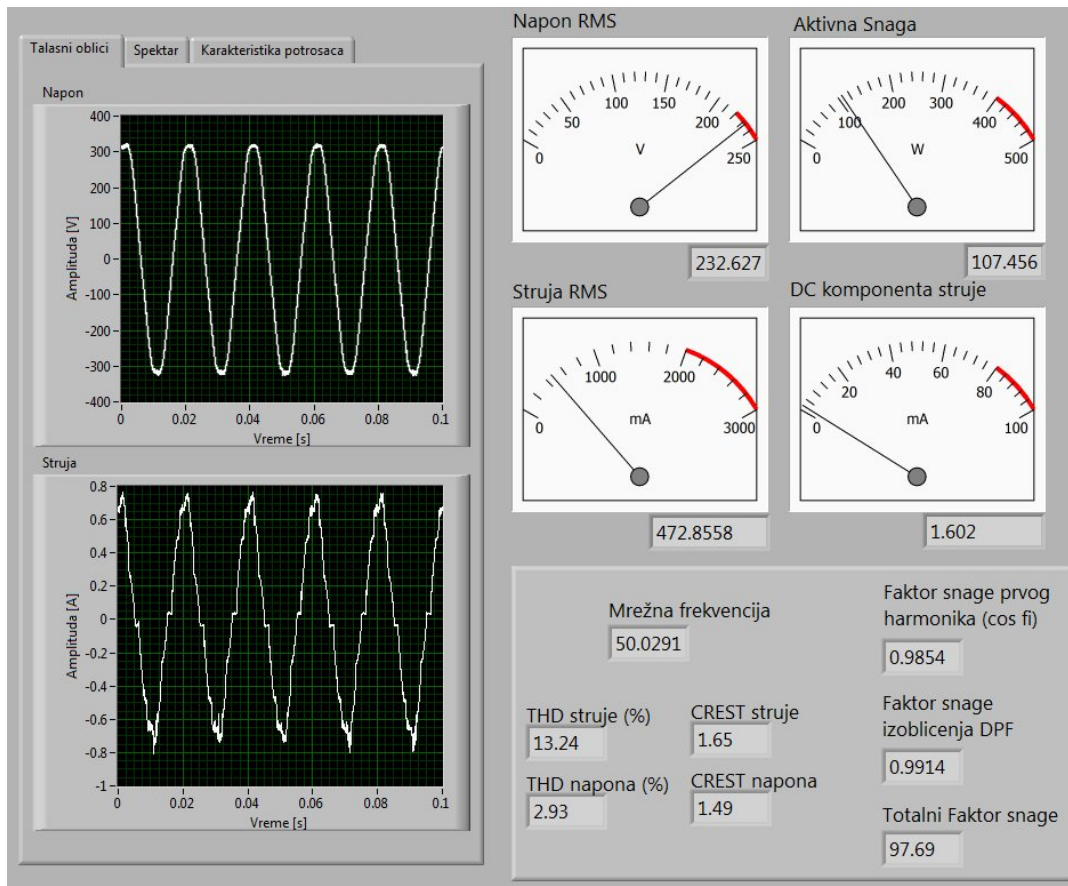
Fig. 3. Virtual instrument — Computer monitor with good distortion correction, with real power of cca 100W. Cos(φ) is 98.54%, current THD is 13.24%, voltage THD is 2.93%, DPF is 99.14%, TPF is 97.69% — current and voltage waveforms are shown at the left side of virtual instrument panel

domain. Measuring time depends of storage capacity of host PC.

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