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The influence of current distortion on indications of smart energy meters

Abstract

Information on the smart grid and smart metering systems with particular emphasis on the benefits resulting from their implementation are shortly summarized in this paper. The essential part of the work is analysis influence of current distortion on indications of some chosen measuring devices used in smart grid systems, allowing for their assessment and classification. For the measurements and analysis both the common induction energy meters and modern electronic meters of various communication modems were taken into consideration.

Keywords: energy meters, smart grid, smart metering, current distortion, THD factor.

1. Introduction

The „smart grid" term applies to modernized power systems with built-in two-way (consumer-producer) communication capabilities and "intelligent" power flow measurement and monitoring systems. A key part of every smart power system is an intelligent measuring system [1, 6, 7, 8].

Guidelines to implementing smart power systems can be found in the I.2 attachment to the 2009/72/WE electricity directive, which obliges EU member countries to perform an assessment of introducing smart measurement systems as the key stage of implementing smart grids [2]. Additionally, the necessity of using measurement systems that can reliably determine exact power usage and its timeline has been expressed in the energy end-use efficiency and energy services and repealing directive (2006/32/WE) [1].

Among positive aspects of implementing smart power grids are [3]:

- the ability to influence power consumers' usage habits, mainly by promoting usage patterns that reduce power consumption and minimize power usage distribution peaks,
- the ability to manage the power grid, what improves the grid reliability and reduces running costs,
- the ability to integrate multiple small-scale power sources (mainly renewable ones), what leads to reducing usage of solid fuels and CO_2 emissions.

One has also to take into account the negative sides of smart grid implementation process, such as high initial costs and consumer privacy concerns. There are also some issues with the accuracy of smart power meters and uncertainty as to costs associates with running such meters.

While the specification of smart grid systems is fairly well defined, there is no single, definitive description of a "smart meter". It is only assumed that a smart meter is a power meter with some additional functionality added, such as: remote power usage reading, remote power delivery switch, on-line power usage recording, remote energy cost adjustment.

From a metrological point of view, a smart power meter does not differ from a plain power meter. The part of a smart meter that performs measurements should comply with the same requirements. The other part that implements the additional functionality such as mentioned above, as concerned from a legal metrology point of view can have no negative influence on the measuring part or the data being transmitted [3, 5]. In the following text, a "plain meter" will be represented by a commonly used induction type meter, and "smart meters" will be represented by electronic devices equipped with different wired and wireless communication interfaces.

The primary aim of the research was an analysis of the influence of current distortions on smart meters and plain electromechanical meters. The distortions were caused by selected non-linear loads, primarily commonly used, gas-discharge lamps.

2. Measuring power and energy consumption of non-linear loads

Power meters measure active and passive power consumption of different loads. The percentage of non-linear loads that introduce significant current distortion is increasing. From the economical point of view, it is important to know how the distortions influence power meters used in smart grid and smart metering solutions. One way to determine the influence is to apply the theory of power. The other, presented in this article, is to perform laboratory experiments.

In case the voltage is sinusoidal while the current is distorted due to the load's non-linearity, the current can be expressed by the function:

$$i(t) = \sum_{n=1}^{\infty} \sqrt{2} I_n \sin(n\omega t - \varphi_n), \tag{1}$$

and the RMS current of the load by the function:

$$I = \sqrt{I_1^2 + I_2^2 + I_3^2 + \dots} = \sqrt{I_1^2 + \sum_{n=2}^{\infty} I_n^2} = \sqrt{\frac{1}{T}\int_0^T i^2(t)dt}, \tag{2}$$

where:

n – the harmonic number,
I_n – the RMS value of the n-th harmonic of current $i(t)$,
φ_n – phase shift between voltage and current for n-th harmonic.

Power $p(t)$ may be expressed by the function:

$$p(t) = UI_1\cos(\varphi_1)(1-\cos(2\omega t)) - UI_1\sin(\varphi_1)\sin(2\omega t) + \sum_{n=2}^{\infty} 2UI_n \sin(\omega t)\sin(n\omega t - \varphi_n), \tag{3}$$

with the primary frequency ($n = 1$) component and the distortion-associated components ($n \geq 2$) singled out.

The apparent power may be expressed by the function:

$$S = UI = U\sqrt{I_1^2 + \sum_{n=2}^{\infty} I_n^2}, \tag{4}$$

while the power equation takes the form:

$$S^2 = U^2I^2 = U^2I_1^2 + U^2\sum_{n=2}^{\infty} I_n^2 = S_1^2 + H^2 = P_1^2 + Q_1^2 + H^2 = P_1^2 + D^2, \tag{5}$$

where the power components for the primary frequency can be singled out as:

P_1 – active power of first harmonic,
Q_1 – passive power of first harmonic,
and the distortion-associated power components can be singled out as:
H – deformation power,
D – distortion power.

$$H = \sqrt{U^2 \sum_{n=2}^{\infty} I_n^2}\ , \tag{6}$$

$$D = \sqrt{Q_1^2 + H^2}\ , \tag{7}$$

For determining the amount of harmonics in the distorted current, the THD (Total Harmonic Distortion) parameter can be defined as:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1}\ , \tag{8}$$

The primary function of an electronic power meter are the same as in case of an induction type meter, i.e. measuring active and passive power. However, this aim is achieved using several technical solutions that differ in their construction details and metering and signal processing algorithms. This can result in additional functionality, but – more importantly – may influence the metrological properties of a device, such as error sources that can be impossible to identify by an end user. In fact, different smart meter implementations may behave differently in similar conditions, with differences observed in error levels, sensitivity to usage conditions and susceptibility to external distortions. To determine whether a power meter that registers active and passive power in accordance with known theories of power, takes into account (n = ?) deformation power H or distortion power D, an experiment has to be performed.

3. The laboratory experiment

Commonly used loads of varying spectral characteristics and THD values have been selected for use in an experiment performed to determine the assessment of influence of current distortions on readings of smart meters. Among these loads are such gas-discharge light sources as:

- low-pressure mercury-vapor lamps (linear and compact fluorescent lamps)
- high-pressure mercury-vapor lamps,
- metal-halide lamps,
- high-pressure sodium-vapor lamps,
- low-pressure sodium-vapor lamps,
- induction lamps.

Because of wide selection of gas-discharge light sources and associated ballast circuits, the real loads have been simulated by arbitrary shape signal calibrator.

The current distortions characteristic to every load were being generated by a software package (Fig. 1) controlling the calibrator. The proper spectral characteristics (Fig. 2) for these distortions have been based on existing publications, such as [9]. This method makes it possible to perform measurements without the need to have physical access to different loads, with the only requirement being the knowledge about the spectral characteristics of simulated loads.

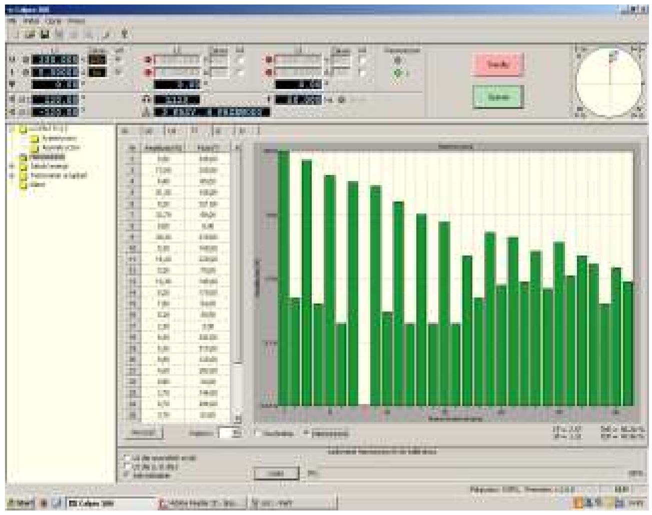

Fig. 1. Software package for generating signal distortions in the calibrator

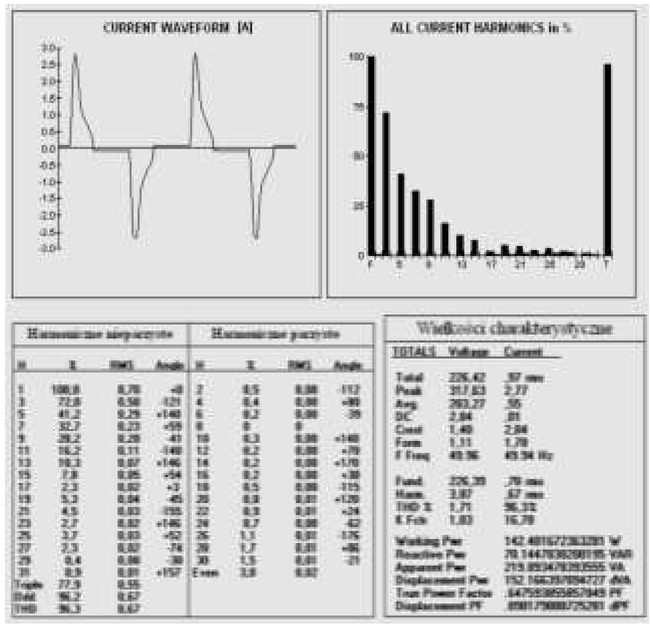

Fig. 2. A sample spectral characteristics of a gas-discharge lamp [9]

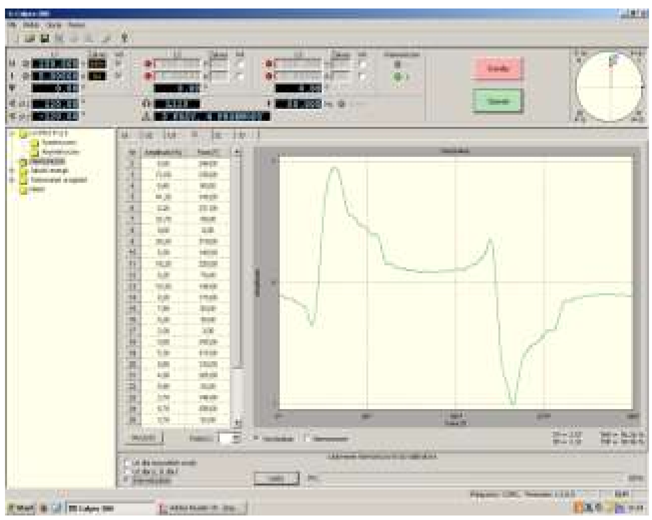

Fig. 3. A sample, computer-generated spectral characteristics of distorted current

The calibrator generated distortions (Fig. 3) of defined amplitudes of harmonic components and their phase shifts. The wave of defined shape was applied to the input of different electromechanical (induction-type) and electronic ("smart") power meters.

4. Selected results

During the research, value errors associated with using different simulated loads have been determined for the power meters being tested. For comparison, indicated value errors of the same meters have been determined with linear loads. With all those data, an analysis of the influence of spectral characteristic of the load on the indicated value error of every meter has been performed. Selected results of this analysis for meters of accuracy class 2 (B) have been presented in Table 1.

Tab. 1. Indicated value errors for different types of loads and meters

loads	THD, %	induction energy meter errors, %	electronic energy meter errors, %
linear load	0.00	0.14	-0.04
compact fluorescent lamp (electronic control gear)	96.26	1.63	**-2.46**
compact fluorescent lamp (induction control gear)	14.21	0.25	0.67
high-pressure mercury-vapor lamp (induction control gear)	33.44	0.69	0.21
high-pressure sodium-vapor lamp	36.14	0.74	0.08
linear fluorescent lamp (adjustable control gear)	21.46	0.48	-0.07

5. Conclusions

The research and analysis of results allowed the following conclusions:

- indicated value errors for linear and non-linear loads of different spectral characteristics are similar for both electromechanical and electronic power meters,
- indicated value errors caused by distortions (at THD value less than 50%) are within the allowed range of uncertainty,
- indicated value errors of electronic ("smart") power meters, caused by distortions generated by compact fluorescent lamps with electronic ballast circuits exceed the limits (the meter registers too low power usage).

In case one does not have access to a physical device, but knows the device's spectral characteristics, and thus knows the influence of this device on current distortions, the methodology presented in the article makes it possible to determine if non-linear loads causes excessive indicated value errors, and if ensures proper functioning of electronic power meters.

6. References

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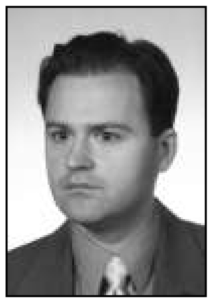

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