Distortion Power Measurements in Education

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Abstract. *This paper deals with digital measurement of single-phase power using DAQ card NI USB-6009 and other similar equipment. Main attention is paid to distortion power measurement. In LabVIEW environment a program for counting and describing all power components based on harmonic analysis of time behaviour of measured voltage and current was created. The program (virtual instrumentation) describes basic characteristics of input signals and similar information about harmonics. This virtual instrumentation is used for the laboratory experiments in electrical measurement undergraduate course at the faculty.*

Keywords: Distortion Power, Automated Measurement, Virtual Instrumentation (VI), Data Acquisition (DAQ), LabVIEW

1. Introduction

With increasing progress in electrical technology and electronics as well as in production and distribution of electric power the need of effective and accurate measurement of electric power is increasing, too. Power measurement still presents complicated task, mainly if taking in account an expansive economical thyristor and other heavy-current and also light-current semiconductor elements. When used then in low-voltage networks the harmonics distortion of both voltage and current time behaviour occurs with higher harmonic components. Created virtual instrument enables students to see and to measure the influence of distorted currents on each power component for linear and non-linear loads.

2. Electric Power

The instantaneous power delivered to a load can be expressed as

$$p(t) = u(t) \cdot i(t) \tag{1}$$

where $u(t)$ and $i(t)$ are the time varying voltage and current waveforms [1]. The instantaneous power may be positive or negative depending on the sign of $u(t)$ and $i(t)$, which is related to the sign of the signal at a given time. A positive value means that the power flows from the supply to the load, and a negative value indicates that the power flows from the load to the supply.

Active power consumed on a load is defined as the mean value of the instantaneous power

$$P = \frac{1}{T}\int_0^T u(t)\,i(t)\,dt \tag{2}$$

We use the following terms to describe energy flow in a system: real or active power P [W], reactive power Q [VAr], complex power $\boldsymbol{S}$ [VA] and apparent power $S=|\boldsymbol{S}|$ [VA] that is the magnitude of complex power. We assign each of them a different unit to differentiate between them.

In the case of a perfectly sinusoidal waveform, P, Q and S can be expressed as vectors that form a vector triangle: $S^2 = P^2 + Q^2$. The mathematical relationship among them can be represented by vectors or expressed using complex numbers, $\boldsymbol{S} = P + jQ$.

Apparent power *S* is the product of rms values of voltage *U* and rms values of current *I* [2]. It is important because it represents the total capacity that must be available to supply power to the load - even though only a part of this is useful power.

$$S = U\,I \tag{3}$$

In case of harmonic supply

$$\boldsymbol{S} = P + jQ = U\,I\,(\cos\varphi + j\sin\varphi) \tag{4}$$

where the active power $P = U\,I\cos\varphi$ and the reactive power $Q = U\,I\sin\varphi$.

The cosine of the phase angle φ between the voltage and the current is called the power factor

$$\lambda = \cos\varphi = \frac{P}{S} \tag{5}$$

When the current is non-sinusoidal the influence of harmonics has to be considered, because it caused that the powers *P* and *Q* are done by harmonics of the same order of both voltage and current

$$P = \sum_{k=0}^{\infty} U_k I_k \cos\varphi_k \quad [\mathrm{W}] \qquad\qquad Q = \sum_{k=1}^{\infty} U_k I_k \sin\varphi_k \quad [\mathrm{VAr}] \tag{6}$$

Apparent power is

$$S = U \cdot I = \sqrt{\sum_{k=0}^{\infty} U_k^2}\sqrt{\sum_{k=0}^{\infty} I_k^2} \quad [\mathrm{VA}] \tag{7}$$

In case of non-sinusoidal signals the inequality $S^2 \geq P^2 + Q^2$ is valid. The influence of so called distortion power *D* occurs. It consists of unequal harmonics of voltage and current

$$D = \sqrt{\sum_{j \neq k}^{\infty} \left[U_k^2 I_j^2 + U_j^2 I_k^2 - 2U_k I_k U_j I_j \cos(\varphi_k - \varphi_j)\right]} \quad [\mathrm{VA}] \tag{8}$$

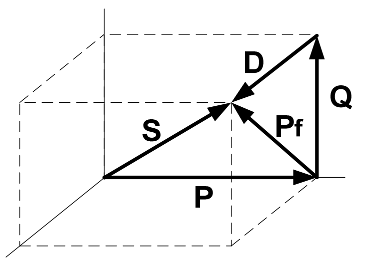

Fig. 1. 3D graph representation of power components

The powers active, reactive and distortion are connected by a relation $S = \sqrt{P^2 + Q^2 + D^2}$. Geometric sum of reactive and distortion powers is equal to non-active power $P_f = \sqrt{Q^2 + D^2}$. The function representation of mentioned powers is in Fig. 1.

Power factor in this case is

$$\lambda = \frac{P}{S} = \frac{\sum_{k=0}^{\infty} U_k I_k \cos\varphi_k}{\sqrt{\sum_{k=0}^{\infty} U_k^2}\sqrt{\sum_{k=0}^{\infty} I_k^2}} \tag{9}$$

Harmonic content is expressed by total harmonic distortion *THD*

$$THD = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} \cdot 100 \quad [\%] \tag{10}$$

This parameter mainly determinates signal distortion. It is calculated by use of harmonic analysis.

3. Application

The measurement of electric power is necessary in various experiments. Computer-aided laboratory exercises based on the LabVIEW system are efficiently used on the topic of Power measurement. In the next example of LabVIEW application the virtual instrument system in

the education of measurement distortion power in single-phase system is presented [3]. Automated procedures have been developed for quantifying various components of power.
In many common measurement applications a DAQ card, with a personal computer and software, can be used to create an instrument - virtual instrument (VI) - for all user interaction and control. In our measurements voltage and current signals through a load are transferred to the computer by means of DAQ card.

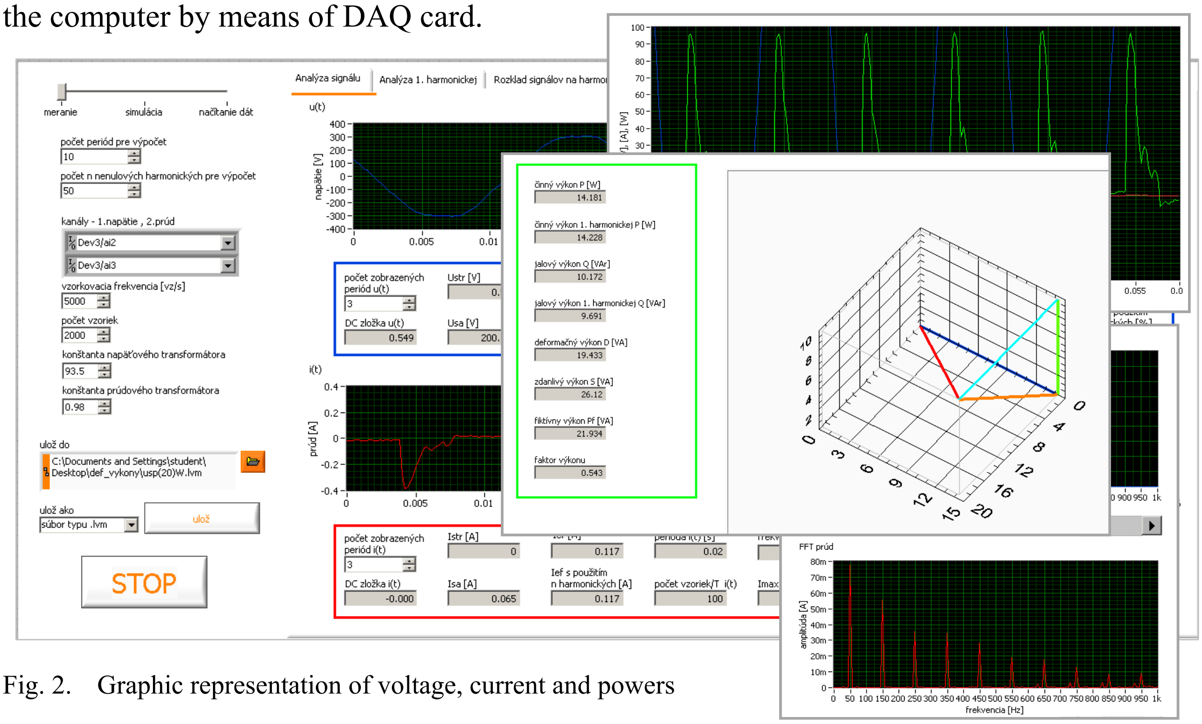

Fig. 2. Graphic representation of voltage, current and powers

Program realises or simulates both voltage and current measurements. The sampled time behaviour is represented in graph. From the samples the parameters of voltage and current (e.g. mean value, rms value, offset, form factor, THD, …) are calculated. There is a possibility to choose the calculation and representation of either the instantaneous power or the powers in 3D graph. Review of relations between the powers, voltage and current and FFT of voltage and current is possible, too – as seen in Fig. 2.
The 3D phasor diagram of powers is displayed to understand the geometric connection. The application allows the presentation of voltage and current phasor diagrams.

4. Measurement and Results

This program was used in the experiment for characterizing the most frequently used electrical light sources - a classic filament lamp 60 W (linear load), LED lamp 20 W and compact fluorescent lamp 15 W (both non-linear loads, equivalent to 60 W filament). To measure the power of concrete lamps the DAQ card NI USB-6009 was selected. It is compatible with LabVIEW program. To adapt a signal in consideration of DAQ input voltage parameters a simple voltage divider was used. Currents were obtained by measuring the voltages across the resistor.

In all cases the voltage time behaviours were almost sinusoidal, but the current time behaviours were different, in upper part in Fig. 3. The current time behaviour of classic filament lamp was also almost sinusoidal as it was expected. Similarly, in LED lamp as in fluorescent one the current was distorted. The great part of their power was created just by distortion component. As seen in lower part in Fig. 3 and Tab.1 this component is smaller for LED lamp in comparison with fluorescent lamp, but LED lamp has lower value of power factor. Because of reactive impedance its reactive power is higher. Similar results are also in [4].

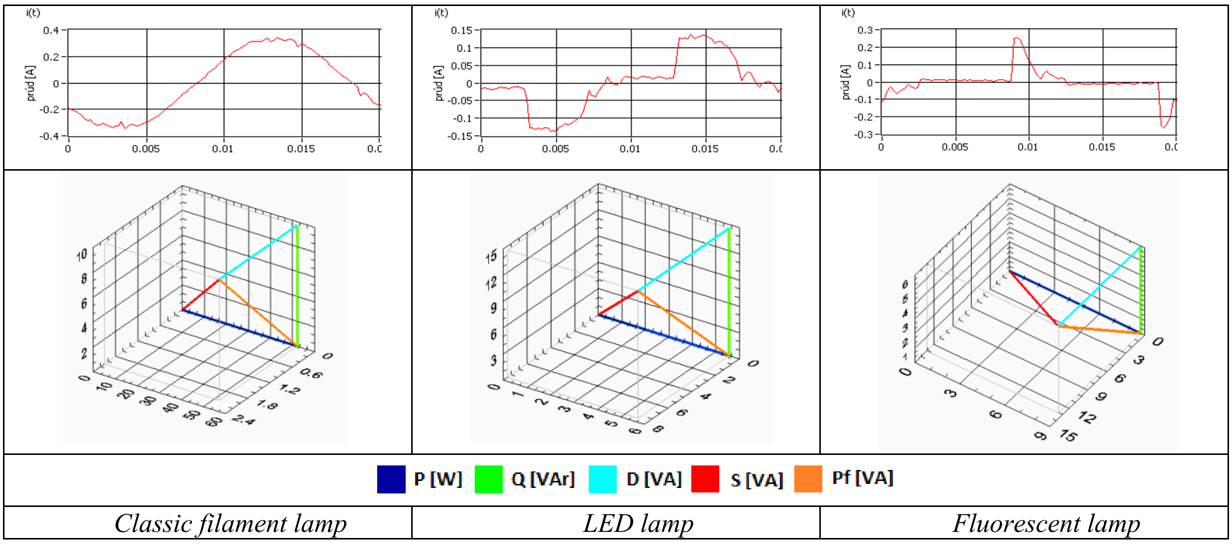

Fig.3 Current time behaviours (upper) and power components (lower) of measured lamps

Table 1. The power components for Incandescent light bulb, LED bulb and Fluorescent light bulb

		Classic	LED	Fluorescent
Active power	P (W)	52.15	5.16	8.77
Reactive power	Q (Var)	9.64	14.68	5.79
Distortion power	D (VA)	2.09	7.65	13.11
Apparent power	S (VA)	53.07	17.35	16.81
Non-active power	Pf (VA)	9.87	16.56	14.33
Power factor	PF	0.98	0.29	0.52

5. Conclusions

Taking into consideration harmonic distortion the automated system presented in this paper proved to be effective and valid for measuring single-phase power systems. It may be used for any kind of periodic voltage and current waveforms, as it calculates power from the harmonic components, extracted from a FFT analysis. The instantaneous, active, reactive, distortion, apparent and fictive power as well as power factor are calculated and presented on the screen. Distortion power has raised increasing interest with the expansion of non-linear electric loads connected to the electrical system.

The application is being used as a powerful tool for teaching single-phase electrical systems and it enriches traditional experiments in objects focused on power measurements in bachelor study. It is suitable for distance measurement and in simulation mode for self-study.

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