Measurement of Electrical Energy Under Non-sinusoidal Voltage and Current - Conditions and Requirements

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Abstract-The main purpose of the paper is to present the metrological aspects of virtual kilo-watt-hours meters developed for measurement of active power in while voltage and current are non-sinusoidal. Today's electrical kilo-watt-hours meters are built as devices for sinusoidal signals both for current and voltage. These electromechanical units are not appropriate for distorted signals, so the new generation of kilo-watt-hours with a used of electronic elements are under development. Deliberation of virtual active electronic electrical power meters are presented here.

I. Introduction

Electrical and electronic devices used in today's technology world are sources of disturbances in electrical power net and are causing distortions in current and voltage. These units are regarded as non-linear loads and loads which are using relatively high current consumption in short periods. The most commonly known non-linear loads are as follows: electrical furnaces, all electromagnetic devices, power suppliers, frequency converters, switching gears, arc-phenomena based devices, fluorescent lamps, power supplies of computers, and also most today's home appliances. Example of a time domain signal for an accelerating frequency converter is shown in Figure 1. It is easy to notice that every 20 ms period is different.

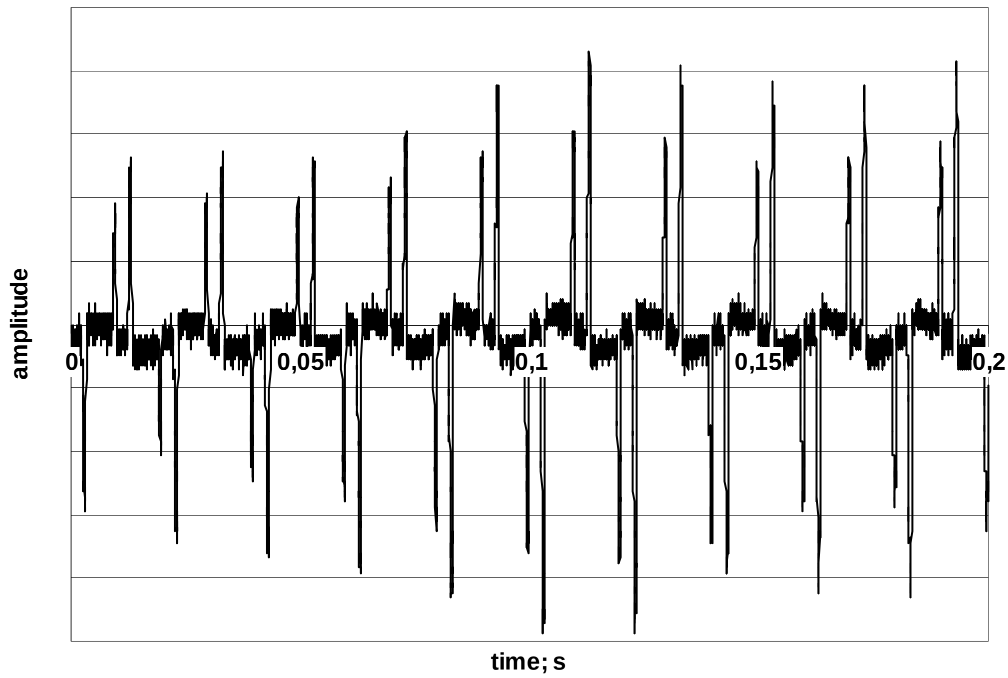

Figure 1. Sampled data of current at the input of a frequency converter, during acceleration; N=10 000 samples, fs = 50 kS/s.

Distorted current is causing a voltage distorted especially while a large capacity loads are in use. There are many disadvantages due to harmonics, inter-harmonics and sub-harmonics. One of the them are additional electrical power losses caused by current of harmonics through electrical line, the other mainly in the form of short picks, spikes can cause even malfunctioning and braking down some electronic equipment.

Effects of harmonics introduce problems in measuring instruments, including conventional kilo-watt-hours meters. The conventional electromechanical electrical power meters are sensitive to such effects. Electrical power consumption should be measured with an adequate necessary accuracy, which satisfies electrical power producers, distributors and consumers. Still mechanical energy counter are in use and will be for a long time, but the new kilo-watt-hours meters are becoming more and more in use now. The new electronic meters are less sensitive to above mentioned distortions. Electronic type of electrical power meters are still as analogue and digital devices. The digital electrical power meters are facilitated by DSP processors using the advantage of digital signal processing, just developed in last decades. The authors have elaborated models of a virtual electrical power meter, of which parameters are described.

II. Models of kilo-watt-hours meter

The two models were elaborated. One is a conventional, as it is based on the definition formula (1) or for sampled data in discrete form (2)

$$E = \int_{t_0}^{t_0+T} v(t)i(t)dt \tag{1}$$

$$E_P = \frac{T}{N}\sum_{n=0}^{n=N-1} v\left(\frac{nT}{N}\right) i\left(\frac{nT}{N}\right) \tag{2}$$

N-number of samples.

Block diagram of such meter is in Figure 2.

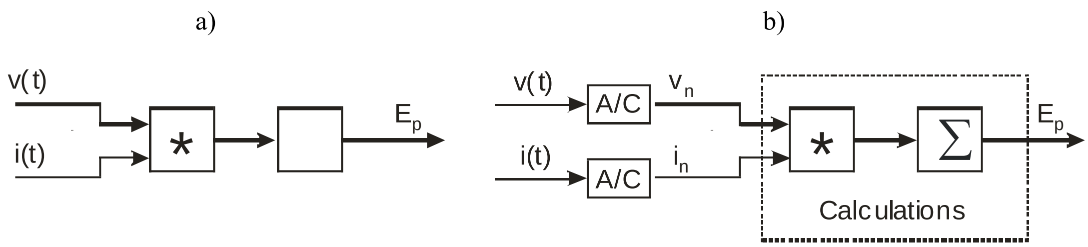

Figure 2. Block diagrams of kilo-watt-hours: a) analogue and b) discrete model

The second model is based on calculation of power of harmonics using the FFT for adequate number of samples (Fig. 3).

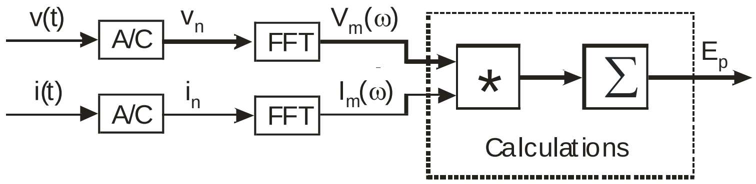

Figure 3. Block diagram of virtual kilo-watt-hours based on FFT procedure

The formula for active power, which is a basic step for calculation active electrical power consumption E_P is as follws:

$$P = \sum_{m=0}^{M-1} V_m(\omega_m) I_m^*(\omega_m) \quad \Rightarrow \quad E_P \tag{3}$$

in which:

V_m - m-th harmonic of voltage, I_m^* - conjunctive current value of m-th harmonic, ω_m - frequency of m-th harmonic, m= 0 … M.

The following formulas were also implemented in procedures of the virtual models:

- active power

$$P = \sum_{m=1}^{M} V_m I_m \cos\varphi_m \quad \Rightarrow \quad E_P \tag{4}$$

- reactive power

$$Q = \sum_{m=1}^{M} V_m I_m \sin\varphi_m \quad \Rightarrow \quad E_Q \tag{5}$$

- apparent power

$$S = VI = \sqrt{\sum_{m=0}^{M} V_m^2 \sum_{m=0}^{M} I_m^2} \quad \Rightarrow \quad E_S \tag{6}$$

- distortion power:

$$D = \sqrt{S^2 - P^2} \quad \Rightarrow \quad E_D \tag{7}$$

- deformation power

$$K = \sqrt{D^2 - Q^2} \quad \Rightarrow \quad E_K \tag{8}$$

III. Testing Signals

For testing purposes, the signals which contain a finite number of higher harmonics, inter-harmonics and sub-harmonics were chosen deliberately. Up to 50^{th} harmonic of 50 Hz was chosen according to most today's standards:

a) testing signal consists only of higher harmonics (up to 50^{th})
b) testing signal consists of inter-harmonics of 5 Hz components up to 50^{th} harmonic of 50 Hz
c) testing signal consists of sub-harmonics of 1 Hz components up to 50^{th} harmonic of 50 Hz

Testing signals can be used from two sources: as real distorted signals at the input of meter or as test files which are equivalent of signals, which may appear. The second type of signals especially can be used for testing procedures.

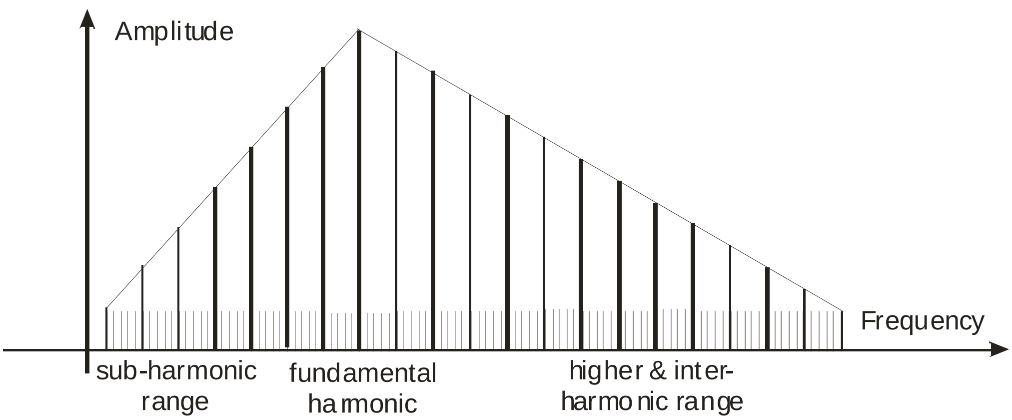

Figure 4. Harmonic contents of three types of testing signals.

IV. Source of errors in virtual kilo-watt-hours meter

Apart from above considerations of errors due to method used in electronic kilo-watt-hours-meter the measurement uncertainties are induced due to errors which can be caused by:

a) The standard, or calibrating instrument, against which the measuring instrument in question was calibrated.
b) Uncertainty in instrument characteristics. These include resolution, which is also known as discrimination uncertainty, lack of repeatability, instability and reproducibility uncertainties.
c) Measurement system uncertainties, which are caused by the characteristics of the measurand, the interface between the measurand and the measuring instrument(s) or measurement instrumentation interfaces. Examples of these are uncertainties caused by lack of cleanliness, uncertainties due to the operator and other similar sources.
d) Measurement environment uncertainties, which include changes in temperature, pressure, humidity and power supply among many others.

The virtual electrical power counter is equipped with LEM voltage and current sensors and the main DSP is performed by software procedures. The accuracy of elaborated the virtual power meter is estimated and also the instrument was calibrated.

The calibration was performed in two ways:

a) based on test signals in a form of files of which parameters were defined by authors
b) based on signals produced by signal generators of which harmonic contents was arbitrary chosen by authors.

IV. Conclusions

The tests of proposed models of the kilo-watt-hours meter, which also identify harmonics, allowed authors to come to conclusions, that although sampling frequency equal of twice of Nyquist frequency is sufficient, the better results from the point of accuracy are for several times higher accuracy. This is due to reduction of errors caused by peripheral elements like filters, current and voltage transformers, and just to reduce random errors coming from outside.

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