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CONSOLIDATED VERSION

Electromagnetic compatibility (EMC) -
Part 1-9: General - Evaluation of uncertainty for the measurement of harmonic current emissions

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Electromagnetic compatibility (EMC) -
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FOREWORD

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This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC TR 61000-1-9 edition 1.1 contains the first edition (2024-03) [documents 77A/1194/DTR and 77A/1204/RVDTR] and its amendment 1 (2026-07) [documents 77A/1281/DTR and 77A/1287/RVDTR].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

IEC TR 61000-1-9 has been prepared by subcommittee 77A: EMC - Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility. It is a Technical Report.

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

Draft	Report on voting
77A/1194/DTR	77A/1204/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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.

This document contains attached files in the form of a spreadsheet. These files are intended to be used as a complement and do not form an integral part of the document.

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

- reconfirmed,
- withdrawn, or
- revised.

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 or as technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61000-6-1).

The purpose of this document is to help testing laboratories that operate in accordance with ISO/IEC 17025 to evaluate measurement uncertainty of harmonic current emission tests for IEC 61000-3-2 and IEC 61000-3-12.

The document contains practical formulae that enable uncertainty calculations in accordance with ISO/IEC Guide 98-3 (GUM).

The tables in this document provide examples relating to a worst-case scenario when the measurement equipment introduces maximum permissible errors, as specified in IEC 61000-4-7 and IEC 61000-3-2 and the combination of fundamental and harmonic currents drawn by the equipment under test (EUT) is least favourable.

Furthermore the detailed formulae, linking the uncertainty contribution with the corresponding source of uncertainty, allow the user of the document to calculate measurement uncertainties based on their own measurement data. Typically, these uncertainties would be significantly lower than the worst-case uncertainties.

1 Scope

This document provides examples for the evaluation of measurement uncertainty of harmonic emission tests performed using IEC 61000-3-2 and IEC 61000-3-12, and their application to the relevant conformity decisions. It also contains practical formulae to enable calculations in accordance with ISO/IEC Guide 98-3 (GUM).

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 edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61000-3-2:2018, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)*
IEC 61000-3-2:2018/AMD1:*2020*

IEC 61000-3-12:2011, *Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase*
IEC 61000-3-12:2011/AMD1:2021

IEC 61000-4-7:2002, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*
IEC 61000-4-7:2002/AMD1:2008

IEC GUIDE 115:2023, *Application of uncertainty of measurement to conformity assessment activities in the electrotechnical sector*

ISO/IEC 17025:2017, *General requirements for the competence of testing and calibration laboratories*

ISO/IEC GUIDE 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC GUIDE 99, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

JCGM 106:2012, *Evaluation of measurement data – The role of measurement uncertainty in conformity assessment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61000-3-2, IEC 61000-3-12, IEC 61000-4-7, IEC GUIDE 115, ISO/IEC 17025, ISO/IEC GUIDE 98-3, ISO/IEC GUIDE 99 and JCGM 106, apply.

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

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

4 Uncertainty evaluation for harmonic emissions tests in IEC 61000-3-2 and IEC 61000-3-12

4.1 Methodology

Testing laboratories that operate in accordance with ISO/IEC 17025 are required to evaluate measurement uncertainty (ISO/IEC 17025:2017, 7.6.3). Other laboratories could, likewise, do so.

This document applies ISO/IEC Guide 98-3 (GUM) to calculate the measurement uncertainty for the tests performed as specified in IEC 61000-3-2 and IEC 61000-3-12.

In 4.3, the uncertainty calculation is made for the worst-case scenario, when the following conditions are met:

– measurement equipment introduces maximum permissible errors, as specified in IEC 61000-4-7, IEC 61000-3-2 and IEC 61000-3-12;

– the combination of fundamental and harmonic currents drawn by the equipment under test (EUT) is the least favourable. It is based on an EUT that reacts linearly to every external influence quantity. While not every EUT item exhibits such behaviour, the use of a linear model provides a meaningful uncertainty estimate for the purpose of conformity assessment. When the EUT is known to be non-linear, for example, when its harmonic emission currents depend on the harmonic composition of the test voltage, further evaluation can be required if accurate uncertainty assessment is sought.

Examples for typical uncertainties are given in Clause 5.

The calculated worst-case uncertainty values are expressed as a percentage of permissible harmonic current limit for a particular class of the EUT and harmonic number.

The detailed formulae, linking the uncertainty contribution with the corresponding source of uncertainty, allow the user of the document to calculate measurement uncertainties for the relevant tests. Typically, these uncertainties would be significantly lower than the worst-case uncertainties.

To calculate measurement uncertainty in accordance with ISO/IEC Guide 98-3, the following steps are performed:

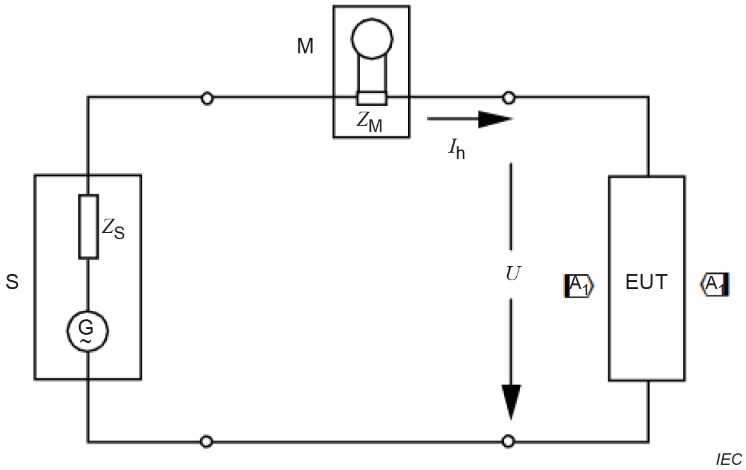
a) a measurement model is established, where the measurement is expressed in terms of formulae linking the measurand with each input quantity (see 4.2);

b) all uncertainty components are listed, their values characterized, and their effect on the measurement calculated numerically (see 4.3);

c) the combined standard uncertainty and the expanded uncertainty values are calculated and tabulated in the uncertainty budget (see 4.4).

4.2 Measurement model

An equipment setup shown in IEC 61000-3-2:2018, Figure A.1, is considered. The setup is used to measure current harmonics of a Class A appliance, see IEC 61000-3-2:2018 and IEC 61000-3-2:2018/AMD1:2020, 5.1.



Key

S	power supply source	Z_M	input impedance of measurement equipment
M	measurement equipment	Z_S	internal impedance of the supply source
EUT	equipment under test	I_h	harmonic component of order h of the line current
U	test voltage	G	open-loop voltage of the supply source

[SOURCE: IEC 61000-3-2:2018, Figure A.1]

Figure 1 – Measurement circuit for single-phase equipment

The measured harmonic current can be expressed as:

$$Y = I_h\left(1+\delta_M\right)\left(1-\delta_{Z_M}\right)\left(1+\delta_{U_{RMS}}\right)\left(1+\delta_{U_{THD}}\right)\left(1-\delta_V\right). \quad (1)$$

where:

Y is the measured value of harmonic current of a particular harmonic frequency, corrected for all known systematic effects,

I_h is the true value of harmonic current,

δ_M is the error of the current measurement equipment such as a power analyser,

δ_{Z_M} is the error due to the input impedance of current measurement equipment,

$\delta_{U_{RMS}}$ is the error due to the RMS value of the test voltage,

$\delta_{U_{THD}}$ is the error due to the harmonic distortion in the test voltage, and

δ_V is the loading effect of the voltmeter (connected in parallel to the EUT but not shown in Figure 1).

The positive or negative sign indicates whether the measured value Y will increase or decrease when a positive value of a particular error component is present. The sign has no bearing on the uncertainty as the uncertainty components are root sum squared to obtain the standard uncertainty, see Formula (8).

4.3 Uncertainty components for worst-case scenario

4.3.1 Method

As an example, to calculate worst-case uncertainties, a Class A EUT drawing a rated RMS current of 16 A and a harmonic current equal to the maximum permissible current of the 5th harmonic (1,14 A) is considered. The EUT and the measurement equipment are connected as shown in Figure 1.

ISO/IEC Guide 98-3 (GUM) is applied to calculate standard uncertainties contributed by each error component in 4.2. Maximum permissible errors, as specified in IEC 61000-4-7 and IEC 61000-3-2, are used for the calculation of each uncertainty component.

In this example, the uncertainties are expressed as a percentage of the permissible 5th harmonic current for Class A EUT (harmonic current limit).

4.3.2 Current measurement equipment

The uncertainty of the current measurement equipment is the expanded uncertainty of the measurement equipment, such as a power analyser. Ideally, the measurement equipment uncertainty is derived from the calibration report and the long-term stability, which is determined from the calibration history or the manufacturer's stability specifications. Alternatively, the measurement equipment uncertainty can be derived from the manufacturer’s accuracy specification.

For the worst-case scenario, the largest of the two values, 5 % of permissible current limit or 0,15 % of the rated current, is used, see IEC 61000-4-7:2002 and IEC 61000-4-7:2002/AMD1:2008, 5.3. For a Class A EUT and harmonic 5, the former is larger and therefore:

$$U(\delta_{\mathrm{M}}) = 5\ \% \tag{2}$$

The uncertainty of a power analyser depends on multiple factors and is therefore normally distributed in accordance with the central limit theorem. Furthermore, it is likely to have a large number of degrees of freedom associated with it. Therefore, a division factor of 2 is used in Table 1 to calculate the standard uncertainty.

The measurement equipment uncertainty includes the effects of the variation of temperature, humidity, supply voltage and other identified factors on the measurement equipment.

4.3.3 Input impedance of the current measurement equipment

The input impedance of the current measurement equipment affects harmonic currents drawn by the equipment under test from the voltage source.

In the worst-case scenario, the voltage drop across the input impedance of the current measurement equipment produces a peak voltage drop in the measurement circuit, $V_{Z_{\mathrm{M}}}$, equal to the limit stated in IEC 61000-4-7:2002, 5.1, for the 5th harmonic. For the nominal test voltage V_{nom} and harmonic current equal to the permissible value this would result in an uncertainty component of:

$$U\left(\delta_{Z_M}\right) = \frac{V_{Z_M}/\sqrt{2}}{V_{nom}} \times 100\% = \frac{0{,}5/\sqrt{2}}{230} \times 100\% = 0{,}2\% \qquad (3)$$

This uncertainty component can take any value between zero and 0,2 %, with little prior knowledge of the distribution. Thus a rectangular probability distribution and, hence, a division factor of $\sqrt{3}$ are most appropriate for $U\left(\delta_{Z_M}\right)$.

For equipment with input current > 16 A and ≤ 75 A per phase, within the scope of IEC 61000-3-12, this component of uncertainty is replaced by the uncertainty due to system impedance. See Annex B.

4.3.4 Test voltage RMS value

The deviation of the RMS value of the test voltage from the nominal value is assumed, in this worst-case evaluation, to produce a linear effect on the measured harmonic current. Then the uncertainty due to the instability of the test voltage can be expressed, as a percentage of harmonic limit, as:

$$U\left(\delta_{U_{RMS}}\right) = \frac{\Delta V_{RMS}}{V_{nom}} \times \frac{I_h}{I_{lim}} \times 100\ \%, \qquad (4)$$

where

ΔV_{RMS} is the absolute deviation of the RMS value of the test voltage from nominal;

I_h is the harmonic current; and

I_{lim} is the permissible value of harmonic current for a particular frequency.

For the worst-case scenario, $\frac{\Delta_{RMS}}{V_{nom}} = 0{,}02$, as in IEC 61000-4-7:2002 and IEC 61000-4-7:2002/AMD1:2008, 5.4.2.2, and $\frac{I_h}{I_{lim}} = 1$, giving $U\left(\delta_{U_{RMS}}\right) = 2\ \%$.

4.3.5 Harmonic distortion of the test voltage

Different types of equipment under test react differently to the harmonic distortion of the test voltage. To estimate the upper value of this uncertainty contribution, this worst-case evaluation uses an appliance that draws the maximum rated RMS current I_r, maximum permissible harmonic current I_{lim} and reacts linearly to test voltage distortion at the frequency of a particular harmonic. Then

$$U\left(\delta_{U_{THD}}\right) = \frac{V_h}{V_{nom}} \times \frac{I_r}{I_{lim}} \times 100\ \%, \qquad (5)$$

where V_h is the harmonic component of the test voltage at a particular frequency. For harmonic 5, taking $\frac{V_\text{h}}{V_\text{nom}} = 0{,}004$ (see IEC 61000-4-7:2002 and IEC 61000-4-7:2002/AMD1:2008, 5.4.2.2), the rated current of 16 A and permissible current of 1,14 A (see IEC 61000-3-2:2018, Table 1) gives:

$$U\left(\delta_{U_\text{THD}}\right) = 0{,}004 \times \frac{16}{1{,}14} \times 100\ \% = 5{,}6\ \% \tag{6}$$

4.3.6 Loading effect of the voltmeter

The input impedance of the voltmeter part of the measuring instrument can produce a small change in the test voltage, causing an error. The worst-case uncertainty component caused by this error is estimated using the limit of 0,05 % stated in IEC 61000-4-7:2002 and IEC 61000-4-7:2002/AMD1:2008, 5.4.2.2. Therefore,

$$U\left(\delta_V\right) = 0{,}05\ \% \tag{7}$$

4.4 Uncertainty budget for Class A harmonic 5

Uncertainty components detailed in 4.3.2 to 4.3.6 are summarised in Table 1.

Table 1 – Worst-case uncertainty budget for Class A, Harmonic 5

Source of uncertainty X_i	**Uncertainty estimate** $U(X_i)$ **(% of limit)**	**Probability distribution**	**Distribution division factor** k	**Standard uncertainty** $u(X_i)$ **(% of limit)**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(y)$ **(% of limit)**
Current measurement equipment uncertainty	5,0	Normal	2	2,5	1	2,5
Input impedance of the measurement equipment	0,2	Rectangular	1,73	0,1	1	0,1
Test voltage RMS value	2,0	Rectangular	1,73	1,2	1	1,2
Test voltage harmonic distortion	5,6	Rectangular	1,73	3,2	1	3,2
Loading effect of voltmeter	0,05	Rectangular	1,73	0,03	1	0,03
					u_c	4,3
					U	**8,5**

The combined uncertainty u_c has been calculated as the square root of the sum of squares of the uncertainty contributions in the right column of Table 1:

$$u_c = \sqrt{\sum_{i=1}^{n} u_i^2(y)} \tag{8}$$

The expanded uncertainty U at 95 % probability level has been calculated by multiplying u_c by a coverage factor of 2. Formula (8) is based on the premise that all uncertainty components are independent of one another.

5 Uncertainty budget for typical measurement data

5.1 General

Clause 5 provides examples of uncertainly calculations based on real-life measurement data for harmonic emission currents and voltage harmonics of the source.

The uncertainly components and formulae for their calculation are similar to those of Clause 4. However, rather than using limits (worst-case scenario) they use actual measured data and actual parameters of the system, confirmed by measurement or calibration where appropriate.

Note that the values for one system cannot be used to predict any values for another system. The tables only give a calculation scheme which can be used for a specific system, based on the values for that system.

The formulae for the calculation of uncertainty estimates, used in the spreadsheet, are given in 5.2 to 5.6. The uncertainty estimates are expressed both as a percentage of current harmonic limit and as an absolute harmonic current value.

5.2 Current measurement equipment

As percentage of the harmonic current limit:

$$U(\delta_{\mathrm{M}}) = \left(I_{\mathrm{h}} \times U_{\mathrm{read}} + I_{\mathrm{range}} \times U_{\mathrm{floor}}\right) / I_{\mathrm{lim}} \tag{9}$$

As harmonic current:

$$U(\delta_{\mathrm{M}}) = \left(I_{\mathrm{h}} \times U_{\mathrm{read}} + I_{\mathrm{range}} \times U_{\mathrm{floor}}\right) / 100 \tag{10}$$

where

I_{h} is the measured value of harmonic current,

U_{read} is the harmonic current meter (power analyser) uncertainty component expressed as a percentage of reading,

I_{range} is the current range of the harmonic current meter (power analyser),

U_{floor} is the "floor" uncertainty component of harmonic current meter (power analyser) expressed as a percentage of current range, and

I_{lim} is the permissible value of harmonic current for harmonic h.

5.3 Input impedance of the measurement equipment

As a percentage of the harmonic current limit:

$$U\left(\delta_{Z_M}\right) = \frac{V_{Z_M}/\sqrt{2}}{V_{nom}} \times \frac{I_h}{I_{lim}} \times 100\ \% \tag{11}$$

As harmonic current:

$$U\left(\delta_{Z_M}\right) = \frac{V_{Z_M}/\sqrt{2}}{V_{nom}} \times I_h \tag{12}$$

where

I_h is the measured value of harmonic current,

V_{Z_M} is the peak voltage drop in the measurement circuit,

V_{nom} is the nominal test voltage, and

I_{lim} is the permissible value of harmonic current for harmonic h.

For equipment with input current > 16 A and ≤ 75 A per phase, where IEC 61000-3-12 is applicable, this component of uncertainty is replaced by the uncertainty due to system impedance:

As a percentage of the harmonic current limit:

$$U\left(\delta_{syst\ imp}\right) = \frac{1}{R_{sce}} \times \frac{I_h}{I_{lim}} \times 100\% \tag{19}$$

As harmonic current:

$$U\left(\delta_{syst\ imp}\right) = \frac{1}{R_{sce}} \times I_h \tag{20}$$

where

R_{sce} is the short-circuit ratio of the EUT (see IEC 61000-3-12:2011, 3.14).