On the calibration of energy and power meters under non-sinusoidal conditions

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Abstract

This paper concentrates on the calibration of power and energy meters under sinusoidal and nonsinusoidal conditions. Criteria for selecting voltage and current waveforms for calibrating power and energy meters under nonsinusoidal conditions and a calibration procedure are proposed.

Introduction

Harmonic distortion in power systems is caused by nonlinear loads and is mainly due to an increase of these loads connected to power systems (e.g. silicon control rectifiers, power transistors) and a change in the equipment design philosophy: to be competitive power devices and equipment are more critically designed [1]. Although some National Measurement Institutes [2,3,4] have developed instrumentation to calibrate power and energy meters (DUT-device under test) under nonsinusoidal conditions, there is not a preferred standard set of current and voltage waveforms for calibrating active power meters based on signal processing techniques [5].

The majority of the DUT are calibrated by using a set of current and voltage waveforms, based on industrial field measurements or theoretical waveforms found in power systems. Durante and Ghosh [6] state that the results from the exclusive use of field captured or theoretical waveforms provide only a specific portion of the DUT performance information and can lead to a systematic error between the measured power and the actual power. For the metrological characterisation of a DUT the difference between the measured power and the actual power should be quantified, but the calibration methods used at present involve only a limited number of waveforms that only partially interrogate the behaviour of the DUT. In this paper a probabilistic approach is suggested to reduce the systematic errors introduced by the calibration waveforms. Criteria for selecting excitation voltage and current waveforms suitable for calibrating power and energy meters under nonsinusoidal conditions and a calibration procedure are proposed.

Criteria for selecting excitation waveforms for calibrating power and energy meters under nonsinusoidal conditions

The desirable characteristics of a suitable set of waveforms for calibrating power and energy meters under nonsinusoidal conditions can be stated as follows. The reference waveforms should:

(a) lead to an error of the measured power larger than the error introduced by any practical waveforms measured by the same DUT.

(b) need simple electronics to be generated and measured (i.e. the waveforms should have small crest factor and small amplitude higher order harmonics).

(c) lead to cost effective (in terms of time required and equipment) calibration procedure of the DUT.

The challenge of finding suitable waveforms to calibrate power and energy meters under nonsinusoidal conditions is to find suitable phase-shift between (a) the current and voltage waveforms and (b) the harmonics of each waveform (current or voltage) relevant to the fundamental that maximise the error of the measured power or energy. From the analyses of these aspects [7] it is clear that there is not a unique set of current and voltage waveforms satisfying the characteristics (*a-c*) of the calibration waveforms. A DUT must be excited with current and voltage waveforms that have the largest possible amplitude of each harmonic to ensure that the errors introduced by the nonlinearities of the measuring electronics are maximised. The phase shift should be adjusted to achieve the maximum possible amplitude of the excitation waveform (i.e. to maximise the crest factor).

The harmonic content of the current and voltage waveforms found in power systems depends on the load. Therefore choosing a particular set of current and voltage waveforms for calibrating a DUT do not guarantee that the calibration specifications of the DUT are valid under any conditions. To overcome this limitation we have developed a method based on a probabilistic approach: several current and voltage waveforms found in the literature (both theoretical and measured in real power systems) were compiled [7] and the probability that the level of each harmonic of the waveforms used to calibrate the DUT will be greater than the corresponding harmonic level of waveforms found in power systems was evaluated.

Let $r(t)$ be the calibration (reference) waveform with r_i the amplitude of its *i-th* harmonic, $s(t)$ the practical waveform with s_i the amplitude of its *i-th* harmonic, CF_s and CF_r the crest factors of the practical and reference waveforms, respectively, and N the maximum number of harmonics of both $r(t)$ and $s(t)$. It is guaranteed that the calibration specifications of a DUT using the reference waveform $r(t)$ are valid for every meter under nonsinusoidal conditions defined by $s(t)$ if:

$$r_i \geq s_i \ \ for\ every\ i \leq N \tag{1}$$

$$\text{and } CF_r \geq CF_s \tag{2}$$

Conditions (1) and (2) are sufficient (but not necessary) for retaining the validity of the provided calibration error when the power meter is excited by current and voltage waveforms found in power systems.

Proposed calibration procedure

To satisfy condition (1) in the new NPL power system the probabilistic approach discussed above will be used. To satisfy condition (2) the calibration procedure of a DUT under nonsinusoidal conditions can proceed as follows:

a) Let the relative phase angle between current and voltage waveforms be *0 rad*. Adjust the phase of each harmonic of the current and voltage waveforms to obtain the maximum positive value of the composite excitation signal.

b) Let the relative phase angle between current and voltage waveforms be *0 rad*. Adjust the phase shift of each harmonic of the current and voltage waveforms to obtain the maximum negative magnitude of the composite excitation waveform.

c) Let the relative phase angle between current and voltage waveforms be *0 rad*. Adjust the phase shift of each excitation harmonic of the current and voltage waveforms to obtain equal positive and negative peaks of the excitation current waveforms.

d) Set the voltage and current harmonics at the phase shift from the test that gave the maximum active power error obtained in steps (a)-(c). Scan the phase angle group of the current waveform from $-\pi/2$ to $\pi/2$ with a predefined step to obtain the error of the active power versus the phase shift between voltage and current waveforms.

The selected current and voltage waveforms for calibration of the specific DUT should be the waveforms obtained from steps (*a-d*) leading to the worst error for the specific power meter. Depending on the input/output characteristic of the current and voltage measuring electronics of the DUT, steps (*a-c*) can lead to the same error of the active power.

Discussion

The current techniques used to calibrate power meters under nonsinusoidal conditions are based on methods using induction (in the mathematical sense). Such techniques contradict Hume's law [8] and the use of induction in science is a matter of dispute in the philosophy of science [9]. Although there is a cause and effect relation between the calibration waveform of a DUT and the resulting DUT error, the procedures currently used to calibrate power meters under nonsinusoidal conditions do not guarantee either necessity or sufficiency for the validity of the calibration results for waveforms different than the waveforms used in the calibration of the DUT. Therefore the results obtained from these calibration procedures are of limited practical significance and can lead to confusion and misinterpretation of the calibration specifications.

To overcome the shortcomings and limitations of the current methods we use a set of waveforms based on statistical observation of waveforms found in power systems (both theoretical and measured) and establish a calibration procedure using deduction. The proposed calibration procedure is based on sufficient (but not necessary) conditions to guarantee that the DUT error for the specific calibration waveforms is larger than the error of the DUT under any other set of waveforms in a probabilistic sense. By assigning a probability that a voltage or current harmonic of the excitation waveform will be greater than the corresponding harmonic level of the waveforms found in power systems, confidence on the selection of the excitation voltage and current waveforms is established and the resulting calibration specifications are of practical importance.

Conclusion

NPL will launch a new measurement service in 2006 to cover the industrial needs for measuring power under nonsinusoidal conditions. To give practical significance to the calibration specifications for a number of industrial loads, a new calibration method and a set of current and voltage excitation waveforms were developed.

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