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BASIC EMC PUBLICATION
PUBLICATION FONDAMENTALE EN CEM

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

Compatibilité électromagnétique (CEM) –
Partie 4-7: Techniques d'essai et de mesure – Guide général relatif aux mesures d'harmoniques et d'interharmoniques, ainsi qu'à l'appareillage de mesure, applicable aux réseaux d'alimentation et aux appareils qui y sont raccordés

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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

FOREWORD

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IEC 61000-4-7 edition 2.1 contains the second edition (2002) [documents 77A/382/FDIS and 77A/387/RVD], its amendment 1 (2008) [documents 77A/645/FDIS and 77A/651/RVD] and its corrigendum of July 2004.

A vertical line in the margin shows where the base publication has been modified by amendment 1.

International Standard IEC 61000-4-7 has been prepared by subcommittee 77A: Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

This standard forms part 4-7 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107.

Annexes A, B and C are for information only.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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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 of the environment

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. Other will be published with the part number followed by a dash and a second number identifying the subdivision (example: 61000-6-1).

These publications will be published in chronological order and numbered accordingly.

This part is an International Standard for the measurement of harmonic currents and voltages in power supply systems and harmonic currents emitted by equipment. It also specifies the performance of a standard measuring instrument.

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

1 Scope

This part of IEC 61000 is applicable to instrumentation intended for measuring spectral components in the frequency range up to 9 kHz which are superimposed on the fundamental of the power supply systems at 50 Hz and 60 Hz. For practical considerations, this standard distinguishes between harmonics, interharmonics and other components above the harmonic frequency range, up to 9 kHz.

This standard defines the measurement instrumentation intended for testing individual items of equipment in accordance with emission limits given in certain standards (for example, harmonic current limits as given in IEC 61000-3-2) as well as for the measurement of harmonic currents and voltages in actual supply systems. Instrumentation for measurements above the harmonic frequency range, up to 9 kHz is tentatively defined (see Annex B).

NOTE 1 This document deals in detail with instruments based on the discrete Fourier transform.

NOTE 2 The description of the functions and structure of the measuring instruments in this standard is very explicit and meant to be taken literally. This is due to the necessity of having reference instruments with reproducible results irrespective of the characteristics of the input signals.

NOTE 3 The instrument is defined to accommodate measurements of harmonics up to the 50th order.

2 Normative references

The following referenced documents are indispensable for the application 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 60038, *IEC standard voltages*

IEC 60050-161, *International Electrotechnical Vocabulary – Chapter 161: Electromagnetic compatibility*

IEC 61000-2-2, *Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*

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

IEC 61000-3-12, *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*

3 Definitions, symbols and indices

For the purposes of this part of IEC 61000, the definitions given in IEC 60050-161 (IEV) and the following, apply.

3.1 Definitions related to frequency analysis

Notations: The following notations are used in the present guide for the Fourier series development because it is easier to measure phase angles by observations of the zero crossings:

$$f(t) = c_0 + \sum_{k=1}^{\infty} c_k \sin\left(\frac{k}{N}\omega_1 t + \varphi_k\right) \qquad (1)$$

with:

$$\begin{cases} c_k = \left|b_k + ja_k\right| = \sqrt{a_k^2 + b_k^2} \\ Y_{\mathrm{C},k} = \dfrac{c_k}{\sqrt{2}} \\ \varphi_k = \pi + \arctan\left(\dfrac{a_k}{b_k}\right) \text{ if } b_k < 0 \qquad \varphi_k = \arctan\left(\dfrac{a_k}{b_k}\right) \text{ if } b_k > 0 \\ \varphi_k = \dfrac{\pi}{2} \text{ if } b_k = 0 \text{ and } a_k > 0 \qquad \varphi_k = -\dfrac{\pi}{2} \text{ if } b_k = 0 \text{ and } a_k < 0 \\ \varphi_k = 0 \text{ if } \left|b_k\right| \le \varepsilon \text{ and } \left|a_k\right| \le \varepsilon, \\ \quad \text{with } \varepsilon = 0{,}05\ \%\ U_{\mathrm{nom}} \text{ and } \varepsilon = 0{,}15\ \%\ I_{\mathrm{nom}} \\ \quad \text{or } \varepsilon = 0{,}15\ \%\ U_{\mathrm{nom}} \text{ and } \varepsilon = 0{,}5\ \%\ I_{\mathrm{nom}} \\ \quad \text{respectively, see table 1 in IEC 61000-4-7} \end{cases} \qquad (2)$$

and:

$$\begin{cases} b_k = \dfrac{2}{T_N}\displaystyle\int_0^{T_N} f(t) \times \sin\left(\frac{k}{N}\omega_1 t\right) \mathrm{d}t \\ a_k = \dfrac{2}{T_N}\displaystyle\int_0^{T_N} f(t) \times \cos\left(\frac{k}{N}\omega_1 t\right) \mathrm{d}t \\ c_0 = \dfrac{1}{T_N}\displaystyle\int_0^{T_N} f(t)\, \mathrm{d}t \end{cases} \qquad (3)$$

NOTE 1 The above definition setting φ_k to zero for the cases where b_k and a_k have very small values provides guidance to instrument manufacturers, as phase measurements of very small amplitudes may result in very large deviations, hence there is no requirement to measure phase for such small signals.

ω_1 is the angular frequency of the fundamental ($\omega_1 = 2\pi f_{\mathrm{H},1}$);

T_N is the width (or duration) of the time window; the time window is that time span of a time function over which the Fourier transform is performed;

c_0 is the d.c. component;

c_k is the amplitude of the component with frequency $f_{C,k} = \frac{k}{N} f_{H,1}$;

$Y_{C,k}$ is the r.m.s. value of component c_k;

$f_{H,1}$ is the fundamental frequency of the power system;

k is the ordinal number (order of the spectral component) related to the frequency resolution $\left(f_{C,1} = 1/T_N\right)$;

N is the number of fundamental periods within the window width;

φ_k is the phase angle of spectral line k.

NOTE 2 Strictly speaking these definitions apply to steady-state signals only. The Fourier series is actually in most cases performed digitally, i.e. as a Discrete Fourier Transform DFT, or a variant thereof, being the FFT.

The analogue signal $f(t)$ which has to be analyzed is sampled, A/D-converted and stored. Each group of M samples forms a time window on which DFT is performed. According to the principles of Fourier series expansion, the window width T_N determines the frequency resolution $f_{C,1} = 1/T_N$ (i.e. the frequency separation of the spectral components) for the analysis. Therefore the window width T_N must be an integer multiple N of the fundamental period T_1 of the system voltage: $T_N = N \times T_1$. The sampling rate is in this case $f_s = M/(NT_1)$ (where M = number of samples within T_N).

Before DFT-processing, the samples in the time window are often weighted by multiplying them with a special symmetrical function ('windowing function'). However, for periodic signals and synchronous sampling it is preferable to use a rectangular weighting window which multiplies each sample by unity.

The DFT-processor yields the orthogonal Fourier-coefficients a_k and b_k of the corresponding spectral-component frequencies $f_{C,k} = k/T_N$, k = 0, 1, 2 ... M-1. However, only k values up to and including half of the maximum value are useful, the other half just duplicates them.

Under synchronized conditions, the component of harmonic order h related to the fundamental frequency $f_{H,1}$ appears as the spectral component of order k, where $k = hN$.

NOTE 3 The Fast Fourier Transform FFT is a special algorithm allowing short computation times. It requires that the number of samples M be an integer power of 2, $M = 2^i$, with $i \geq 10$ for example.

NOTE 4 The symbol Y is replaced, as required by the symbol I for currents, by the symbol U for voltages. Index C qualifies the variable as spectral component.

3.2 Definitions related to harmonics

3.2.1
harmonic frequency

$f_{H,h}$

frequency which is an integer multiple of the fundamental frequency of the power system ($f_{H,h} = h \times f_{H,1}$)

NOTE The harmonic frequency $f_{H,h}$ is identical with the component frequency $f_{C,k}$ with $k = h \times N$.

3.2.2
harmonic order

h

(integer) ratio of a harmonic frequency to the fundamental frequency of the power system. In connection with the analysis using DFT and synchronisation between $f_{H,1}$ and f_s (sampling rate), the harmonic order h corresponds to the spectral component $k = h \times N$ (k = number of the spectral component, N = number of periods of the fundamental frequency in time window T_N)

3.2.3
r.m.s. value of a harmonic component

$Y_{H,h}$

r.m.s. value of one of the components having a harmonic frequency in the analysis of a non-sinusoidal waveform

For brevity, such a component may be referred to simply as a “harmonic”

NOTE 1 The harmonic component $Y_{H,h}$ is identical with the spectral component $Y_{C,k}$ with $k = h \times N$; ($Y_{H,h} = Y_{C,h \times N}$). The symbol Y is replaced, as required by the symbol I for currents, by the symbol U for voltages. The index H qualifies the variable *I or U* as harmonic.

NOTE 2 For the purposes of this standard, the time window has a width of N = 10 (50 Hz systems) or N = 12 (60 Hz system) fundamental periods, i.e. approximately 200 ms (see 4.4.1). This yields $Y_{H,h} = Y_{C,10 \times h}$ (50 Hz systems) and $Y_{H,h} = Y_{C,12 \times h}$ (60 Hz systems).

3.2.4
r.m.s. value of a harmonic group
$Y_{g,h}$
square root of the sum of the squares of the r.m.s. value of a harmonic and the spectral components adjacent to it within the time window, thus summing the energy contents of the neighbouring components with that of the harmonic proper. See also equation 8 and Figure 4. The harmonic order is given by the harmonic considered.

NOTE The symbol *Y* is replaced, as required by the symbol *I* for currents, by the symbol *U* for voltages.

3.2.5
r.m.s. value of a harmonic subgroup
$Y_{sg,h}$
square root of the sum of the squares of the r.m.s. value of a harmonic and the two spectral components immediately adjacent to it. For the purpose of including the effect of voltage fluctuation during voltage surveys, a subgroup of output components of the DFT is obtained by summing the energy contents of the frequency components directly adjacent to a harmonic with that of the harmonic proper. (See also equation 9 and Figure 6.) The harmonic order is given by the harmonic considered

NOTE The symbol *Y* is replaced, as required by the symbol *I* for currents, by the symbol *U* for voltages.

3.3 Definitions related to distortion factors

3.3.1
total harmonic distortion
THD
THD_Y (symbol)

ratio of the r.m.s. value of the sum of all the harmonic components ($Y_{H,h}$) up to a specified order (h_{max}) to the r.m.s. value of the fundamental component ($Y_{H,1}$):

$$THD_Y = \sqrt{\sum_{h=2}^{h_{max}} \left(\frac{Y_{H,h}}{Y_{H,1}} \right)^2} \qquad (4)$$

NOTE 1 The symbol *Y* is replaced, as required, by the symbol *I* for currents or by the symbol *U* for voltages.

NOTE 2 The value of h_{max} is 40 if no other value is defined in a standard concerned with limits (IEC 61000-3 series).

3.3.2
group total harmonic distortion
THDG
$THDG_Y$ (symbol)
ratio of the r.m.s. value of the harmonic groups ($Y_{g,h}$) to the r.m.s. value of the group associated with the fundamental ($Y_{g,1}$):

$$THDG_Y = \sqrt{\sum_{h=h_{min}}^{h_{max}} \left(\frac{Y_{g,h}}{Y_{g,1}} \right)^2} \qquad \text{where} \quad h_{min} \geq 2 \qquad (5)$$

NOTE 1 The symbol *Y* is replaced, as required, by the symbol *I* for currents or by the symbol *U* for voltages.

NOTE 2 The value of h_{min} is 2 and that of h_{max} is 40 if no other values are defined in a standard concerned with limits (for example IEC 61000-3 series).

3.3.3
THDS
subgroup total harmonic distortion
$\boldsymbol{THDS_Y}$ (symbol)
ratio of the r.m.s. value of the harmonic sub-groups ($Y_{sg,h}$) to the r.m.s. value of the sub-group associated with the fundamental ($Y_{sg,1}$):

$$THDS_Y = \sqrt{\sum_{h=h_{\min}}^{h_{\max}} \left(\frac{Y_{sg,h}}{Y_{sg,1}}\right)^2} \qquad \text{where} \quad h_{\min} \geq 2 \tag{6}$$

NOTE 1 The symbol Y is replaced, as required, by the symbol I for currents or by the symbol U for voltages.

NOTE 2 The value of $h_{\min}$ is 2 and that of $h_{\max}$ is 40 if no other values are defined in a standard concerned with limits (for example IEC 61000-3 series).

3.3.4
partial weighted harmonic distortion
PWHD
$\boldsymbol{PWHD_{\mathrm{H},Y}}$ (symbol)
ratio of the r.m.s. value, weighted with the harmonic order h, of a selected group of higher order harmonics (from the order $h_{\min}$ to $h_{\max}$) to the r.m.s. value of the fundamental:

$$PWHD_{\mathrm{H},Y} = \sqrt{\sum_{h=h_{\min}}^{h_{\max}} h\left(\frac{Y_{\mathrm{H},h}}{Y_{\mathrm{H},1}}\right)^2} \tag{7}$$

NOTE 1 The symbol Y is replaced, as required, by the symbol I for currents or by the symbol U for voltages.

NOTE 2 The concept of partial weighted harmonic distortion is introduced to allow for the possibility of specifying a single limit for the aggregation of higher order harmonic components. The partial weighted group harmonic distortion $PWHD_{g,Y}$ can be evaluated by replacing the quantity $Y_{\mathrm{H},h}$ by the quantity $Y_{g,h}$. The partial weighted sub-group harmonic distortion $PWHD_{sg,Y}$ can be evaluated by replacing the quantity $Y_{\mathrm{H},h}$ by the quantity $Y_{sg,h}$. The type of $PWHD$ ($PWHD_{\mathrm{H},Y}$, $PWHD_{g,Y}$ or $PWHD_{sg,Y}$) is defined in each standard which uses the $PWHD$, for example in standards concerned with limits (IEC 61000-3 series).

NOTE 3 The values of $h_{\min}$ and $h_{\max}$ are defined in each standard which uses the $PWHD_Y$, for example in a standard concerned with limits (IEC 61000-3 series).

3.4 Definitions related to interharmonics

3.4.1
r.m.s. value of a spectral component
$\boldsymbol{Y_{\mathrm{C},k}}$
in the analysis of a waveform, the r.m.s. value of a component whose frequency is a multiple of the inverse of the duration of the time window

NOTE 1 If the duration of the time window is multiple of the fundamental period, only some of the spectral components have frequencies which are integer multiples of the fundamental frequency.

NOTE 2 The frequency interval between two consecutive spectral components is the inverse of the width of the time window, approximately 5 Hz for the purposes of this standard.

NOTE 3 The symbol Y is replaced, as required, by the symbol I for currents or by the symbol U for voltages.

3.4.2
r.m.s. value of an interharmonic component
$\boldsymbol{Y_{\mathrm{C},i}}$
r.m.s. value of a spectral component, $Y_{\mathrm{C},k \neq h \times N}$, with a frequency between two consecutive harmonic frequencies (see Figure 4). For brevity, such a component may be referred to simply as an “interharmonic”.

NOTE 1 The frequency of the interharmonic component is given by the frequency of the spectral line. This frequency is not an integer multiple of the fundamental frequency.

NOTE 2 A difference is made between an “interharmonic component” produced as a physical component by an equipment, for example at 183,333 Hz, and a “spectral component” calculated by the instrument as the result of the waveform analysis e.g. for a 50 Hz system at 185 Hz (the frequency of the FFT bin). The “spectral component” is also the “harmonic component” for $h \times N$ where h is an integer.

3.4.3
r.m.s. value of an interharmonic group
$Y_{ig,h}$
r.m.s. value of all spectral components in the interval between two consecutive harmonic frequencies (see Figure 4).

NOTE 1 For the purpose of this standard, the r.m.s. value of the interharmonic group between the harmonic orders h and h + 1 is designated as $Y_{ig,h}$, for example the group between h = 5 and h = 6 is designated as $Y_{ig,5}$.

NOTE 2 The symbol Y is replaced, as required, by the symbol I for currents or by the symbol U for voltages.

3.4.4
r.m.s. value of an interharmonic centred subgroup
$Y_{isg,h}$
r.m.s. value of all spectral components in the interval between two consecutive harmonic frequencies, excluding spectral components directly adjacent to the harmonic frequencies (see Figure 6)

NOTE 1 For the purpose of this standard, the r.m.s. value of the centred subgroup between the harmonic orders h and h + 1 is designated as $Y_{isg,h}$, for example the centred subgroup between h = 5 and h = 6 is designated as $Y_{isg,5}$.

NOTE 2 The symbol Y is replaced, as required, by the symbol I for currents or by the symbol U for voltages.

3.4.5
interharmonic group frequency
$f_{ig,h}$
mean of the two harmonic frequencies between which the group is situated, i.e. $f_{ig,h} = (f_{H,h} + f_{H,h+1})/2$.

3.4.6
interharmonic centred subgroup frequency
$f_{isg,h}$
mean of the two harmonic frequencies between which the subgroup is situated, i.e. $f_{isg,h} = (f_{H,h} + f_{H,h+1})/2$.

3.5 Notations

3.5.1 Symbols

In this standard, voltage and current values are r.m.s. unless otherwise stated.

a	amplitude coefficient of a cosine component in a Fourier series
b	amplitude coefficient of a sine component in a Fourier series
c	amplitude coefficient in a Fourier series
f	frequency; function
$f_{C,k}$	spectral component frequency of order k
$f_{C,1}$	the frequency of the spectral component of order 1. The frequency resolution is equal to this frequency
$f_{g,h}$	harmonic-group frequency of order h
$f_{sg,h}$	harmonic-subgroup frequency of order h
$f_{ig,h}$	interharmonic-group frequency of order h
$f_{isg,h}$	interharmonic centred subgroup frequency of order h
$f_{H,h}$	harmonic component frequency of order h
$f_{H,1}$	fundamental frequency of the power system
f_s	sampling rate
h_{max}	the order of the highest harmonic that is taken into account
h_{min}	the order of the lowest harmonic that is taken into account
j	$\sqrt{-1}$