IEC TR 61000-4-40

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TECHNICAL REPORT

Electromagnetic compatibility (EMC) –
Part 4-40: Testing and measurement techniques – Digital methods for the measurement of power quantities of modulated or distorted signals

colour inside

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-40: Testing and measurement techniques – Digital methods for the measurement of power quantities of modulated or distorted signals

FOREWORD

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IEC TR 61000-4-40, which is a Technical Report, has been prepared by subcommittee SC77A: EMC – Low frequency phenomena, of IEC technical committee TC 77: Electromagnetic compatibility.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
77A/1055/DTR	77A/1065/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61000 series, published under the general title *Electromagnetic compatibility (EMC)*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

IEC 61000 is published in separate parts, according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description levels

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (in so far as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts, published either as International Standards, Technical Specifications or Technical Reports, some of which have already been published as sections. Others are and will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61000-6-1).

This document gives the rationale for the assessment of electrical power quantities (RMS voltage, RMS current and active power) under non-stationary conditions. It explains and compares two digital methods that can be used in digital measurement instrumentation to either average or filter the signals when measuring fluctuating loads, and algorithms for the realization of both methods. The examples relate to 50 Hz or 60 Hz power systems because power quantity assessments are predominantly required for these systems.

The digital averaging or integration algorithm is evaluated for fluctuating, or non-stationary, conditions, as is a digital filtering algorithm that emulates the traditional analogue power meter.

This document aims to illustrate the application of the two measurement algorithms given above to characterize existing, and commonly found, non-stationary loads, which have been selected to help interpret the measurement results obtained using both algorithms.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-40: Testing and measurement techniques – Digital methods for the measurement of power quantities of modulated or distorted signals

1 Scope

This part of IEC 61000, which is a Technical Report, deals with the assessment of electrical power quantities (RMS voltage, RMS current and active power). It explains and compares two digital algorithms suitable for power quantity measurements in fluctuating or non-periodic loads. The examples are from 50 Hz or 60 Hz power systems.

This document does not attempt to cover all possible digital implementations of the algorithms used for power quantity assessment in fluctuating loads, for example in the context of the EMC assessment described in several IEC documents. Rather, it compares averaging with one of the filtering algorithms. This document aims to highlight some examples of applications that illustrate how the presented algorithms work. Further, guidance is given for quantifying the accuracy of each approach.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the cited edition applies. For undated references, the latest edition of the referenced document applies, including any amendments.

IEC TR 61000-1-7:2016, *Electromagnetic compatibility (EMC) – Part 1-7: General – Power factor in single phase systems under non-sinusoidal conditions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TR 61000-1-7 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 General

IEC TR 61000-1-7:2016, 3.1, defines the root-mean square (RMS) value of a time-dependent quantity as a positive square root of the mean value of the square of the quantity taken over a given time interval.

IEC TR 61000-1-7:2016, 5.1.4, further states that the RMS value of the voltage U (current I) is defined as the positive square root of the mean value of the square of the voltage $u(t)$ (current $i(t)$) taken over an integer number of periods kT of the AC power supply system:

$$U = \sqrt{\frac{1}{kT} \int_{\tau}^{\tau+kT} [u(t)]^2 \; dt} \tag{1}$$

$$I = \sqrt{\frac{1}{kT} \int_{\tau}^{\tau+kT} [i(t)]^2 \; dt} \tag{2}$$

where

T is the reciprocal of the reference fundamental frequency;

k is an integer number;

τ is the time when the measurement starts.

Similarly, the active power is defined in IEC TR 61000-1-7 as the mean value, taken over an integer number of periods kT, of the instantaneous power $p(t) = u(t)\ i(t)$:

$$P = \frac{1}{kT} \int_{\tau}^{\tau+kT} p(t) \; dt \tag{3}$$

In digital instrumentation, the assessment of the RMS value of voltage or current is performed by first obtaining the squares of the sampled values of the signal. Similarly, for the assessment of active power the products of each pair of the instantaneous voltage $u(t)$ and current $i(t)$ samples are obtained. Then the instrument performs the integration of the squared or multiplied samples over the measurement time interval. To adhere to IEC TR 61000-1-7, the measurement time interval is normally set to an integer multiple of the period of the power system fundamental frequency, but many instruments permit the user to select arbitrary time intervals. Further, for AC power systems, such as 50 Hz or 60 Hz public supply networks, the values of non-active power and apparent power can be derived from the obtained RMS values of current, voltage and active power.

For a sinusoidal signal, the multiplication of voltage and current, or the squaring operation, gives a function whose period is half of the period of the sine wave. This function contains a zero-frequency (DC) component that is equal to the active power or the square of the RMS value. In addition to the desired DC component, there is also an AC component at twice the frequency of the sine wave that it is essential to remove, or at least heavily attenuate, to retrieve the DC value.

Historically, instruments for the measurement of power quantities were implemented in an analogue form, using certain characteristics of thermal, magnetic or electrical components. In moving iron meters, for example, the squaring step is realised through a magnetic force applied to a vane made of iron. This magnetic force, proportional to the square of the current, is generated by a current flowing in a coil. When measuring a sinusoidal signal, the force oscillates at twice the frequency of the sine wave and causes the vane with its attached pointer to vibrate at the same frequency. To produce a stable reading, the assembly is mechanically damped (a smoothing function). The damper is analogous to a low-pass filter, decreasing oscillations caused by the alternating current. The measured RMS value is indicated on a non-linear scale devised according to the electromechanical properties of the meter.

Since the RMS value of an electric signal represents a heating effect, another analogue approach, implemented using thermal converters, is to heat a resistor (heater) with a voltage or a current applied across its terminals. The heater temperature is then measured with a thermocouple producing a DC voltage proportional to the square of the RMS current passing through the resistor. The thermal medium of the thermal converter smoothes the temperature measured by the thermocouple. Thus this thermal smoothing effect also behaves like a low-pass filter.

Further modifications of these techniques, with two coils (electrodynamic wattmeters) or two or more thermal converters (thermal wattmeters and thermal power comparators), enable the measurement of active power in stationary conditions.

In analogue devices the processed signal is smoothed with the internal time constant of the meter, which allows for a steady reading of the result to be made for stationary input signals. Even with fluctuating loads, when the needle of the meter is not completely stable, it is often possible to determine the average value by observing where the variation is centred.

To obtain a similar result, the manufacturers of digital instruments usually add digital filtering to their measuring algorithms, which helps stabilize and/or average the readings. In the simplest form, the filtering is based on averaging over multiple periods of the signal. As the power system frequency is usually quite accurate, digital measurement instruments often use a constant measurement time interval corresponding to a multiple of the nominal period of the power system. For example, the 200 ms time interval specified in IEC 61000-4-7 corresponds to 10 cycles of a 50 Hz signal and 12 cycles of a 60 Hz signal. Further filtering can be obtained by using a digital implementation of the low-pass filter function. For example, in IEC 61000-4-7 a low-pass filter with a 1,5 s time constant was selected, partly because it reproduces the typical behaviour of a moving coil instrument.

When the period of the signal does not correspond to the nominal 50 Hz or 60 Hz power system frequency, readings from instruments that use a constant measurement time interval often show fluctuating results. For example, multi-cycle symmetrical control (MCSC) used in water heaters produces current waveforms with periods that are longer than the fundamental frequency period of the power system voltage feeding the device. Additionally, these MCSC controls can vary the control cycle from one instant to another as required, to maintain water temperature under different flow conditions. Another example is fluctuating loads, such as refrigerators, where compressor motors can be energised at random times, producing non-periodic currents. It is also noted that supply voltage frequency variations are common, for example, in isolated power systems having no electrical connections to a large interconnected system, such as is common in remote communities served by small generation sources.

To characterise the performance of various devices, many documents require the determination of reference current or power. Additionally, for various voltage quality assessments, specific measurement time intervals have been defined by IEC documents, such as half-cycle, 10 or 12 cycles for 50 Hz or 60 Hz power systems, 3 s, 10 min and 2 h.

Stable readings are often a prerequisite in order to obtain comparable results. In the case of fluctuating loads these are sometimes difficult to achieve using conventional voltage, current and power meters. In these situations the current and voltage can be recorded by data loggers and post-processed using, for example, spreadsheet software. Smoothing functions corresponding to the fluctuation rates can then be implemented as required. As data logger recordings are often limited in their duration, fast-settling filters are desirable.

This document compares one averaging and one filtering algorithm used to assess the power quantities for four typical groups of waveforms. For simplicity, the amplitude of the current waveform used in the study was adjusted to give an RMS current of 1 A. The voltage was also adjusted at the appropriate level to obtain an active power of 100 W.

5 Modulated sine waveforms used in this document to compare measurement algorithms

5.1 General

For an ideal sine wave with constant amplitude and frequency, most measurement algorithms would produce accurate results within the capabilities of the measuring instrument. The situation becomes more complicated if the sine wave is randomly modulated and/or contains distortion, as found in uncontrolled environments. Some examples of current waveforms produced by real-life equipment that challenge the assessment of power quantities are described in Clause 5. There exist even more complex situations that are not addressed in this document.

5.2 Half-wave rectification

Half-wave rectification occurs when the equipment is connected only during one polarity of the cycle (e.g. the current of a hair dryer, illustrated in Figure 1). In this case there are, in principle, two possible measurement time intervals of interest.

The half-wave rectified current waveform is asymmetrical with a period of around 16,667 ms in a 60 Hz power system. Therefore, the first appropriate measurement time interval to select is one or more whole cycles of the power line frequency. If the current varies, a stable measurement can only be obtained, if desired for the application, by the use of a measurement time interval containing a larger number of periods.

Secondly, to assess instantaneous voltage fluctuation *d(t),* as required by IEC 61000-4-15 for flicker assessment, the measurement time interval should be equal to one half-cycle. Whilst measurement of the power of this waveform in half-cycle intervals is not usually used for general power quantity assessment, the analysis of this waveform over a half-cycle interval can highlight the need for correct synchronisation for the averaging measurement algorithm.

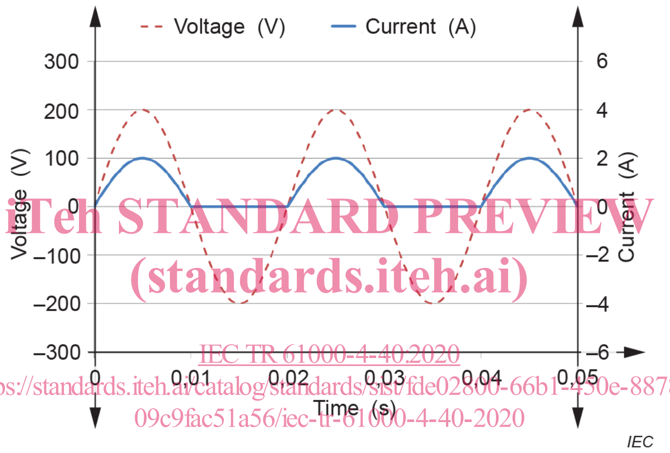

Figure 1 – Typical resistive load current and supply voltage waveform of half-wave rectification

5.3 Full-wave rectification

Full-wave rectification is used in DC power supplies of various common electronic devices. An interesting feature of these power supplies is the concentration of current conduction near the peak of the voltage. When the energy is concentrated in a small part of the period, a larger number of samples covering that part is required to reduce the instrumental errors.

For the purposes of this document, voltage and current in a real item of equipment based on full-wave rectification were measured using a 100 kHz sampling frequency. The results were then normalised to give an RMS current of 1 A and a power of 100 W (see Figure 2).