CEI 61000-4-7

(Deuxième édition – 2002)

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

IEC 61000-4-7

(Second edition – 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

CORRIGENDUM 1

Page 14

3.1 Définitions relatives à l'analyse fréquentielle

Dans le système d'équations (3) :

lire:

$$\begin{cases} b_m = \frac{2}{T_w}\int_0^{T_w} f(t)\times \sin\left(\frac{m}{N}\omega_1 t\right)dt \\ a_m = \frac{2}{T_w}\int_0^{T_w} f(t)\times \cos\left(\frac{m}{N}\omega_1 t\right)dt \\ c_0 = \frac{1}{T_w}\int_0^{T_w} f(t)\,dt \end{cases}$$

au lieu de:

$$\begin{cases} b_m = \frac{2}{T_w}\int_0^{T_w} f(t)\times \sin\left(\frac{m}{N}\omega_1 t + \phi_m\right)dt \\ a_m = \frac{2}{T_w}\int_0^{T_w} f(t)\times \cos\left(\frac{m}{N}\omega_1 t + \phi_m\right)dt \\ c_0 = \frac{1}{T_w}\int_0^{T_w} f(t)dt \end{cases}$$

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3.1 Definitions related to frequency analysis

In equation system (3):

read:

$$\begin{cases} b_m = \frac{2}{T_w}\int_0^{T_w} f(t)\times \sin\left(\frac{m}{N}\omega_1 t\right)dt \\ a_m = \frac{2}{T_w}\int_0^{T_w} f(t)\times \cos\left(\frac{m}{N}\omega_1 t\right)dt \\ c_0 = \frac{1}{T_w}\int_0^{T_w} f(t)\,dt \end{cases}$$

instead of:

$$\begin{cases} b_m = \frac{2}{T_w}\int_0^{T_w} f(t)\times \sin\left(\frac{m}{N}\omega_1 t + \phi_m\right)dt \\ a_m = \frac{2}{T_w}\int_0^{T_w} f(t)\times \cos\left(\frac{m}{N}\omega_1 t + \phi_m\right)dt \\ c_0 = \frac{1}{T_w}\int_0^{T_w} f(t)dt \end{cases}$$

et dans la définition de c_m :

lire:

$$f_m = \frac{m}{N} f_1$$

au lieu de:

$$f_m = \frac{m}{N} f_m$$

and in the definition of c_m :

read:

$$f_m = \frac{m}{N} f_1$$

instead of:

$$f_m = \frac{m}{N} f_m$$

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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

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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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.

This second edition cancels and replaces the first edition published in 1991, and constitutes a technical revision.

The text of this standard is based on the following documents:

FDIS	Report on voting
77A/382/FDIS	77A/387/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annexes A, B and C are for information only.

The committee has decided that the contents of this publication will remain unchanged until 2005. At this date, the publication will be

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

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

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

IEC 61967-1, *Integrated circuits – Measurement of electromagnetic emissions, 150 kHz to 1 GHz – Part 1: Measurement conditions and definitions*[1]

[1] To be published

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:

$$f(t) = c_0 + \sum_{m=1}^{\infty} c_m \sin\left(\frac{m}{N}\omega_1 t + \varphi_m\right) \tag{1}$$

with:

$$\begin{cases} c_m = \left|b_m + ja_m\right| = \sqrt{a_m^2 + b_m^2} \\ C_m = \dfrac{c_m}{\sqrt{2}} \\ \varphi_m = \arctan\left(\dfrac{a_m}{b_m}\right) \text{ if } b_m \geq 0 \\ \varphi_m = \pi + \arctan\left(\dfrac{a_m}{b_m}\right) \text{ if } b_m < 0 \end{cases} \tag{2}$$

and:

$$\begin{cases} b_m = \dfrac{2}{T_w}\displaystyle\int_0^{T_w} f(t) \times \sin\left(\frac{m}{N}\omega_1 t + \phi_m\right) dt \\ a_m = \dfrac{2}{T_w}\displaystyle\int_0^{T_w} f(t) \times \cos\left(\frac{m}{N}\omega_1 t + \phi_m\right) dt \\ c_0 = \dfrac{1}{T_w}\displaystyle\int_0^{T_w} f(t) dt \end{cases} \tag{3}$$

where

ω_1 is the angular frequency of the fundamental ($\omega_1 = 2\pi f_1$);

T_w is the width (or duration) of the time window ($T_w = NT_1$; $T_1 = 1/f_1$); the time window is that time span of a time function over which the Fourier transform is performed;

c_m is the amplitude of the component with frequency $f_m = \frac{m}{N} f_m$;

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

c_0 is the d.c. component;

m is the ordinal number (order of the spectral line) related to the frequency basis ($f = 1/Tw$).

NOTE 1 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).

The analogue signal $f(t)$ to be analysed 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_w determines the frequency resolution $f_w = 1/T_w$ (i.e. the frequency separation of the spectral lines) for the analysis and thus the frequency basis for the result of the transform. Therefore, the window width T_w must be an integer multiple N of the fundamental period T_1 of the system voltage: $T_w = N \times T_1$. The sampling rate is in this case $f_s = M/(NT_1)$ (where M = number of samples within T_w).

Before DFT-processing, the samples in the time window T_w 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_m and b_m of the corresponding harmonic frequencies $f_m = m/T_w$, m= 0, 1, 2....2^i-1. However, only m values up to half of the maximum value are useful, the other half just duplicates them.

When there is sufficient synchronisation, the harmonic order n related to the fundamental frequency f_1 is given by $n = m/N$ (N = number of periods in T_w.).

NOTE 2 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.

3.2 Definitions related to harmonics

3.2.1
harmonic frequency

f_n

frequency which is an integer multiple of the power supply (fundamental) frequency ($f_n = n \times f_1$)

3.2.2
harmonic order

n

(integer) ratio of a harmonic frequency to the power-supply frequency. In connection with the analysis using DFT and synchronisation between f_1 and f_s (sampling rate), the harmonic order n is given by $n = k/N$ (k = number of the Fourier component, N = number of periods T_1 in T_w)

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

G_n

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 G_n is identical with the spectral component C_k with $k = N \times n$; ($G_n = C_{Nn}$). It is replaced, as required, by the symbol I_n for currents or by the symbol U_n for voltages.

NOTE 2 The symbol C_k represents the r.m.s. value of the spectral component C_m for $m = k$ in equation 2.

NOTE 3 For the purposes of this standard, the time window has a width of N = 10 (50 Hz systems) or N = 12 (60 Hz systems) fundamental periods, i.e. approximately 200 ms (see 4.4.1). This yields $G_n = C_{10n}$ (50 Hz systems) and $G_n = C_{12n}$ (60 Hz systems).

3.2.4
r.m.s. value of a harmonic group
$G_{g,n}$
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 lines with that of the harmonic proper. See also equation 8 and figure 4. The harmonic order is given by the harmonic considered

3.2.5
r.m.s. value of a harmonic subgroup
$G_{sg,n}$
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

3.3 Definitions related to distortion factors

3.3.1
total harmonic distortion
THD

THD (symb.)
ratio of the r.m.s. value of the sum of all the harmonic components (G_n) up to a specified order (H) to the r.m.s. value of the fundamental component (G_1):

$$THD = \sqrt{\sum_{n=2}^{H} \left(\frac{G_n}{G_1} \right)^2} \qquad (4)$$

NOTE 1 The symbol G represents the r.m.s. value of the harmonic component (see 3.2.3). It is replaced, as required, by the symbol I for currents or by the symbol U for voltages.

NOTE 2 The value of H is defined in each standard concerned with limits (IEC 61000-3 series).

3.3.2
group total harmonic distortion
THD
THDG (symb.)
ratio of the r.m.s. value of the harmonic groups (g) to the r.m.s. value of the group associated with the fundamental:

$$THDG = \sqrt{\sum_{n=2}^{H} \left(\frac{G_{gn}}{G_{g1}} \right)^2} \qquad (5)$$

3.3.3
subgroup total harmonic distortion
THDS
THDS (symb.)
ratio of the r.m.s. value of the harmonic subgroups (*sg*) to the r.m.s. value of the subgroup associated with the fundamental:

$$THDS = \sqrt{\sum_{n=2}^{H}\left(\frac{G_{\mathrm{sg}n}}{G_{sg1}}\right)^2} \qquad (6)$$

3.3.4
partial weighted harmonic distortion
PWHD
PWHD (symb.)
ratio of the r.m.s. value, weighted with the harmonic order *n*, 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:

$$PWHD = \sqrt{\sum_{n=H_{\mathrm{min}}}^{H_{\mathrm{max}}} n\left(\frac{G_n}{G_1}\right)^2} \qquad (7)$$

NOTE 1 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 can be evaluated by replacing the quantity G_n by the quantity $G_{g,n}$. The partial weighted subgroup harmonic distortion can be evaluated by replacing the quantity G_n by the quantity $G_{sg,n}$.

NOTE 2 The values of H_{min} and H_{max} are defined in each standard concerned with limits (IEC 61000-3-series).

NOTE 3 *PWHD* is defined in this standard because it is used in IEC 61000-3-4 and in IEC 61000-3-2 Ed. 2 with amendment 1.

3.4 Definitions related to interharmonics

3.4.1
r.m.s. value of an interharmonic component
r.m.s. value of a spectral component of an electrical signal with a frequency between two consecutive harmonic frequencies (see figure 4)

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

NOTE 3 For the purposes of this standard, the interharmonic component is assumed to be the spectral component C_k for $k \neq n \times N$.

3.4.2
r.m.s. value of an interharmonic group
$C_{ig,n}$
r.m.s. value of all interharmonic components in the interval between two consecutive harmonic frequencies (see figure 4)

NOTE For the purposes of this standard, the r.m.s. value of the interharmonic group between the harmonic orders *n* and *n* + 1 is designated as '$C_{ig,n}$'; for example, the group between *n* = 5 and *n* = 6 is designated as $C_{ig,5}$.

3.4.3
r.m.s. value of an interharmonic centred subgroup
$C_{isg,n}$
r.m.s. value of all interharmonic components in the interval between two consecutive harmonic frequencies, excluding frequency components directly adjacent to the harmonic frequencies (see figure 6)

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

3.4.4
interharmonic group frequency
$f_{ig,n}$
mean of the two harmonic frequencies between which the group is situated

3.4.5
interharmonic centred subgroup frequency
$f_{isg,n}$
mean of the two harmonic frequencies between which the subgroup is situated

3.5 Notations

3.5.1 Symbols and abbreviations

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

a	amplitude coefficient of a sine component in a Fourier series
b	amplitude coefficient of a cosine component in a Fourier series
c	amplitude coefficient in a Fourier series
d	distortion factor
f	frequency; function
f_1	fundamental frequency
f_s	sampling rate
j	$\sqrt{-1}$
p	value of a cumulative probability function, expressed as a percentage
t	running time
x	sampled value
B	bandwidth
C	r.m.s. value of the spectral line
D	weighted distortion factor
Fc	frequency component
H	the order of the highest harmonic that is taken into account
Hz	hertz
I	current (r.m.s. value)
K	number of windows in 3-s interval
M	integer number; number of samples within the window width
N	number of periods within the window width
P	power
PCC	point of common coupling
T	time interval
T_1	fundamental period
T_w	NT_1 (window width)
U	voltage (r.m.s. value)

ω angular frequency

ω_1 angular frequency of the fundamental

φ phase angle

3.5.2 Indices

b centre-band frequency

i running-integer number

k running-integer number

m measured value; spectral content of order m (not necessarily integer)

max maximum value

min minimum value

n harmonic order: running number (integer)

g,n harmonic group order associated with harmonic order n

$g,1$ harmonic group order associated with the fundamental

sg,n harmonic subgroup order associated with harmonic order n

$sg,1$ harmonic subgroup order associated with the fundamental

ig,n interharmonic group above harmonic order n

isg,n interharmonic centred subgroup above harmonic order n

nom nominal value

r rated value

s sampled; synchronised

1 fundamental

4 General concepts and common requirements for all types of instrumentation

4.1 Characteristics of the signal to be measured

Instruments for the following types of measurement are considered:

a) harmonic emission measurement;

b) interharmonic emission measurement;

c) measurements above the harmonic frequency range up to 9 kHz.

Strictly speaking, harmonic measurements can be performed only on a stationary signal; fluctuating signals (signals varying with time) cannot be described correctly by their harmonics only. However, in order to obtain results that are inter-comparable, a simplified and reproducible approach is given for fluctuating signals.

4.2 Accuracy classes of instrumentation

Two classes of accuracy (I and II) are considered, to permit the use of simple and low-cost instruments, consistent with the requirements of the application. For emission tests, the upper class I is required if the emissions are near to the limit values (see also note 2 of table 1).

4.3 Types of measurement

Requirements for harmonic and interharmonic measurements are given. Measurements in the frequency range up to 9 kHz are also considered.

4.4 General structure of the instrument

New designs of instrument are likely to use the discrete Fourier transform (DFT), normally using a fast algorithm called fast Fourier transform (FFT). Therefore this standard considers only this architecture but does not exclude other analysis principles (see clause 6).

The general structure is represented in figure 1. An instrument may or may not comprise all the blocks and outputs given.

4.4.1 Main instrument

The main instrument comprises

- input circuits with anti-aliasing filter,
- A/D-converter including sample-and-hold unit,
- synchronisation and window-shaping unit if necessary,
- DFT-processor providing the Fourier coefficients a_m and b_m ("OUT 1").

It is complemented by the special parts devoted to current assessment and/or voltage assessment.

NOTE 1 For further details, see 5.5.

NOTE 2 For the analysis of harmonics and interharmonics, the signal $f(t)$ which has to be analysed is pre-treated to eliminate frequencies higher than the operating range of the instrument.

For full compliance with this standard, the window width shall be 10 (50 Hz systems) or 12 (60 Hz systems) periods with rectangular weighting (see also clause 7). Hanning weighting is allowed only in the case of loss of synchronisation. This loss of synchronisation shall be indicated on the instrument display and the data so acquired shall be flagged.

The time window shall be synchronised with each group of 10 or 12 cycles according to the power system frequency of 50 Hz or 60 Hz. The time between the leading edge of the first sampling pulse and the leading edge of the (M+1)th sampling pulse (where M is the number of samples; see 3.5.1) shall be equal to the duration of the specified number of cycles of the power system, with a maximum permissible error of ±0,03%. Instruments including a phase-locked loop or other synchronisation means shall meet the requirements for accuracy and synchronisation for measuring at any signal frequency within a range of at least ±5% of the nominal system frequency. However, for instruments having integrated supply sources, so that the source and measurement systems are inherently synchronised, the requirement for a working input frequency range does not apply, provided the requirements for synchronisation and frequency accuracy are met.

The output (OUT 1, see figure 1) shall provide the individual coefficients a_m and b_m of the DFT, for the current or voltage, i.e. the value of each frequency component calculated.

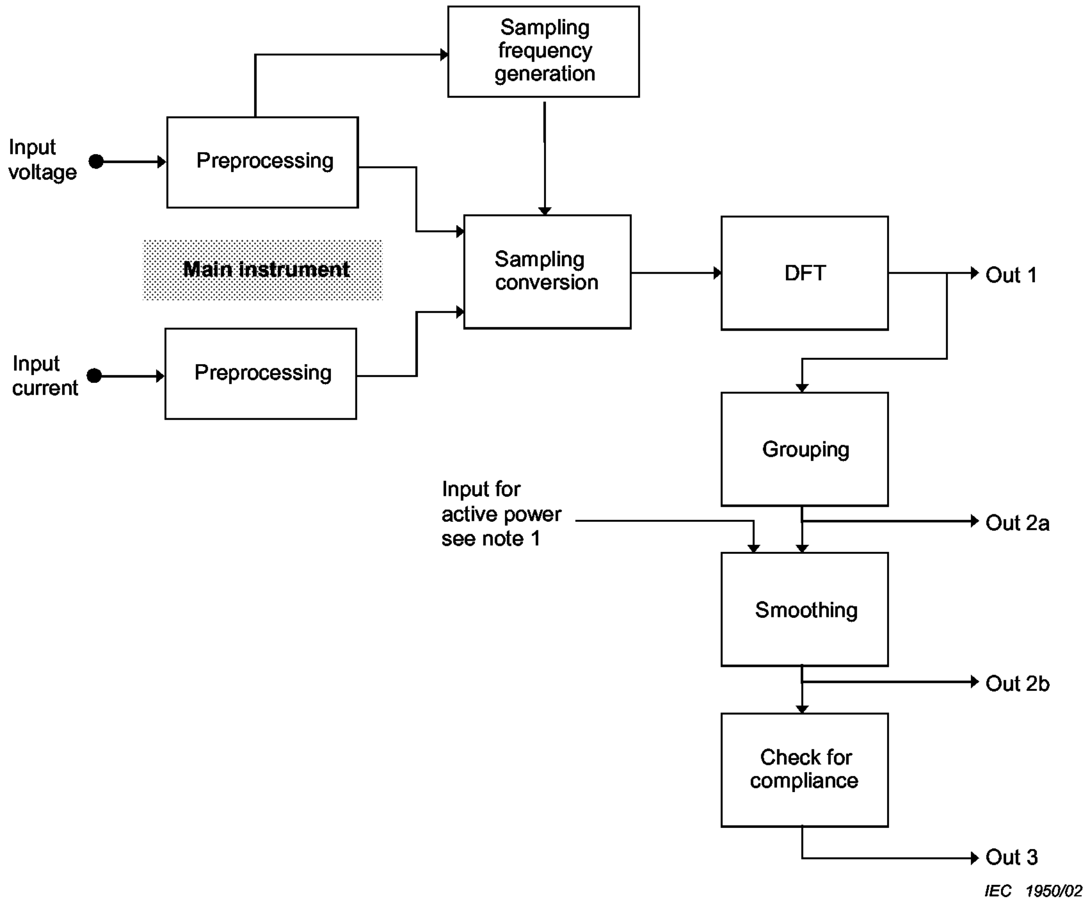


Figure 1 – General structure of the measuring instrument

A further output, not necessarily from the DFT, shall provide the active power P evaluated over the same time window used for the harmonics. For the harmonic emission measurements according to IEC 61000-3-2, this power shall not include the d.c. component.

NOTE 3 The active power P is provided as input to the smoothing process, not to the grouping process.

NOTE 4 Measurement of the d.c. components and of the power associated with them may be included as an option but is not required by this standard.

4.4.2 Post-processing parts

As required by emission standards, additional operations on the raw data like smoothing and weighing of the raw results are performed in successive parts of the instrument.

If output values are to be related to a corresponding value (fundamental, declared or nominal values), this normalization shall be performed only after these additional smoothing procedures.

5 Harmonic measurements

5.1 Current input circuit

The input circuit shall be suitable for the currents to be analysed. It shall provide a direct measurement of the harmonic currents and, in addition, should have a low-voltage high-impedance voltage input which may be associated with external resistive shunts (or a combination of current transformers with resistive shunts). Appropriate input circuit sensitivities range from 0,1 V to 10 V, with 0,1 V being the preferred value, provided they comply with the requirements given in 5.3.

NOTE For current measurements directly in the circuit, it may be advisable, but is not required, to provide the following nominal r.m.s. input current measurement ranges I_{nom}: 0,1 A ; 0,2 A ; 0,5 A ; 1 A ; 2 A ; 5 A ; 10 A ; 20 A ; 50 A ; 100 A.

The power absorption of the current input circuit shall not exceed 3 VA for class II instrumentation. For class I instrumentation, the r.m.s. input voltage drop shall not exceed 0,15 V.

Each current input circuit shall be able to be continuously stressed by 1,2 I_{nom} and a stressing by 10 I_{nom} for 1 s shall not lead to any damage.

The instrument shall be able to accept input signals with a crest factor up to 4 for the ranges up to 5 A r.m.s., 3,5 for the 10 A r.m.s. range and 2,5 for higher ranges.

An overload indication is required.

The overall accuracy requirements are stated in table 1.

For other requirements, see clause 8.

NOTE A d.c. component is often associated with the distorted current to be measured; such a d.c. component may produce large errors in input current transformers. The manufacturer should indicate in the instrumentation specifications the maximum allowed d.c. component so that the additional influence error does not exceed the stated accuracy.

5.2 Voltage input circuit

The input circuit of the measuring instrument shall be suitable for the maximum voltage and the frequency of the supply voltage to be analysed and shall keep its characteristics and accuracy unchanged up to 1,2 times the maximum voltage. A crest factor of at least 1,5 is sufficient for measurements, except for highly distorted voltages in industrial networks, for which a crest factor of at least 2 may be necessary. An overload indication is required in any case.

Stressing the input for 1 s by an a.c. voltage of four times the input voltage setting or 1 kV r.m.s., whichever is less, shall not lead to any damage in the instrument.

Many nominal supply voltages between 60 V and 690 V exist, depending on local practice. To permit a relatively universal use of the instrument for most supply systems, it may be advisable for the input circuit to be designed for the following nominal voltages:

U_{nom} : 66 V, 115 V, 230 V, 400 V, 690 V for 50 Hz systems

U_{nom} : 69 V, 120 V, 240 V, 277 V, 347 V, 480 V, 600 V for 60 Hz systems.

NOTE 1 In association with external voltage transformers, additional ranges may also be useful (100 V, 100/√3 V, 110/√3 V)

NOTE 2 Inputs with higher sensitivity (0,1 V; 1 V; 10 V) are useful for operation with external sensors. The input circuit should be capable of accepting an input signal with a crest factor of at least 2.

The power absorption of the input circuit shall not exceed 0,5 VA at 230 V. If high-sensitivity inputs (less than 50 V) are provided, their input resistance shall be at least 10 kΩ/V.

Care should be taken that the high value of the fundamental (supply frequency) voltage as compared to the other voltage components to be measured does not produce overload causing damage or intermodulation signals in the input stages of the instrument. Errors so caused shall be below the stated accuracy. An overload indication shall be provided.

5.3 Accuracy requirements

Two classes of accuracy are suggested for instrumentation measuring harmonic components. The maximum allowable errors given in table 1 refer to single-frequency and steady-state signals, in the operating frequency range, applied to the instrument under rated operating conditions to be indicated by the manufacturer (temperature range, humidity range, instrument supply voltage, etc.).

NOTE When testing appliances according to IEC 61000-3-2, the uncertainty terms are related to the permissible limits (5 % of the permissible limits) or to the rated current (I_r) of the tested appliance (0,15 % I_r), whichever is greater. This should be considered when choosing the proper input current range of the measuring instrument.

Table 1 – Accuracy requirements for current, voltage and power measurements

Class	Measurement	Conditions	Maximum error
I	Voltage	$U_m \geq 1\% \ U_{nom}$ $U_m < 1\% \ U_{nom}$	$\pm 5\% \ U_m$ $\pm 0{,}05\% \ U_{nom}$
	Current	$I_m \geq 3\% \ I_{nom}$ $I_m < 3\% \ I_{nom}$	$\pm 5\% \ I_m$ $\pm 0{,}15\% \ I_{nom}$
	Power	$P_m \geq 150$ W $P_m < 150$ W	$\pm 1\% \ P_{nom}$ $\pm 1{,}5$ W
II	Voltage	$U_m \geq 3\% \ U_{nom}$ $U_m < 3\% \ U_{nom}$	$\pm 5\% \ U_m$ $\pm 0{,}15\% \ U_{nom}$
	Current	$I_m \geq 10 \ \% \ I_{nom}$ $I_m < 10 \ \% \ I_{nom}$	$\pm 5\% \ I_m$ $\pm 0{,}5\% \ I_{nom}$

I_{nom}: Nominal current range of the measurement instrument

U_{nom}: Nominal voltage range of the measurement instrument

U_m and I_m : Measured values

NOTE 1 Class I instruments are recommended where precise measurements are necessary, such as for verifying compliance with standards, resolving disputes, etc. Any two instruments that comply with the requirements of Class I, when connected to the same signals, produce matching results within the specified accuracy (or indicate an overload condition).

NOTE 2 Class I instruments are recommended for emission measurements, Class II is recommended for general surveys, but can also be used for emission measurements if the values are such that, even allowing for the increased uncertainty, it is clear that the limits are not exceeded. In practice, this means that the measured values should be lower than 90% of the allowed limits.

NOTE 3 Additionally, for Class I instruments, the phase shift between individual channels should be smaller than $n \times 1°$.

Frequencies outside the measuring range of the instrument shall be attenuated so as not to affect the results. To obtain the appropriate attenuation, the instrument may sample the input signal at a frequency much higher than the measuring range. For example, the analysed signal may have components exceeding 25 kHz, but only components up to 2 kHz are taken into account. An anti-aliasing low-pass filter, with a –3 dB frequency above the measuring range shall be provided. The attenuation in the stop-band shall exceed 50 dB.

NOTE For example, a 5th order Butterworth filter achieves 50 dB attenuation at approximately three times the -3 dB frequency.

When it is necessary to assess harmonics with an order greater than 15 and with a rated current greater than 5 A with the minimum uncertainty, it is advisable to use external shunts or current sensors matched to give a range equal to the rated current of the tested equipment.

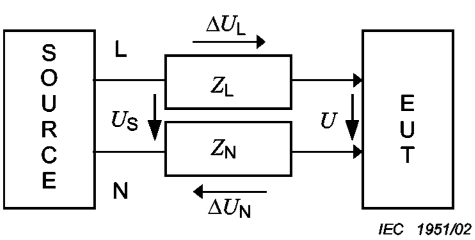
For instrumentation intended for measuring harmonics only, the accuracy requirements apply to harmonic components only.

To achieve the accuracy stated in table 1 some simple adjustment of the instrument, according to clear indications to be given by the manufacturer, by means of an internal or external calibrator may be required. The uncertainty of the calibrator (if internal) shall be specified.

The errors due to the most important influence factors (temperature, auxiliary mains supply voltage, etc.) shall be indicated by the manufacturer for the instrument itself and for the internal calibrator if it is provided.

5.4 Measurement set-up for emission assessment

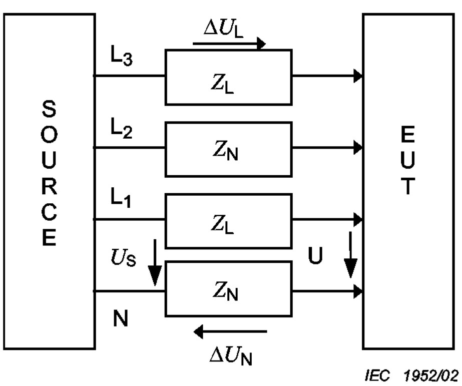
The measurement set-up is given in figures 2 and 3.



Key

U_S	Source voltage line-neutral
U	EUT terminal voltage
$Z_{L,N}$	Impedance of wiring and current sensing part
EUT	Equipment under test
ΔU	Voltage drop across Z_L and Z_N ($\Delta U = \Delta U_L + \Delta U_N$)
L	Line connection
N	Neutral connection

Figure 2 – Measurement set-up for single-phase emission measurement



Key

U_S	Source voltage line-neutral
U	EUT terminal voltage
$Z_{L,N}$	Impedance of wiring and current sensing part
EUT	Equipment under test
ΔU	Voltage drop across Z_L and Z_N ($\Delta U = \Delta U_L + \Delta U_N$); For interphase connection, $\Delta U = 2 \times \Delta U_L$
L_{1-3}	Line connections
N	Neutral connection

Figure 3 – Measurement set-up for three-phase emission measurements

While the measurements are being made, the test voltage U at the terminals of the EUT shall meet the following requirements.

a) The long-term stability of the test voltage shall be maintained within ±2 % of the selected value and the frequency shall be maintained within ±0,5 % of the selected value. If the EUT has a specified supply voltage range, the test voltage shall correspond to the nominal voltage of the power system expected to supply the equipment (for example, 230 V line-neutral, corresponding to 400 V line-line). For a three-wire, three-phase connection, an artificial neutral point realised with three resistors matched within 1 % may be used if the neutral conductor is not available from the source. The purpose of the artificial neutral point is to permit voltage and power-per-phase measurements to be made in a line-to-neutral configuration as well as line-to-line. The errors introduced into measurements of EUT currents, during emission tests by the loading effect of the voltmeter part of the instrument and any installed artificial neutral network shall not exceed 0,05 %.

   NOTE In many cases the artificial neutral is not required, but if it is, several approaches can be used. It may be provided by the three input impedances of the voltmeters in the measuring instrument. Alternatively, the artificial neutral may effectively consist of the combined effect of an explicit network plus the input impedances of the voltmeters in the measuring instrument. It is also possible that the artificial neutral network, if it is present, and the input impedances of the voltmeters may be so connected as not to introduce any errors in current measurements (because the loading occurs on the source side of the current transducer). In still other cases, errors introduced by the loading effect of the artificial neutral network and the input impedances of the voltmeters in the instrument may be adequately compensated by regulating feedback loops in the source such that errors that otherwise might be introduced do not, in fact, occur. Many other configurations may be satisfactory, provided the required uncertainty is not exceeded.

b) For a three-phase supply, the three line voltages shall have a phase relationship of 0°; 120° ± 1,5°; 240° ± 1,5°.

c) The voltage harmonic distortion of the EUT test voltage U shall not exceed the following values with the EUT connected and operating under the specified test conditions:
   - 0,9% for a harmonic of order 3;
   - 0,4% for a harmonic of order 5;
   - 0,3% for a harmonic of order 7;
   - 0,2% for a harmonic of order 9;
   - 0,2% for even harmonics of order from 2 to 10;
   - 0,1% for harmonics of order from 11 to 40.

d) The peak value of the test voltage shall be within a range of 1,40 times to 1,42 times its r.m.s. value and shall be reached between 87° and 93° after the zero crossing.

e) The voltage drop ΔU across the impedance of the current sensing part and the wiring shall not exceed a peak voltage of 0,5 V.

Equipment power, if required, shall be measured using the EUT terminal voltage U in figure 2 or figure 3 and the current into the EUT. For sources that include the current sensing part, equipment power shall be measured using the voltage at the source output terminals and the current into the EUT. In this case, the voltage shall be measured on the EUT side of the current sensing part on the presumption that the source is regulated at its output terminals.

5.5 Assessment of harmonic emissions

The following relates to the post-processing parts of figure 1.

5.5.1 Grouping and smoothing

For the assessment of harmonics, the output (OUT 1; see figure 1) of the DFT is first grouped to be the sum of squared intermediate lines between two adjacent harmonics according to equation 8, visualized in figure 4. The resulting harmonic group of order n (corresponding to the centre line in the hatched area) has the magnitude $G_{g,n}$ (r.m.s. value).

$$G_{g,n}^2 = \frac{C_{k-5}^2}{2} + \sum_{i=-4}^{4} C_{k+i}^2 + \frac{C_{k+5}^2}{2} \quad \{50\text{ Hz system}\}$$
$$G_{g,n}^2 = \frac{C_{k-6}^2}{2} + \sum_{i=-5}^{5} C_{k+i}^2 + \frac{C_{k+6}^2}{2} \quad \{60\text{ Hz system}\} \qquad (8)$$

In these equations, C_{k+i} is the r.m.s. value of the spectral component corresponding to an output bin (spectral line) of the DFT, and $G_{g,n}$ is the resulting r.m.s. value of the harmonic group.

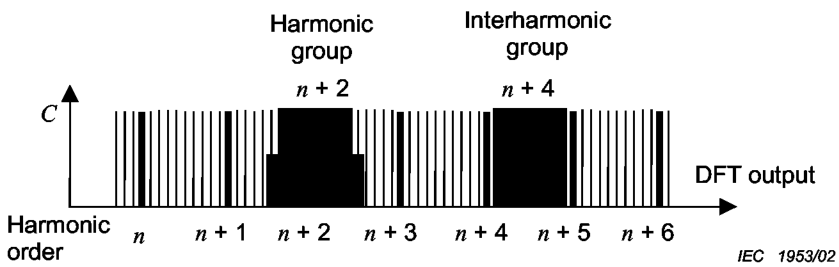


Figure 4 – Illustration of harmonic and interharmonic groups (shown here for a 50 Hz supply)

NOTE The grouping of interharmonics is illustrated in figure 4 only to clarify the definitions (see annex A for interharmonic current assessment).

A smoothing of the signal shall be performed over the r.m.s. value $G_{g,n}$ of each harmonic order, according to equation 8 (OUT 2a of figure 1), using a digital equivalent of a first-order low-pass filter with a time constant of 1,5 s, as shown in figure 5.

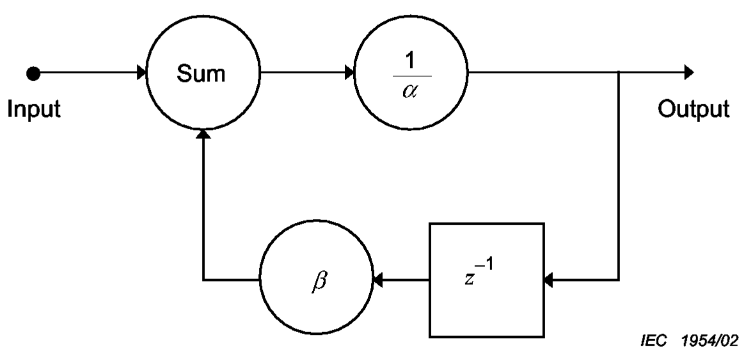


Figure 5 – Realisation of a digital low-pass filter: z^{-1} designates a time window delay, α and β are the filter coefficients (see table 2 for values)

For the fundamental component G_1 (if required, as, for example, for Class C in IEC 61000-3-2 and possibly for distortion factors), the same smoothing of the r.m.s value G_1 from OUT 1 shall be performed.

For the active power P and the power factor (if required as, for example, for Classes C and D in IEC 61000-3-2), a similar smoothing of the modulus of the active power values from OUT 1 shall be performed.

NOTE The modulus was chosen in order to accommodate regenerative systems.

To coordinate with surveys of harmonic voltages, it is highly recommended to provide a further type of smoothing, where the output is derived from the components according to equation 8 as an average over 15 contiguous time windows, updated either every time window (about each 200 ms) or every 15 time windows (about each 3 s).

5.5.2 Compliance with emission limits

Assessment of compliance with emission limits (OUT 2b) shall be performed by statistical handling of the data according to the conditions given in the relevant standards, such as IEC 61000-3-2.

If the emission limits include distortion factors (other than THD) according to 3.3, they shall be calculated using the values of OUT 2a.

5.6 Assessment of voltage harmonic subgroups

The Fourier transform analysis assumes that the signal is stationary. However, the voltage magnitude of the power system may fluctuate, spreading out the energy of harmonic components to adjacent interharmonic frequencies. To improve the assessment accuracy of the voltage, the output components C_k for each 5 Hz of the DFT shall be grouped according to equation 9 and figure 6:

$$G_{sg,n}^2 = \sum_{i=-1}^{1} C_{k+i}^2 \tag{9}$$

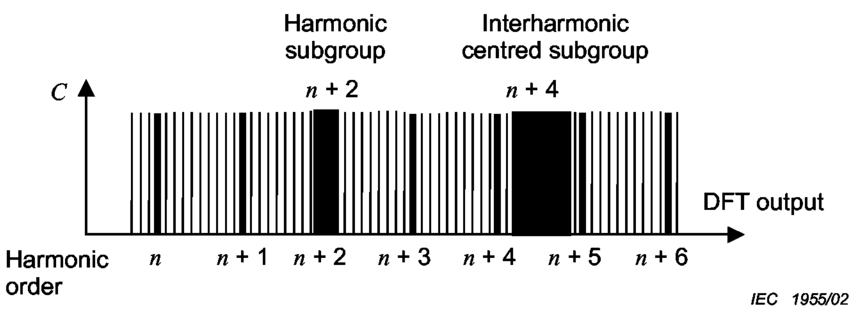


Figure 6 – Illustration of a harmonic subgroup and an interharmonic centred subgroup (of a 50 Hz supply)

NOTE Further smoothing procedures to assess voltage subgroups are specified in IEC 61000-4-30.

6 Other analysis principles

The fact that this standard specifies a DFT instrument as the reference instrument does not preclude the application of other analysis principles, such as (digital) filter banks or even other analysis principles such as wavelet analysis.

Also, especially for low-cost instruments, a shorter time window, possibly only one period long, can be considered. However, such instrumentation should not be used for assessing the compliance of non-stationary signals with emission limits, as such signals cannot be assessed in this way.

Specifications of instruments based on an alternative analysis principle shall state the range of uncertainty caused by all influence factors including the non-stationary characteristic of the signal, the aliasing phenomenon and the failure of synchronisation. The uncertainty shall be such that the requirements of clause 5 are met.

7 Transitional period

The use of existing measuring instruments based upon the requirements given in IEC 61000-4-7 (1991) continues to be permitted until the next revision of this standard. However, measurements performed with such instruments shall be marked with "Measuring instrumentation according to IEC 61000-4-7, 1991".

For measurements performed with instrumentation using 16-cycle windows according to IEC 61000-4-7 1991, the procedure of the smoothing (OUT 2b of figure 1) shall be modified according to the entries in table 2. The filter shall be realised as shown in figure 5.

Table 2 – Smoothing filter coefficients according to the window width

Frequency	Cycles N in window	Sampling rate	α	β
50	10	≈ 1/200 ms	8,012	7,012
60	12	≈ 1/200 ms	8,012	7,012
50	16	≈ 1/320 ms	5,206	4,206
60	16	≈ 1/267 ms	6,14	5,14
NOTE Coefficients for 10/12 cycle windows and the sampling rate are given for reference to figure 5.				

8 General

The manufacturer shall specify the rated operating conditions and possibly the magnitude of error introduced by changes in

- temperature;
- humidity;
- instrument supply voltage and related series interferences;
- common-mode interference voltage between the earth connection of the instrument its input circuits and the auxiliary supply voltage;
- static electricity discharges;
- radiated electromagnetic fields.

NOTE In applying IEC 61010-1 for safety and insulating requirements, it should be taken into account that the input circuits (voltage as well as current) may be directly connected to the mains supply voltages.

Annex A
(informative)

Measurement of interharmonics

Interharmonic components are caused primarily by two sources:

– variations of the amplitude and/or phase angle of the fundamental component and/or of the harmonic components, for example, inverter drives;
– power electronics circuits with switching frequencies not synchronised to the power supply frequency, for example, a.c./d.c. supplies and power factor correctors.

Possible effects are, for example:

– noise in audio amplifiers;
– additional torques on motors and generators;
– disturbed zero crossing detectors, for example, in dimmers;
– additional noise in inductive coils (magnetostriction);
– blocking or unintended operation of ripple control receivers.

The measurement set-up is based on the general description given in clause 4.

Interharmonic components usually vary not only in magnitude but also in frequency. A grouping of the spectral components in the interval between two consecutive harmonic components forms an interharmonic group. This grouping provides an overall value for the interharmonic components between two discrete harmonics, which includes the effects of fluctuations of the harmonic components. Equation A1 or A2, depending on the supply frequency, permits the calculation of the value of the interharmonic group:

$$C_{ig,n}^2 = \sum_{i=1}^{9} C_{k+i}^2 \quad \text{(50 Hz power system)} \qquad \text{(A1)}$$

$$C_{ig,n}^2 = \sum_{i=1}^{11} C_{k+i}^2 \quad \text{(60 Hz power system)} \qquad \text{(A2)}$$

NOTE In this context, ig,n is the interharmonic group of order n (see figure 4 and 3.4.2). For the purposes of this standard, the r.m.s. value of the interharmonic group between the harmonic orders n and n+1 is designated as ' $C_{ig,n}$ ', for example, the group between n = 5 and n = 6 is designated as $C_{ig,5}$.

The effects of fluctuations of harmonic amplitudes and phase angles are partially reduced by excluding from equations A1 and A2 the components immediately adjacent to the harmonic frequencies. Also, to determine the r.m.s. values $C_{isg,n}$ of interharmonic centred subgroups the components, that is, the output data at OUT1 of the DFT in figure 1, are regrouped as follows (see 3.4.3):

$$C_{isg,n}^2 = \sum_{i=2}^{8} C_{k+i}^2 \quad \text{(50 Hz power system)} \qquad \text{(A3)}$$

$$C_{isg,n}^2 = \sum_{i=2}^{10} C_{k+i}^2 \quad \text{(60 Hz power system)} \qquad \text{(A4)}$$

In these equations, C_{k+i} is the r.m.s. values of the corresponding spectral components obtained from the DFT that exceed the frequency of the harmonic order n, $C_{isg,n}$ is the r.m.s. value of the interharmonic centred subgroup of order n, (for example, the subgroup between $n = 5$ and $n = 6$ is designated as $C_{isg,5}$). See figure 6 and 3.4.3.

NOTE 1 Since non-stationary harmonics cause 'sidebands' close to the harmonics, the components ($k = 1$ and 9 or 11) directly adjacent to the considered harmonics may represent amplitude or phase-angle variations. They are, therefore, excluded from the interharmonic group in order to give the interharmonic centred subgroup. See also figure 6.

NOTE 2 If only harmonics are evaluated, the grouping equation 8 applies. If harmonics and interharmonics are evaluated separately (such as for the assessment of equipment prone to produce interharmonics), the interharmonic components ($i = -1$ and $+1$) directly adjacent to a harmonic are grouped together with this harmonic to form a harmonic subgroup of order n, whereas the remaining interharmonic components ($i = 2$ to 8 or 10) form the interharmonic centred subgroup of order n according to equation A3 or A4. See also figure 6.

The smoothing of the interharmonic centred subgroups is performed in the same manner as that used for the harmonic measurement (see 5.5.1). A smoothing of the single interharmonic components is not recommended.

NOTE Further smoothing procedures are described in IEC 61000-4-30.

The accuracy requirements are identical to those given for measuring harmonics (see table 1).

Annex B
(informative)

Measurements above the harmonic frequency range up to 9 kHz

B.1 General

Components in signals (currents or voltages) with frequencies exceeding the harmonic frequency range (approximately 2 kHz) but below the upper limit of the low-frequency range (approximately 9 kHz) are due to several phenomena, for example:

– pulse-width modulated control of power supplies at the mains side connection (synchronous or asynchronous to the frequency of the mains), such as used in "power factor correcting systems";
– emissions, such as mains signalling;
– feed-through of components from the (load side) output to the (supply side) input of power converters;
– oscillations due to commutation notches.

These components can be at a single frequency or broadband.

B.2 Measurement methods

The measurement of these components does not require a high resolution in the frequency domain. Instead, it is customary to group the energy of the signal to be analysed into predefined frequency bands. In accordance with the measurements performed in the higher frequency bands (see CISPR 16-1), the bandwidth for the grouping of these emissions should be fixed at 200 Hz. The centre frequency of the first possible group is 2,1 kHz.

For the frequency analysis, the DFT method (linked to the methods described in clause 4), and for the grouping procedure a method similar to that described in 5.5.1, are under consideration. The DFT method is suitable for voltage and current measurements whereas CISPR 16-1 considers only voltages.

B.3 Basic instrument

For measurements in this higher frequency range, a discrete Fourier transform can be performed according to 4.4.1.

NOTE The frequency range of external voltage and current sensors should be appropriate for measurements up to 9 kHz.

In view of the low level of the signal to be measured, a filter can considerably decrease the uncertainty of the measurement by attenuating the amplitudes of the fundamental and of components above 9 kHz. The attenuation for the fundamental frequency should exceed 55 dB.

The sampling frequency should be chosen in accordance with the established rules of signal analysis such that frequency components up to 9 kHz inclusive can be measured. For this type of analysis, the sampling need not be synchronised to the fundamental period of the supply. A rectangular data acquisition window with a width of 100 ms can be used corresponding to approximately 5 (6) fundamental periods of 50 Hz (60 Hz) systems. In consequence, the frequency separation between consecutive measured components C_f is 10 Hz.

NOTE The r.m.s. value of the component at the frequency f is C_f, e.g. C_{3160} is the r.m.s. value of the component at 3160 Hz.

The output of the raw DFT (OUT 1 in figure 1) is grouped in bands of 200 Hz (see figure B.1), beginning at the first centre band above the harmonic range, of, for example, 2100 Hz. The output G_b of each band is the r.m.s. value according to

$$G_b = \sqrt{\sum_{f=b-90\,(Hz)}^{b+100} C_f^2} \tag{B1}$$

NOTE 1 The bandwidth has been chosen so that it is in accordance with the bandwidth used in CISPR 16-1 for frequencies above 9 kHz.

NOTE 2 The centre frequency b, for example, 2 100 Hz, 2 300 Hz, 2 500 Hz designates the band. The highest centre frequency is 8 900 Hz (see figure B.1).

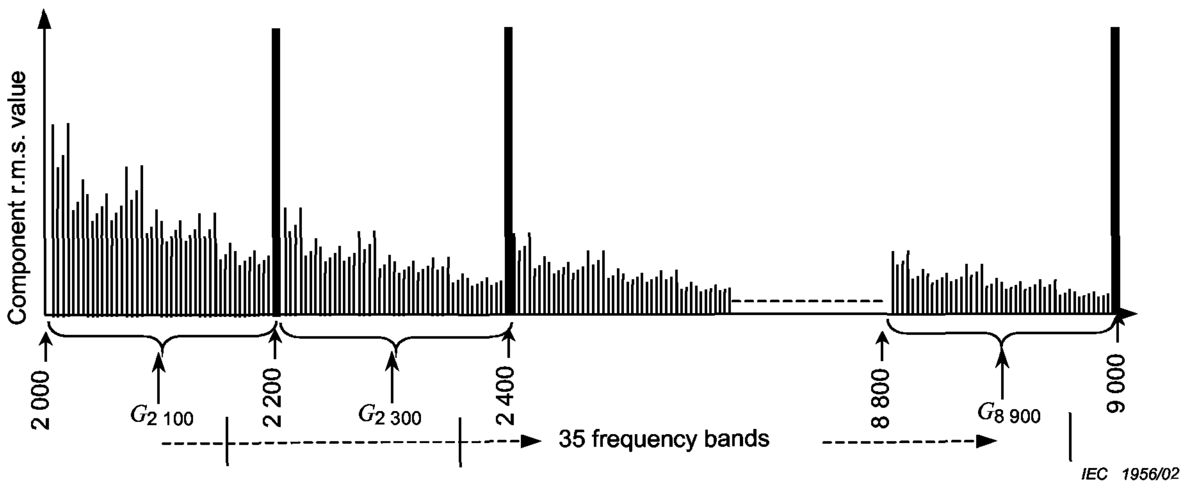


Figure B.1 – Illustration of frequency bands for measurement, in the range 2 kHz to 9 kHz

B.4 Measurement set-up

In addition to the measurement instrument, for emission assessment related to current or voltage components, special test circuits should be part of the measurement set-up in order to provide repeatability of the measurement results. These circuits which should correctly represent the supply system in the relevant frequency range and provide, if necessary, separate terminals for the measurement instrument, are also under development and should be considered for a future amendment to this standard.

B.5 Accuracy requirements

The total uncertainty should not exceed ±5 % of the measured value when tested with a single-frequency emission in the frequency band considered.

NOTE Compared to the magnitude of the fundamental current or voltage the components to be measured are expected to be in the range of 2×10^{-5} to 5×10^{-2}.

Annex C
(informative)

Technical considerations for grouping method

Measurement methods defined in this standard follow from careful consideration and balancing of competing objectives (for example, measurement bandwidth and frequency resolution). In certain cases, the need for defining a practical measurement results in compromises rather than the achievement of the ultimate in precision in characterising the signal in question. Considerations for resolution of several particularly difficult issues are documented in this annex.

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

C.1 Power equivalence of time and frequency domain representations of signals

Parseval's relation, also known as the Rayleigh energy theorem, defines the equivalence of signal power (or energy) expressed in the time domain to signal power (or energy) expressed in the frequency domain.

$$\int_{-\infty}^{+\infty} [g(t)]^2 \, dt = \frac{1}{2\pi} \int_{-\infty}^{+\infty} |G(j\omega)|^2 \, d\omega \qquad \text{(C1)}$$

where

$g(t)$ is a time function;

$G(j\omega)$ is the complex Fourier transform of the function; and

$\omega = 2\pi f$.

NOTE Since the power is proportional to the square of a voltage or current the squared signal is understood to be the "power" of the signal. For example, if $g(t)$ is assumed to be the time function of a voltage, the physical dimension of the left-hand side of the equation (time domain) would be V^2 s ("energy"). The Fourier transform presents the spectral density of the voltage and, in the example, $G(j\omega)$ would have the dimension V/Hz or V s, i.e. the right-hand side yields also the dimension V^2 s ("energy").

If the function is not periodic, its spectrum is continuous, but if it is periodic it can be represented in a time window T_w, i.e. the infinite repetition of the time window would yield the total function $g(t)$. The Fourier transform of this now time-limited signal is no longer continuous but consists of spectral lines at a frequency distance of $f_w = 1/T_w$. The product of the window time T_w and the squared r.m.s. value, G_k^2, of the (complex) line at the frequency $f = k \times f_w$ represents approximately the "energy" of the continuous spectral density integrated over $f - f_w/2$ to $f + f_w/2$. The "energy" sum contributed by all spectral lines is equivalent to the "energy" of the time function within the window. Dividing the "energy" by the window time T_w yields equation (C2):

$$\frac{1}{T_W} \int_{-T_W/2}^{+T_W/2} [g(t)]^2 \, dt = \sum_{k=-\infty}^{\infty} |G_k|^2 \qquad \text{(C2)}$$

where

the left-hand side corresponds to the average "power" of the time function within the window; and

the right-hand side to the total "power" of all lines within the spectrum.

A characteristic of the Fourier transform is that the spectral lines at negative frequencies are conjugate complex to the lines at the same positive frequencies, i. e. the "power" spectrum is symmetrical about the frequency f = 0. By folding the negative part of the spectrum over the positive one, equation (C2) is simplified:

$$\frac{1}{T_W}\int_{-T_W/2}^{+T_W/2}[g(t)]^2\,dt = G_0^2 + 2\sum_{k=1}^{\infty}|G_k|^2 \tag{C3}$$

The definition of the amplitude c_k of the Fourier components according to equation (3) of the standard is related to $T_w/2$, not to T_w (except c_0 which is related to T_w), i.e. $c_k = 2 \times G_k$ or $C_k = \sqrt{2} \times G_k$. Equation (C3) can therefore be rewritten:

$$\frac{1}{T_W}\int_{-T_W/2}^{+T_W/2}[g(t)]^2\,dt = c_0^2 + \sum_{k=1}^{\infty}|C_k|^2 = \sum_{k=0}^{\infty}|C_k|^2 \tag{C4}$$

In practice, the number of coefficients in the sum has to be limited: k = 1 ... K. If the signal is "band-limited" to frequencies $f_K \leq K \times f_w$, no "power" is associated with coefficients of order $k > K$, and they can be left out of the sum in equation (C4). The frequency f_K should be well beyond the operating frequency range of the instrument.

C.2 Characteristics of digital realisation

Digital instrumentation is considered in this standard. In order to fulfil the Shannon theorem, the time signal should be sampled with a sampling frequency $f_s > 2 \times f_K$ so that – in principle – all coefficients up to C_K can be calculated. The number of samples within a time window is $N = f_s \times T_w$.

Under the above-mentioned ideal conditions, i.e. the digitized signal is real, periodic and band-limited, and the time window is synchronised to the signal period, equation (C4) can be written:

$$\sqrt{\frac{1}{N}\sum_{i=1}^{N}[g(t_i)]^2} = \sqrt{\sum_{k=0}^{N/2}|C_k|^2} \tag{C5}$$

where

$g(t_i)$ are the values of the time function at the sampling points; and

$t_i = i \times T_w/N$.

Equation (C5) states that the r.m.s. content of the frequency domain components equals the r.m.s. content of the time domain representation of the signal, in this case a sampled and digitised form of the signal. Parseval's relation may be usefully employed to ascertain whether the power spectrum accurately represents the time domain signal under certain specific circumstances.

Under the ideal conditions defined above, the power spectrum calculated by the methods defined in this standard, returns the average power of spectral components present in the measured signal during a defined time window. The power spectrum exactly represents the total power of the signal, the power of the individual frequency components, and the frequencies of these components. For practical situations, ideal conditions exist when all components of the measured signal are exact harmonics of the "basic" frequency $f_w = 1/T_w$. Because of the strict requirements defined in this standard for synchronisation, these nearly ideal conditions occur by definition for the fundamental component of the power system and for any components with frequencies which are integer multiples of the "basic" frequency; this includes, of course, the harmonics of the fundamental frequency.

NOTE The "basic" frequency is the reciprocal of the window width. The "fundamental" frequency is the reciprocal of the system cycle.

The width of the time window, $T_w \approx$ 200 ms, is defined as 10 or 12 fundamental cycles for 50 Hz or 60 Hz systems respectively for future designs, and 16 cycles (≈320 ms or ≈267 ms) for instruments designed to comply with requirements given in the first edition of IEC 61000-4-7. The frequency distance of the spectral lines ("basic" frequency f_w) is therefore ≈5 Hz or ≈3,125 Hz or ≈3,75 Hz, respectively. The grouping method according to equation (8) of this standard ensures that the total power is accurately evaluated. It takes account of all spectral lines and not only the lines ("harmonics") at integer multiples of the fundamental frequency. Equation (8) relates only to lines with a distance of ≈5 Hz and has therefore to be modified if other "basic" frequencies are used. By proper application of equation (8) – modified if necessary – under ideal conditions, the power spectrum exactly represents the average power of the measured signal as defined by Parseval's relation.

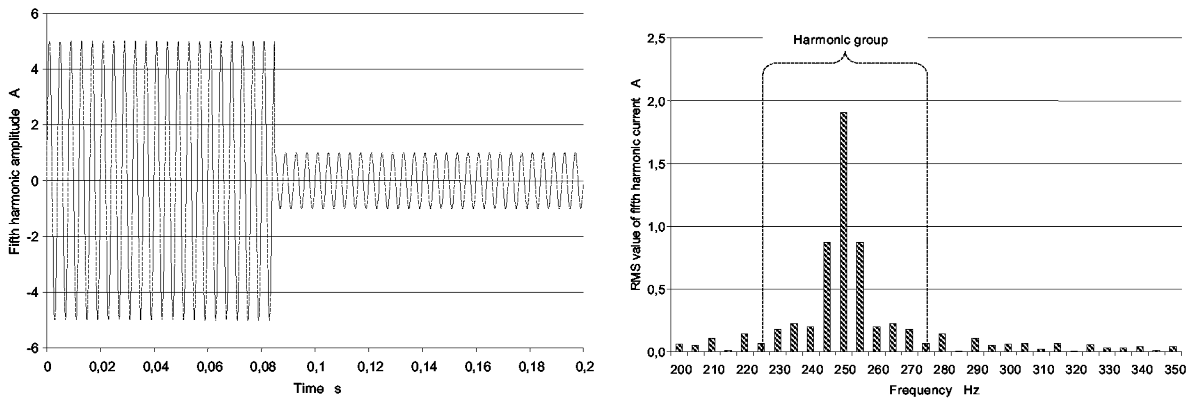
Under less than ideal conditions, for example, where non-harmonic signal content with frequencies $f \neq k \times f_w$ (k: integer number) is present, the phenomenon of spectral leakage acts to cause a loss of information about frequency content, but signal power generally remains accurately represented. Considering the case of a time window equal to 200 ms, non-harmonic signal content is present whenever there are inter-harmonic signals at frequencies which are not integer multiples of 5 Hz, for example 287 Hz, or when amplitude fluctuation occurs within the analysed time window. The grouping methods defined in this standard assist in ensuring that the total power is for the most part accurately evaluated. Allocation of power to a specific signal group depends upon the nature of the signals involved.

A few examples will help to illustrate the point. The examples in C.3 show the effect of voltage and current amplitude fluctuation. The interharmonic effects are illustrated in C.4. The fundamental component which predominates in practice by far in voltage and current signals is left away in the examples in order to use the full scale of the figures for a more clear presentation of the interesting spectral lines and the grouping effect.

C.3 Fluctuating harmonics

EXAMPLE 1

Figure C.1 illustrates the case of the r.m.s. 5th harmonic current fluctuating from 3,536 A to 0,7071 A. The step in the current occurs after 21,25 periods of the 5th harmonic. The expected calculated r.m.s. current for this case is 2,367 A. The measured 5th harmonic (single line) results in only 1,909 A, i.e. neglecting the other lines produces an error of 19,3 %. The measured harmonic subgroup value in this case results in 2,276 A and would already reduce the error to 3,84%, but the harmonic group of the measured lines yields a value of 2,332 A which corresponds to the small remaining error of only 1,47%.

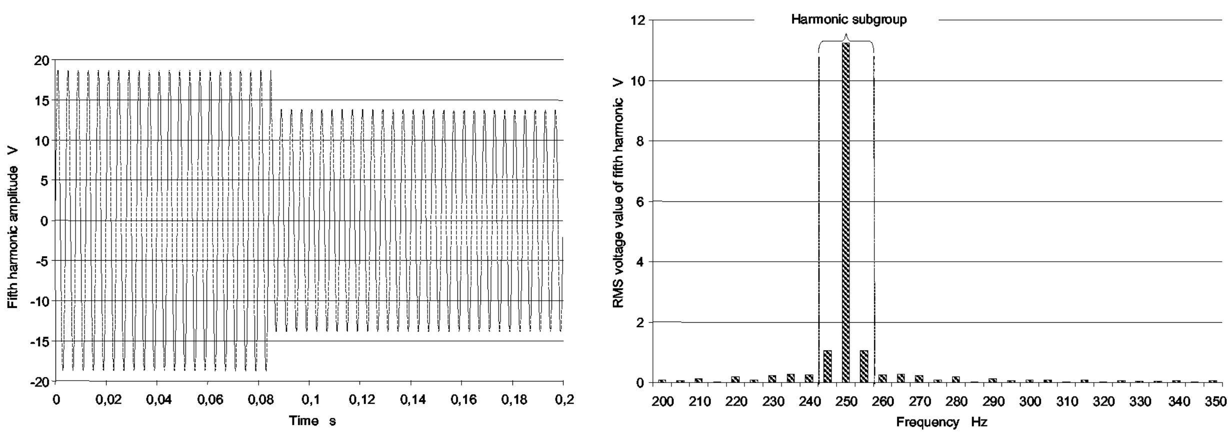


IEC 1957/02

Figure C.1 – Large 5th harmonic current fluctuation

EXAMPLE 2

Power-system harmonic voltages normally result from the combination of emitted harmonic currents produced by several non-linear loads. These loads are generally not fluctuating with significant correlation. Furthermore, quasi-stationary loads are also connected to the power system. Therefore, fast fluctuating harmonic voltage levels with a high fluctuation magnitude are an exception and seldom occur on the power system. For example, figure C.2 shows a fifth harmonic r.m.s. voltage that reduces from 13,225 V to 9,775 V. In this case, the expected total r.m.s. value is 11,37 V, but the single harmonic line is only 11,24 V. The proposed algorithms in this standard yield 11,33 V for the subgroup and 11,34 V for the group which results in errors of only 0,35 % or 0,24 % respectively. These errors are well below the uncertainty of the instrument itself.



IEC 1958/02

Figure C.2 – Large 5th harmonic voltage fluctuation

EXAMPLE 3

A microwave appliance produces (amongst others) a 3rd harmonic current, for example, 1 A during continuous operation. Its average power is controlled by the zero-crossing multi-cycle method with, for example, a repetition rate of 5 Hz and a duty-cycle of 50%. Figure C.3 illustrates the time function of the 3rd harmonic current and the corresponding spectrum. The total r.m.s current is 0,707 A. The r.m.s. value of the 3rd harmonic spectral line is 0,5 A which results in an error of 29,3 %. The harmonic subgroup yields, however, 0,673 A, and the error is only 4,8 %. The harmonic group value is 0,692 A, reducing the error down to 2,0 %.

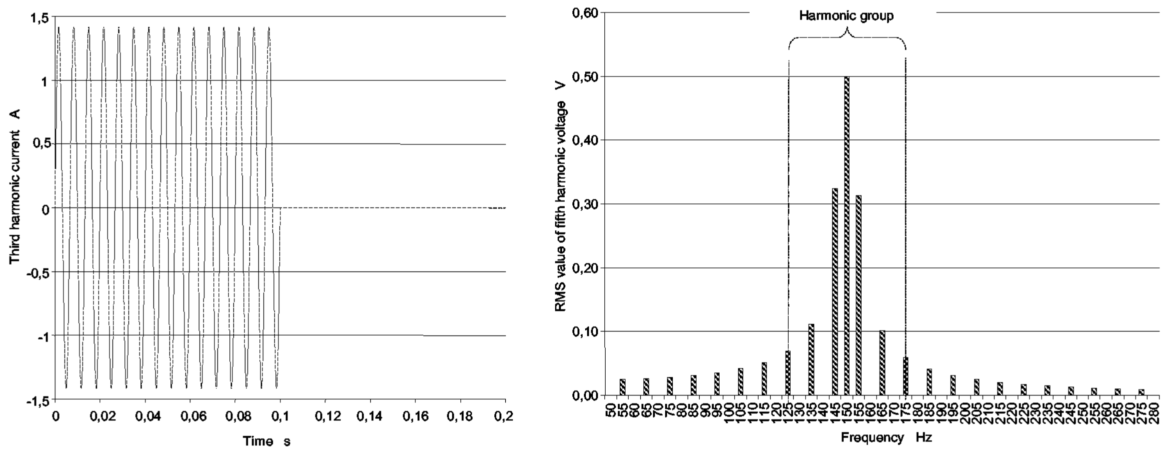


Figure C.3 – Fluctuating 3rd harmonic current of a micro-wave appliance

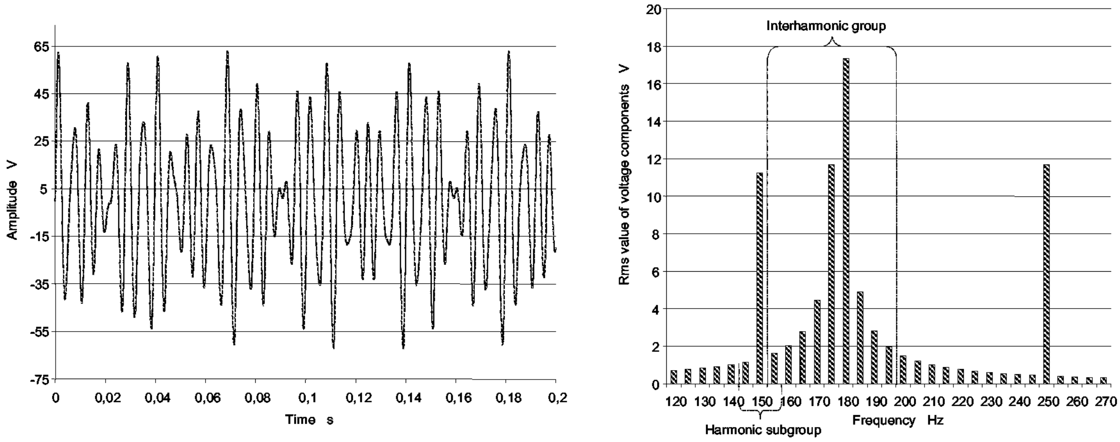
It is evident from these examples that the grouping procedure is well suited to give results which are in good conformity with Parseval´s equation.

C.4 Interharmonics

EXAMPLE 1

Communication (signalling) systems may also be connected to the power system. To prevent them being disturbed by harmonics, the frequencies used are generally between two harmonic frequencies, i.e. interharmonic frequencies. If they are integer multiples of the "basic" frequency f_w and have a constant magnitude within the time window, then the spectrum shows one additional line just at this frequency, and an additional grouping may not be necessary. But in order to transmit information the signal is modulated. The effect on the spectrum is similar to the previous examples, the only difference being that the lines due to the modulation are now centred on the signalling frequency. The "interharmonic grouping" according to annex A reduces the error in the same manner as the harmonic grouping shown in C.3.

In many cases, signalling frequencies which are not integer multiples of f_w are used. For example, figure C.4 shows a communication signal at 178 Hz with constant magnitude of 23 V r.m.s. superposed on a third and fifth harmonic of 11,5 V each, which might already exist on the system. The discrete Fourier transform, which cannot resolve the line at 178 Hz, spreads the energy to the neighbouring lines ("leakage"). In this case, the interharmonic group of order 3,5 (see annex A) collects the major part of the spread "energy" of the communication signal, with a resulting value of 22,51 V, and the error is only 2,15 %.



IEC 1960/02

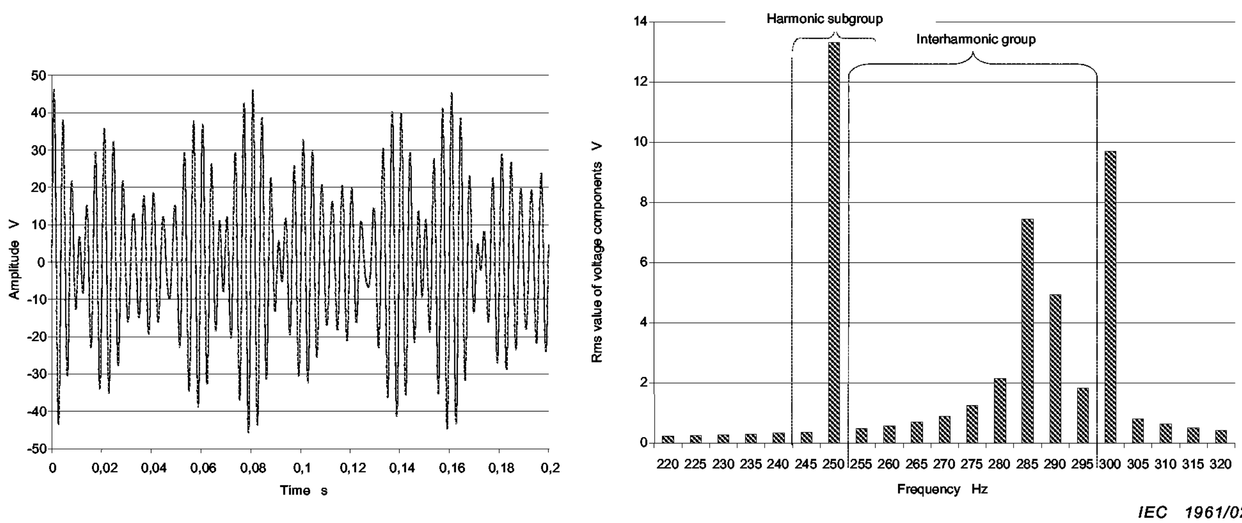
Figure C.4 – Communication signal of 178 Hz together with 3rd and 5th harmonics

NOTE 1 The "leakage" effect of the signal with non-integer multiple of the "basic" frequency superimposes additional vectors on the vectors of the original harmonics (see figure C.7). The phase angle between the additional and the original vector of the same frequency increases (or decreases) by approximately the same amount from window to window. Depending on the actual phase angle, the resulting vector may vary between the difference and the sum of the vector magnitudes. In the given example, the magnitudes are 11,5 V for the original vectors and ≈1,2 V at 150 Hz or ≈0,4 V at 250 Hz (see figure C.4). The resulting vectors may vary between ≈10,3 V and ≈12,7 V at 150 Hz and between ≈11,1 V and ≈11,9 V at 250 Hz. The r.m.s value of the resulting vector evaluated over many contiguous windows equals the "common" r.m.s. value of the original and the additional vector, in the example 11,56 V at 150 Hz and 11,51 V at 250 Hz. The smoothing procedure, which is applied after the grouping, reduces considerably the variation and provides an average output close to this common r.m.s. value.

NOTE 2 The magnitude of the communication signal will in practice be smaller than in the example, so the leakage effect is reduced correspondingly.

EXAMPLE 2:

Interharmonics can also appear in the emission r.m.s. current and consequently in the r.m.s. voltage of the supply. They may occur randomly between two contiguous harmonics. For example, 9,8 V at 287 Hz, 13,2 V of the 5th harmonic and 10 V of the 6th are shown in figure C.5. The "leakage" effect can be seen from the spectrum. The interharmonic group of order 5 (see 3.4) yields 9,534 V, and the remaining error is 2,7 %.



IEC 1961/02

Figure C.5 – Interharmonic at 287 Hz, 5th and 6th harmonic

EXAMPLE 3

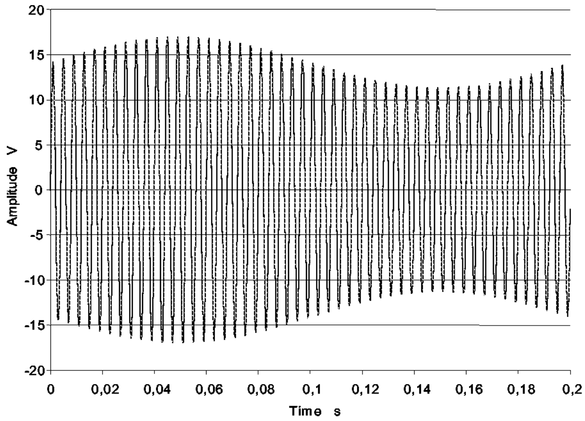
An electronic motor drive with a varying torque, for example a piston pump, produces a 5th harmonic voltage on the supply system which fluctuates around the average r.m.s. value of 10 V with a sinusoidal modulation of 20 % and 5 Hz, figure C.6 a). The total r.m.s. value of the time function, evaluated over 0,2 s, is 10,10 V. The spectrum contains the 250 Hz “carrier” line with an r.m.s. value of 10 V and the two side-lines at 245 Hz and 255 Hz with 1 V each, figure C.6 c). The error of the single line at 250 Hz is 0,99 %, and no error results from the harmonic subgroup.

A communication signal of 9,8 V and 287 Hz may be used on the same system (figure C.6 b)). The “leakage” effect in the spectrum (figure C.6 d), follows from the non-integer number of 57,4 periods of this signal in the time window of 200 ms. The r.m.s. value of the interharmonic group is 9,538 V and the resulting error 2,7 %.

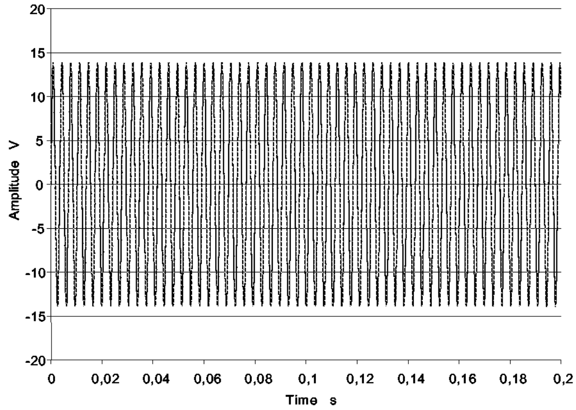
Both the fluctuating harmonic and the communication signal are superimposed on the voltage (figure C.6 e). The total r.m.s. value is 14,07 V. For the grouping of the resulting spectral lines different options exist (figure C.6 f). Since the presence of a harmonic at 250 Hz and a signal close to 285 Hz is obvious from the envelope of the spectrum, two grouping arrangements are reasonable (no line must be counted more than once):

– interharmonic group with 9,36 V (4,5 % error related to 9,8 V) and harmonic single line with 10,16 V (1,6 % error related to 10,0 V) resulting into a total r.m.s. value of 13,81 V (1,8 % error related to 14,07 V) or
– interharmonic sub-group with 9,34 V (4,7 % error related to 9,8 V) and harmonic subgroup with 10,23 V (1,29 % error related to 10,1 V) resulting in a total r.m.s. value of 13,85 V (1,5 % error related to 14,07 V).

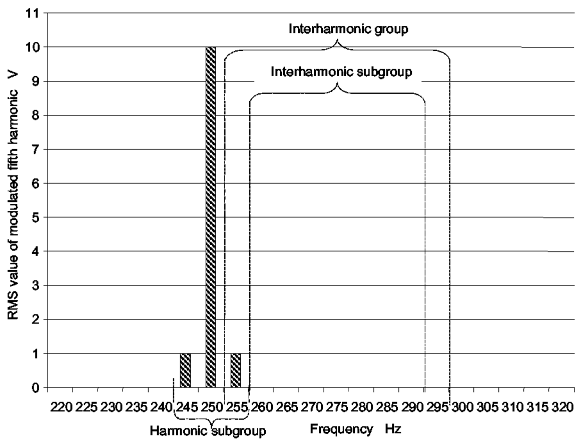
The 2nd grouping corresponds better to the “physics” since the lines at 245 Hz and 255 Hz do not fit to the “leakage” envelope. This is clarified if several spectra from contiguous windows are observed.



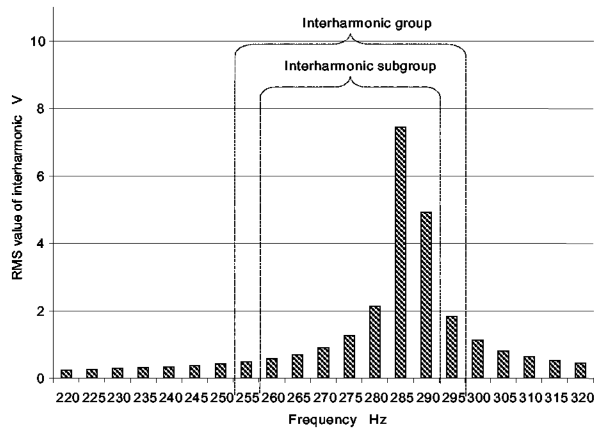
a) 5th harmonic with 20 % amplitude fluctuation



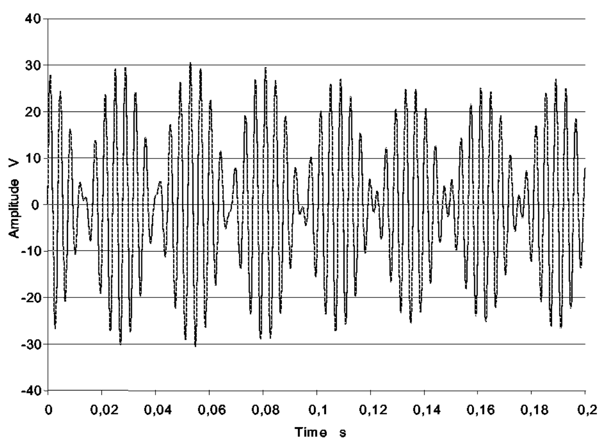
b) Interharmonic at 287 Hz



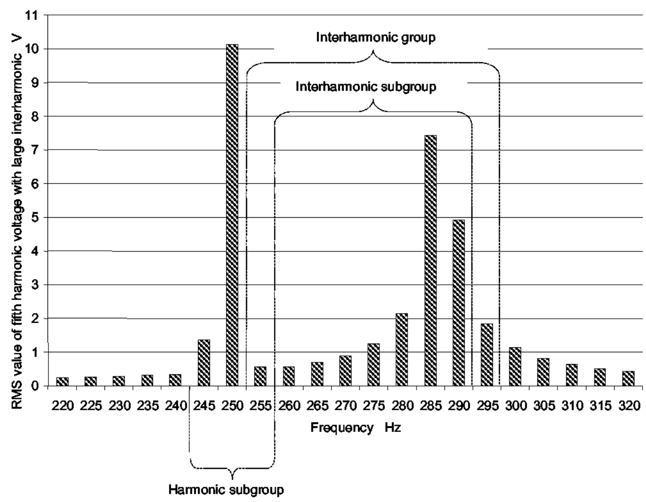
c) Spectrum: 5th harmonic, 20 % amplitude fluctuation



d) Spectrum: Interharmonic at 287 Hz



e) Sum of the harmonic and interharmonic



f) Spectrum: result of the summed signal

IEC 1962/02

Figure C.6 – Modulated 5th harmonic and interharmonic at 287 Hz

The spectral lines due to the sidebands around the fifth harmonic are those which are mainly affected by the leakage effect. For a fluctuating harmonic, the vectors of the components at the same distance from the harmonic frequency, i.e. 245 Hz and 255 Hz, have identical magnitudes but opposite directions. The magnitudes of the vectors remain constant for constant modulation depth but their angles rotate step by step from window to window if the modulation frequency is not an integer multiple of the basic frequency. The magnitudes of the vectors resulting from the interharmonic at 287 Hz remain also nearly constant but their angles change from window to window since the position of the interharmonic within the windows changes. The vectors resulting from the combination of the modulation and the leakage vary from window to window, of course, in angle and magnitude. Figure C.7 illustrates the two components at 5 Hz above and below the 5th harmonic for the time window of figure C.6. In this case, the magnitude of the "combined" 245 Hz is increased, and that of the 255 Hz vector is decreased, compared to the "modulation" vector. Other time windows would yield other angles of the vectors resulting from the 287 Hz signal and, consequently, the magnitudes of the "combination" vectors change: The time presentation of the spectrum shows fluctuating lines at 245 Hz and 255 Hz, and the average over the time would approximate the common r.m.s value of the "modulation" and the "leakage" vector.

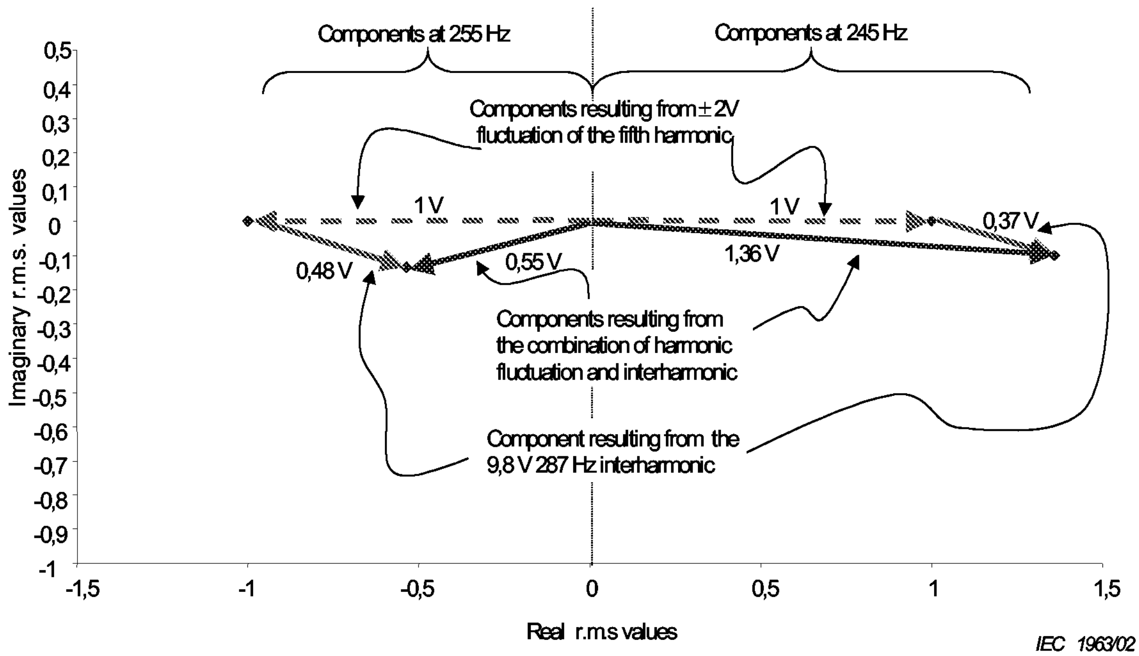


Figure C.7 – Component vectors at frequencies of 245 Hz and 255Hz

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