IEC TR 61000-1-4

Edition 2.0 2022-06
REDLINE VERSION

TECHNICAL REPORT

colour inside

Electromagnetic compatibility (EMC) –
Part 1-4: General – Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz

IEC TR 61000-1-4:2022-06 RLV(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 1-4: General – Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC TR 61000-1-4:2005. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC TR 61000-1-4 has been prepared by subcommittee 77A: EMC – Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility. It is a Technical Report.

This second edition cancels and replaces the first edition published in 2005. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) relation between compatibility levels, emission limits and immunity requirements clarified;
b) sharing of emission levels between LV, MV and HV clarified;
c) new historical information added.

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

Draft	Report on voting
77A/1136/DTR	77A/1141/RVDTR

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

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

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

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

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

- reconfirmed,
- withdrawn,
- 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 product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

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

IEC TR 61000-1-4:2005 (first edition) gave a historical rationale for the emission limits for equipment up to 2005. Since there is new historical material available about the developments in the past several years, SC77A is adding this new historical material as a revision of IEC TR 61000-1-4. The revision also clarifies and amends some existing statements that are now known not to report the history until 2005 correctly.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 1-4: General – Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz

1 Scope

This part of IEC 61000, which is a technical report, reviews the sources and effects of power frequency conducted harmonic current emissions in the frequency range up to 2 kHz on the public electricity supply, and gives an account of the reasoning and calculations leading to the existing emission limits for equipment in the editions of IEC 61000-3-2 [1][1], up to and including ~~the second edition (2000) and its first amendment (2001), and in the first edition of IEC 61000-3-12 (2004)~~ the fifth edition (2018) with Amendment 1 (2020), and in the second edition of IEC 61000-3-12 (2011) [2].

The history is traced from the first supra-national standard ~~on~~ low-frequency conducted emissions into the public electricity supply, EN 50006:1975 [3] and its evolution through IEC (60)555-2 [4] to IEC 61000-3-2 [1], IEC TR 61000-3-4 [5] and IEC 61000-3-12 [2]. To give a full picture of the history, that of the standard for the measuring instrument IEC 61000-4-7 [6] is mentioned as well.

NOTE All IEC standards were renumbered starting from 60000 from 1998-01-01. To indicate the references of standards withdrawn before, or not reprinted after, that date, the "60x" prefix is here enclosed in parentheses. Hence "IEC (60)555-2".

Some concepts in this document apply to all low voltage AC systems, but the numerical values apply specifically to the European 230 V/400 V 50 Hz system.

~~NOTE A rationale for the limits in future complete revisions of IEC 61000-3-2 or IEC 61000-3-12 or both will be included in a new technical report.~~

2 Normative references

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

IEC 61000 (all parts), *Electromagnetic compatibility (EMC)*

~~IEC 61000-2-2:2002[2)], *Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*~~

1 Numbers in square brackets refer to the Bibliography.

~~2) This technical report also refers to the first edition of IEC 61000-2-2 (1990), *Electromagnetic compatability (EMC) – Part 2: Environment – Section 2: Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*, since superseded by the second edition of that publication.~~

IEC 61000-3-2:2000[3], *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*[4]
Amendment 1 (2001)

IEC 61000-3-3:1994, *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage fluctuations and flicker in public low-voltage supply systems for equipment with rated current ≤ 16 A*[5]
Amendment 1 (2001)

IEC 61000-3-4, *Electromagnetic compatibility (EMC – Part 3-4: Limits – Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A*

IEC 61000-3-6, *Electromagnetic compatibility (EMC) – Part 3: Limits – Section 6: Assessment of emission limits for distorting loads in MV and HV power systems*

IEC 61000-3-11, *Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subjet to conditional connection*

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

IEC 61000-4-13, *Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests*

3 Terms and definitions

Definitions of terms used in this technical report can be found in other publications in the IEC 61000 series.

For the purposes of this document, the terms and definitions given in IEC 61000 (all parts) apply.

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

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

4 General appraisal

The electricity supply industry intends to supply electric power with a sinusoidal voltage waveform, and customers' equipment is designed to operate correctly on such a supply.

[3] This technical report also refers to the first edition of IEC 61000-3-2 (1995), *Electromagnetic compatability (EMC) – Part 3: Limits – Section 2: Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*, and its Amendment 1 (1995), since superseded by the second edition and its amendments of that publication.

[4] A consolidated edition 2.2 exists, which includes IEC 61000-3-2:2000 and its Amendments 1 (2001) and 2 (2004).

[5] A consolidated edition 1.1 exists, which includes IEC 61000-3-3:1994 and its Amendment 1 (2001), *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*

However, because the internal impedance of the supply system is not zero, a non-linear load connected by one customer produces distortion of the voltage waveform that may can adversely affect another customer's equipment, as well as equipment in the supply system itself. There is no type of load or supply system equipment that is totally immune to distortion of the voltage waveform, although and "natural" immunity levels (those achieved by customary designs without special attention to improving immunity) vary greatly. Based largely on experience of the amounts of voltage distortion that give rise to evidence of malfunction of, or damage to, equipment, compatibility levels of voltage distortion for the low-voltage (LV) public supply system have been determined and are given in IEC 61000-2-2 [7]. The correspondences between these levels and other values are shown schematically in IEC 61000-2-2:2002, Figure A.1. Compatibility levels are set as an acceptable compromise between immunity to harmonics and reduction of emissions. Methods to check that the immunity of equipment to voltage distortion is adequate are given in IEC 61000-4-13 [8].

NOTE 1 For the purposes of this technical report, the compatibility levels in the first edition of IEC 61000-2-2 apply. Logically, compatibility levels would be set somewhat below the lowest acceptable immunity levels, but those data were hard to come by in the past. Recommended immunity levels were first established in IEC 61000-4-13.

The intention of applying limits on the harmonic current emissions of equipment connected to the public low-voltage (LV) system is to keep the actual levels of voltage distortion on the system below the compatibility levels for a very large proportion of the time, and below lower levels, known as planning levels, for a lesser but still large proportion of the time. (See Figure 1.)

NOTE 12 Emissions into the medium-voltage (MV) and high voltage (HV) systems can be controlled by other methods and procedures. See IEC TR 61000-3-6. [9]

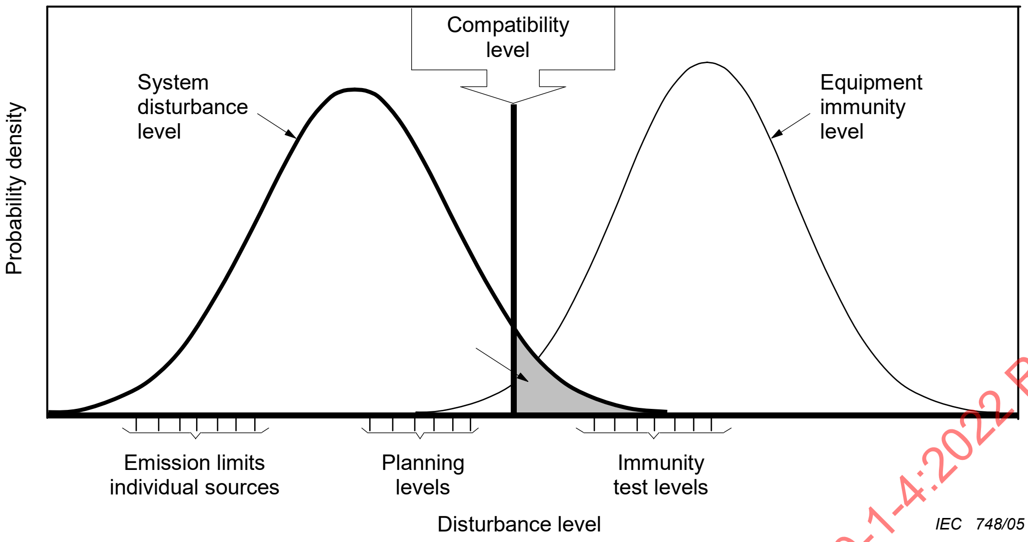
NOTE 23 In some countries, the electricity supply industry places reliance on IEC 61000-3-2 [1] to control emissions from portable equipment, whether the point of common coupling is at LV, MV or HV.

Emissions from equipment are expressed as currents, because these are largely, but not completely, independent of the source impedance of the supply system, whereas the voltage distortion produced by the equipment is almost proportional to the supply-system impedance and therefore has no definite value. A product that draws a non-linear current from the supply system may can alternatively be regarded as drawing a sinusoidal current, while emitting into the supply system harmonic currents of the opposite polarity to those that it actually draws.

Compatibility levels are set, using system disturbance data and standardized immunity levels, so that the probability of the system disturbance level exceeding the lowest immunity test level is acceptably low, and at present is set at 5 %.

NOTE 4 Because the system disturbance level is an aggregate of the emissions of very many loads, the emission limits for equipment are set at quite low disturbance levels.

NOTE 5 For system design, planning values of disturbance levels are adopted unilaterally by distribution system operators; these are not expected to be exceeded but are not subject to standardization.



~~Figure 1 – Diagram showing compatibility level in relation to disturbance and immunity levels~~

5 Acceptable provisions in standards related to regulatory legislation

The equipment manufacturing industry can accept requirements in a voluntary standard, whose application ~~may~~ can be determined by custom or moderated during individual contract negotiations, that would be unacceptable in a standard backed by regulatory enforcement. For example, a standard ~~may~~ can contain provisions that, if fully applied, would result in very long test times. Parties to a contract might waive these provisions, wholly or partly (calculation or simulation might be employed, for example) whereas in an enforcement situation, no deviation from the provisions might be allowed.

Both EN 50006:1975, 7.1 and IEC (60)555-2:1988, IEC (60)555-2:1988/AMD1:1988 and IEC (60)555-2:1988/AMD2:1988[6], 5.3.1 [4], required the test operator to search for worst-case conditions using the controls of the equipment under test, and in IEC (60)555-2, this was required for each harmonic in turn. Such a test might well take many days, with no assurance that another test operator might not find a different worst-case condition for just one harmonic. Such a provision was also contained in IEC 61000-3-2:1995 (first edition), Clause C.1 and was not removed until the publication of IEC 61000-3-2:2000/AMD1:2001 (second edition) [1].

A standard must not include regulatory requirements: it is concerned only with the procedures necessary to determine whether a product within its scope meets its requirements.

6 History of IEC 61000-3-2 and its predecessors

6.1 History table

The revision histories of IEC 61000-3-2 and IEC 61000-3-12 are given in Annex G (informative).

An up-to-date table of the entire publication history of each IEC publication can be obtained via the IEC webstore at https://webstore.iec.ch.

6 IEC (60)555-2 was withdrawn in 1995 and replaced by IEC 61000-3-2.

6.2 Before 1960

The most numerous non-linear loads were television receivers with half-wave rectifiers. Because most of these had mains connectors of reversible polarity, the DC components approximately cancelled. The number of receivers installed was insufficient to create any significant system problems due to harmonic current emissions, but there is evidence that there was enough random unbalance of polarity of connection in some countries for the resultant DC component to cause corrosion problems in underground cables.

6.3 1960 to 1975

Phase-controlled dimmers for household lighting began to be marketed. These created high-frequency conducted emissions, thus initially drawing the attention of radio-spectrum protection authorities. Measures to limit these emissions could be made mandatory, but it was also noted that the dimmers produced harmonic currents and there was no practicable way of reducing the ratios of harmonic to fundamental current.

A system survey in Europe determined the 90th percentile value for supply impedance for residential customers (who were mostly fed by overhead LV distribution) as (0,4 + jh0,25) ohms, where h is the harmonic order (0,4 + j0,25) Ω, and this value was included in IEC TR 60725:1981 [10]. In addition it was determined that without some control of emissions from dimmers, the voltage distortion might grow to exceed acceptable levels (later to be called “compatibility levels”).

NOTE There is no direct relationship between compatibility levels and emission limits generally. Further information on this subject can be found in Annex A.

NOTE In IEC (60)555-2:1982, Annex A [4], the supply impedance was regarded as purely resistive and inductive ((0,4 + jh0,25) Ω, where h is the harmonic order number). However, evidence was later presented that showed that the impedance rises above 500 Hz more nearly proportional to the square root of frequency, rather than proportional to frequency. The impedance presented to a particular load at the interface with the network (which is what determines the voltage distortion produced by the current emissions from that load) includes the effect of the impedances of other loads on the feeder. Even a light 10 kW load due to other equipment considerably lowers the impedance at high-order harmonic frequencies. See 6.9.

The first standard on this subject (according to its own text it is not based on any previous standard) was the European standard EN 50006:1975, implemented as various national standards, including BS 5406:1976. This standard took burst-firing techniques into account and also covered voltage fluctuations, now the subject of IEC 61000-3-3 [11] and IEC 61000-3-11 [12]. Limitation of harmonic current emissions was achieved by:

- prohibiting the use of phase control for heating loads over 200 W;
- applying limits for odd-harmonic emissions;
- applying limits for even-harmonic emissions to both symmetrical and asymmetrical control techniques.

The limits were expressed as voltage-harmonic percentages, produced with a supply system whose impedance (for single-phase loads) was (0,4 + jh0,25) Ω. However, the test procedure actually required measurement of the harmonic currents, from which the voltage distortions were calculated.

EN 50006 [3] does not include any explanation of the derivation of the limits, which are preserved as the Class A limits in IEC 61000-3-2, up to the 2000 edition (second edition). In fact, the numerical values were undoubtedly established piecemeal by negotiation between supply industry and equipment manufacturer experts. The retention of a strict mathematical rule for determining the values would not have been a priority for either group.

There was a study that led to an approximate algorithm for determining the cumulative contribution of many dimmers set at different firing angles to a net voltage distortion level at the terminals of the LV transformer feeding the final distribution. (See also Annex A.)

6.4 1975 to 1982

During this period, a more comprehensive standard, IEC (60)555-2 (published in 1982), was developed. Still effectively restricted to 220 (380) V to 240 (415) V 50 Hz European systems, it was adopted by CENELEC as EN (60)555-2 in 1987. It introduced three sets of limits; the original current limits unchanged from EN 50006, limits 1,5 times greater for products used only for short periods, such as portable tools, and special limits for television receivers, although an exemption for receivers whose input power was less than 165 W caused the limits to apply only to a small proportion of the receivers manufactured. The limits were expressed directly as currents, even for television receivers.

~~NOTE All IEC standards were renumbered in the 60000 series from 1998-01-01. To indicate the references of standards withdrawn before, or not reprinted after, that date, the '6xxx' prefix is here enclosed in parentheses. Hence 'IEC (60)555-2'.~~

Although IEC (60)555-2 included an annex that claimed to explain the derivation of the original current limits, in fact, it did not do so, merely citing the voltage distortion limits that were included in EN 50006 without explanation.

6.5 1982 to 1995

This period saw three profound changes; the great expansion of the use of switch-mode power supplies, both in business and in the home, the intimation that mandatory regulation of the electromagnetic compatibility (EMC) characteristics of electronic products would be introduced in Europe, and the further intimation that the European public electricity supply would be subject to "product quality" requirements.

The early standards, EN 50006 [3]and IEC (60)555-2, did not apply to professional equipment, but there is no relevant definition in either standard, although EN 50006 cites "office machinery" as an example. Thus it was unclear whether the standards applied to desktop computers. This was clarified in Europe by a decision that such computers were "household appliances", so that the original current limits applied. ~~(But CISPR 14/EN 55014 was not applied for high-frequency emissions.)~~ However the great expansion of single phase consumer electronics using direct on line switch mode DC power units, such as television receivers and desktop computers, led to significant peak flattening of the supply voltage waveforms due to near coincidence of the large current pulses drawn by these products. Although direct-on-line switch mode DC power units provided technology advantages (higher efficiency, lighter weight, smaller size), the near coincidence of the large current pulses being drawn can result in significant distortion of the supply voltage waveform. (Products with transformer-fed non-switching supplies have proportionally lower emissions because the series impedance of the transformer results in a larger conduction angle of the rectifiers.)

As a result, the development of the successor to IEC (60)555-2 was extremely controversial. It has been suggested that while the electricity supply industry continued to work in depth on the development of IEC 61000-3-2, the involvement of the equipment manufacturing industry was less structured. This ~~may~~ could be true, but should be seen in the context that "equipment manufacture" is a very diverse industry sector, whose sub-sectors have very different priorities in considering harmonic current emissions, while the supply industry has very little diversity in priorities, mainly deriving from differing infra-structure configurations in different countries.

IEC 61000-3-2:1995 (first edition) introduced many new features. Most notably, it applies to "[all] electrical and electronic equipment having an input current up to and including 16 A per phase and intended to be connected to public low-voltage distribution systems." (However, "professional equipment", as defined in the standard, enjoys exemption from some requirements.)

IEC 61000-3-2:1995 thus includes requirements and limits that apply to several different types of product, grouped into four classes. It effectively applies only to European systems, as for previous standards.

NOTE 1 It is still not known whether the characteristics of 220 V to 240 V, 50 Hz supply systems in other countries are sufficiently similar to the European for the standard to be applied, while it has been shown that "scaling" operations, intended to make the provisions applicable to systems of other voltages and frequencies, are rather unreliable. Different distribution system configurations affect the effective supply impedance and the propagation of harmonic currents through the system. The characteristics of electricity supplies world-wide are under study in SC77A.

Class A is a general class, applying to products within the scope that are not specifically included in another class. The limits are derived from the original voltage limits, dating effectively from before 1975, and the assumed supply impedances at the fundamental and harmonic frequencies. The limits are related to the current emissions of dimmers for incandescent lamps. See Annex B.

Class B is a specific class, applying to portable tools, which are assumed to be used for short periods only (a few minutes). The limits are 1,5 times the Class A limits. As far as can be determined, this factor of 1,5 is purely heuristic, although for the third harmonic, one piece of equipment that just meets the third-harmonic limit of 3,45 A thereby takes up almost all the allowable fraction (0,25) of the compatibility level of 5 % that can be allocated to the low-voltage network.

NOTE 2 For an explanation of the "allowable fraction of the compatibility level", see Annex A.

Class C is for lighting equipment, which has to be carefully defined. There is not a single set of limits for this class, and the limits are quite stringent. Some of these originally appeared, with similar values, in the product standard IEC (600)82 [24], now withdrawn. See Annex C.

Class D applied originally to products drawing a current pulse from the supply that lay within a specified mask centred on the peak of the current waveform. The rectifier conduction angle of a typical high-efficiency direct-on-line DC power unit is 35°. The individual low-order odd harmonic currents emitted by a group of such products add nearly arithmetically, producing peak-flattening of the voltage waveform of single-phase supplies. This class was intended to apply to DC power units, separate or built into products, and was based, after considerable study (including the effect of supplying the rectifier with already peak-flattened sine waves), on a rectifier conduction angle of approximately 65°, with some heuristic adjustments to accommodate other products. See Annex D.

The Class D limits, which are proportional to the active power drawn and are thus expressed in mA/W, were nominally aligned with the (fixed current) Class A limits at a power of 600 W, but because of rounding errors, the limits of the two classes for each harmonic become equal at significantly different powers, which caused some confusion initially. It was possible to determine that the expected effect on the supply system was that the compatibility limits would not be exceeded with these limits applied. The details of this prediction are given in [31] and [22].

It was also agreed that there should be a lower bound to Class D below which no limits would apply, because the impact on the network of a large variety of such products would be acceptable. The lower bound was set at 75 W, with a provision to reduce to 50 W "after four years". It was not realised that this is not a provision that could actually be implemented as stated. Consequently, those who relied on this provision have been disappointed that it has not been implemented.

NOTE 3 There is no definite date from which to count the period of four years, because IEC standards are voluntary and can be applied, or not, at any time. Furthermore, IEC standards can only be amended by a voting process, which ~~must be~~ is contemporaneous; National committees cannot determine which way they ~~should~~ will vote on a provision that would become effective many years in the future.

Unfortunately, the conduction angle of 65° required to meet the limits of Class D results in a rather unacceptably low efficiency of the power unit, manifesting as heat emission or the need for the inclusion of an inductor or an active power-factor correction circuit, at extra cost.

~~Consequently,~~ This requirement ~~was, and still is, by far the most controversial. It~~ was introduced on the grounds that statistical evidence showed a rising level of voltage distortion on European networks, together with daily variations in the 5th harmonic levels that tracked with television viewing habits. The rate of rise determined in several European countries was about 1 % over ten years, although not all the data were measurements at the same sites or at the same times over the ten-year period. But the “background” level due to miscellaneous sources was about 3 % in some places and the compatibility level was 5 % for the 5th harmonic at that time, so an unchecked rise could have had serious consequences in about ten years. Considering the service lifetimes of the products concerned (3 years to 10 years), it was clearly necessary to forestall any close approach to the compatibility level some years before it was forecast to occur.

A principle known as “equal rights” was applied in the setting of limits at that time. This can be simply stated as, “any product consuming x watts has an equal right to produce y % of harmonic currents”. Consequently, the classification and limits derived for television receivers were applied to all products with a DC power unit. However, this principle does not allow for the fact that there are, for example, far more television receivers in use than, say, some rare piece of scientific equipment, of which there ~~may~~ might be only ten in any one country. So applying the limits to the ten rare units, at a cost, achieves nothing of any significance to the well-being of the supply network or its load equipment.

NOTE 4 “Equal rights” also suggests that the allowable harmonic emissions ~~should~~ would be proportional to the power drawn by the product. From the equipment design point of view, this is entirely logical. Fixed current limits are very lax for low-power equipment and ~~may~~ can be very stringent indeed for higher-power equipment.

The introduction in Europe of mandatory control of EMC characteristics effectively turned IEC 61000-3-2 into a quasi-legal document, ~~and~~ although it was not editorially suited to such a role.

6.6 1995 to 2000

Amendment 1 to IEC 61000-3-2:1995 (first edition) was issued in 1997. It introduced the following changes:

- “The designation shall be specified by the manufacturer” was added to the definition of “professional equipment". (Unfortunately, a definition is not allowed to contain a requirement, so other committees have not been allowed to adopt this definition verbatim.)
- Test conditions for vacuum cleaners and air-conditioners were added to Annex C.

Amendment 2 was issued in February 1998. This introduced requirements for lighting equipment with active input power not greater than 25 W. The limits applying to Class D, without the lower bound of 75 W, can be applied, or, in addition to limits for low-order harmonic currents, the current waveform ~~may~~ can meet shape requirements. In setting these requirements, note was taken of the fact that there can be partial cancellation of the 5th harmonic current produced by discharge lamps by the 5th harmonic current produced by DC power units with capacitive filter, such as in television receivers.

Amendment 3 resulted from a proposal to amend the CENELEC version of the standard unilaterally, which was changed to a request for IEC to prepare it. Additional amendments were consolidated with it, resulting in a combined text dealing with:

– limits for motor driven equipment with phase angle control;
– test conditions for kitchen machines;
– asymmetrical control methods;
– symmetrical control methods;
– test condition for arc welding equipment intended for non-professional use.

None of these involved fundamental changes to the standard.

In accordance with IEC publication procedures, this third amendment resulted in a second edition, dated August 2000.

6.7 The “Millennium Amendment”

An initiative in CENELEC led to a reappraisal of the standard, with much discussion in a working group. The output document was referred to IEC SC 77A, and this resulted in further very extensive discussions. During this time, economic considerations were introduced as a specific subject (see Annex E). By the end of 1999, a somewhat reluctant consensus had been achieved, mainly on the grounds that further discussion would not produce significant improvement, and it had been agreed to begin work, immediately after finalizing the amendment, on a full revision of the standard, with documented rationales for all provisions. The resulting amendment became known as the 'Millennium Amendment', because it was substantially finalized at the beginning of 2000.

Unfortunately, Amendment 3 was also in process in IEC during 1998 and 1999, and the IEC procedures resulted in a divergence of the editions of the IEC standard from those of CENELEC, which implemented the Millennium Amendment, but not the third IEC amendment, in a consolidated edition, creating confusion that might have been avoided.

The Millennium Amendment eliminated many of the ambiguities and uncertainties that made the 1995 edition difficult to use in a regulatory situation. It also abandoned the mask for determining Class D membership, on the technical grounds that for some products it was impossible to be sure whether they should be in Class D or not. Instead, it substituted what was finally a rather short list, of high-volume products with high simultaneity of use, which contribute (in the absence of built-in mitigation measures) to odd harmonic currents of little phase diversity (rather than the overall harmonic content of the system voltage): personal computers, personal computer monitors and television receivers.

The amendment also included a clarification of the requirements for lighting equipment.

~~6.7 Future development of IEC 61000-3-2~~

~~A detailed consideration of this subject is a matter for IEC 61000-1-X (to be published). Initial considerations are described in Annex F.~~

6.8 2000 to 2019

The second edition of IEC 61000-3-2 was issued in 2000, followed by Amendment 1 in 2001 and Amendment 2 in 2004. The third edition followed in 2005 and was amended in 2008 and 2009. In 2006, a new concept, “impact factor approach”, was introduced, but after very long discussions, it did not achieve consensus. However, it has not been completely abandoned. See 6.9.1.

In 2005, SC77A became aware that the use of APC reduced inrush current in on-line rectifiers and allowed more active power to be drawn from the supply. These are direct benefits to product specifications, thus providing economic justification for the additional cost of APC. Consequently, the low-frequency conducted emissions of many types of product were greatly reduced.

The fourth edition was published in 2014. This edition includes the following significant technical changes with respect to the previous edition:

a) a clarification of the repeatability and reproducibility of measurements;

a) a more accurate specification of the general test conditions for information technology equipment;

b) the addition of optional test conditions for information technology equipment with external power supplies or battery chargers;

c) the addition of a simplified test method for equipment that undergoes minor changes or updates;

d) an update of the test conditions for washing machines;

e) a clarification of the requirements for Class C equipment with active input power ≤ 25 W;
f) an update of the test conditions for audio amplifiers;
g) a clarification of the test conditions for lamps;
h) an update of the test conditions for vacuum cleaners;
i) the addition of test conditions for high pressure cleaners;
j) an update of the test conditions for arc welding equipment;
k) the reclassification of refrigerators and freezers with variable-speed drives into Class D;
l) the addition of test conditions for refrigerators and freezers.

The fifth edition was published in 2018 as a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

a) an update of the emission limits for lighting equipment with a rated power ≤ 25 W to take into account new types of lighting equipment;
b) the addition of a threshold of 5 W under which no emission limits apply to all lighting equipment;
c) the modification of the requirements applying to the dimmers when operating non-incandescent lamps;
d) the addition of test conditions for digital load side transmission control devices;
e) the removal of the use of reference lamps and reference ballasts for the tests of lighting equipment;
f) the simplification and clarification of the terminology used for lighting equipment;
g) the classification of professional luminaires for stage lighting and studios under Class A;
h) a clarification about the classification of emergency lighting equipment;
i) a clarification for lighting equipment including one control module with an active input power ≤ 2 W;
j) an update of the test conditions for television receivers;
k) an update of the test conditions for induction hobs, taking also into account the other types of cooking appliances;
l) for consistency with IEC 61000-3-12, a change of the scope of IEC 61000-3-2 from “equipment with an input current ≤ 16A” to “equipment with a rated input current ≤ 16A”.

6.9 2020 to 2022

6.9.1 Impact factor approach

A different approach to conducted emissions and their limits might be considered in future editions of IEC 61000-3-2. Initial considerations are described in Annex F. This approach has been extensively discussed in committee (see 6.8), but so far no consensus has been achieved.

6.9.2 Effect of the coronavirus pandemic from 2020 to 2022

The restriction to on-line meetings of necessarily short duration caused the maintenance of standards, and other subjects needing extensive discussion, to be postponed until face-to-face meetings resume.

7 History of IEC 61000-3-12 and its predecessor

7.1 Origin

IEC 61000-3-12 was adapted from IEC TR 61000-3-4 with the following changes:

- IEC 61000-3-12 is limited to equipment rated ≤ 75 A per phase. IEC TR 61000-3-4 can be applied by the distribution system operators (DSOs) for equipment rated > 75 A per phase.
- The IEC TR 61000-3-4 assessment stages were not kept in IEC 61000-3-12 since the DSO is not required to decide whether the equipment can be connected to the public low-voltage network if the harmonic current emission limits in the relevant tables are met.
- IEC TR 61000-3-4:1998, Table 1, Table 2, and Table 3 are slightly modified and included in IEC 61000-3-12:2004 (first edition). Table 4 is also added for balanced three-phase equipment under specified conditions and given relaxed limits that account for the 5th harmonic current phase angle diversity compared to single-phase equipment.
- Table 5 is added for C-less drives in IEC 61000-3-12:2011 (second edition). All the tables undergo changes.
- The reference fundamental rated equipment current I_1 is replaced by the reference current I_{ref} for the calculated emission limits. I_{ref} is the average RMS input line current that is measured during test.
- THD and $PWHD$ are replaced by THC/I_{ref} and $PWHC/I_{ref}$, respectively.

IEC 61000-3-12:2011 has type test conditions for some types of equipment in Annex A. Annex B has an illustration of linear interpolation of the 5th harmonic current values based on R_{sce}.

7.2 1989 to 1998

IEC 61000-3-2 deals with equipment rated at up to 16 A/phase. A complementary document, dealing with equipment rated at over 16 A/phase, was prepared as IEC TR 61000-3-4, a Technical Report type 2 (“prospective standard for provisional application”), by a team comprising experts from ES, FR, DE, IE, IT, ~~UK~~GB and US. Some conclusions of the team were recorded:

- an arithmetic superposition law was used for harmonics up to the 5th and a geometric law for higher orders;
- approximately 75 % of the compatibility level ~~(for the fifth harmonic, for example)~~ for low-order non-triplen harmonics is transmitted from the MV level and is present as a background disturbance throughout the LV network. Hence only 25 % of the compatibility level is left for the admissible additional voltage distortion due to non-linear loads connected to a specific LV supply. For harmonic orders above approximately the 13th, phase diversity allows a higher percentage of the compatibility level to be allocated to the LV network. See Annex A.

Rough calculations, depending on different assumptions on the partition of distorting loads, yielded:

- $I_5/I_1 \leq 11$ % (~~UK~~GB)
- $I_5/I_1 \leq 15$ % (IT)
- $I_5/I_1 \leq 16$ % (CH)
- $I_5/I_1 \leq 9$ % to 16 % (DE)

It was decided that the limits should depend on the short-circuit ratio R_{sce}, with higher limits with higher R_{sce}, but remain in principle in the range of the rough calculations.

Further studies were made to find a justified relation between the R_{sce} values and the limits. The detailed calculations are lost. An attempt to “recover” the basis of these studies, and relate it to the limits in IEC 61000-3-12, is presented in Annex G.

This rationale does not consider the provisions of IEC TR 61000-3-4 in detail, since all but one (relating to equipment rated at over 75 A/phase) ~~will~~ have been superseded by provisions of IEC 61000-3-12 ~~by the time that the rationale is published~~.

~~The report was published in October 1998.~~

~~NOTE Technical reports type 2 are no longer produced by IEC.~~

~~Such reports were required to be reviewed within three years of publication, and IEC decided to convert the report into a standard, IEC 61000-3-12, which might also be adopted by CENELEC and could then be used to demonstrate compliance with the European EMC Directive.~~

~~NOTE This was seen to be helpful for manufacturers intending to export to Europe, as well as for manufacturers within Europe.~~

7.3 After 1998

As was expected, experience gained from applying IEC TR 61000-3-4 led to proposals for changes to be incorporated in IEC 61000-3-12. After a very great deal of discussion, a first voting document was circulated in 2003.

8 History of IEC 61000-4-7 up to 2008

8.1 First edition in 1991

As the title indicates, this was a "general guide" (but it was not a Technical Report of any kind). It allowed analogue measurements as well as digital, the latter only recently becoming possible due to improvements in low-cost computer hardware. Analogue methods can work for harmonic spectra with near-stable harmonic amplitudes, but much equipment produces fluctuating harmonic amplitudes. The measurement bandwidth was nominally set at 3 Hz. (At that time, IEC 61000-3-2 did not exist: emission limits were specified in IEC (60)555-2, which was under revision in 1991.)

An editorial correction was published in 1994.

8.2 Second edition in 2002

This edition is very different from the first edition. Only digital methods are specified, and the scope was greatly changed. Instead of a "guide" the document is a "standard" and it is a complete and normative specification of a measuring instrument for testing individual items of equipment in accordance with emission limits (such as in IEC 61000-3-2), as well as for measurements in supply systems (see IEC 61000-4-30 [16]).

In spite of this profound change, the title of the document was not changed.

The basic measurement bandwidth was set at 5 Hz, but this was profoundly modified by the controversial introduction of "grouping" – summation of the measured values over 50 Hz (in 50 Hz systems) centred on each harmonic frequency. This effectively increases the measurement bandwidth from 3 Hz to 50 Hz, but there was no corresponding change of the emission limits in IEC 61000-3-2. This "grouping" change allows interharmonic emissions to be taken into account, but whether they should be summed with harmonic emissions is still a matter of debate. To resolve this issue on a temporary basis, a concession to use an instrument complying with the first edition was introduced, provided that its use was reported with the results.

An editorial correction was published in 2004.

8.3 Amendment 1 to the second edition

This very large amendment was published in 2008 after several years work in the responsible committee. Amendment 1 includes corrections to several mathematical expressions and symbols, new and revised definitions and many changes to the text and some figures.

The major changes and additions are:

- Various definitions are added, such as the group and sub-group total harmonic distortion $THDG_y$, and $THDS_y$.
- The partially weighted harmonic distortion is added – $PWHD_{h,y}$.
- Inter-harmonics measurements and inter-harmonic grouping are defined. Technical considerations for grouping are explained in an informative Annex C.
- A measurement window of 200 ms allows the same processing of 50 Hz and 60 Hz signals, with a 5 Hz spectral resolution. The digital 1,5 s LP filtering for 50 Hz and 60 Hz is defined.
- A transitional period that permits the use of instruments that adhere to the older 1991 version of IEC 61000-4-7 is included in the second edition with Amendment 1.

An informative Annex B explains the measurement methods up to 9 kHz, with grouping in 200 Hz intervals. Annex B also includes information on an artificial mains network (AMN) to facilitate measurements up to 9 kHz.

8.4 Developments since 2008

Various developments in the emission standards IEC 61000-3-2 and IEC 61000-3-12, require amendments and updates to the second edition with Amendment 1. The responsible committees have been working on various topics. Some of the work on a new edition was delayed due to ongoing discussion on what is called “grouped limits” for IEC 61000-3-2 [1], and possible impact on IEC 61000-4-7 (mainly whether or not IEC 61000-4-7:2002 and IEC 61000-4-7:2002/AMD1:2008, Clause 7, allowing the use of “edition 1” instruments can be deleted).

In summary, the agreed upon changes/additions include:

- A change in title of the standard to better reflect its content.
- Adding definitions for POHC (partial odd harmonic current) and POHV (partial odd harmonic voltage).
- Clear definition of the phase angle measurement and evaluation to support IEC 61000-3-12:2011, Table 4 and Table 5, and for general purposes of harmonic current assessment. Application examples are detailed in a new Annex D.
- Measurement methods of the partial odd harmonic current (POHC) which is specified in IEC 61000-3-2 for Class-A evaluations.
- Various editorial matters, some proposed by National Committees, and some required as IEC guidelines have changed or have been updated.
- Given the extensive changes, a new edition 3 of IEC 61000-4-7 will be published.

9 Economic considerations taken into account in setting limits in IEC 61000-3-2 before publication in 1995, and before the finalization of the text of the Millennium Amendment

Only passive mitigation was considered by IEC as economically practicable at that time, and only for single-phase equipment. Approximately €1 or $1 would be added to the production cost (not selling cost) for a TV-set, i.e. approximately 1 % to 2 % for high volume, not low-price products (a self-ballasted lamp is a typical low-price product).

The cost-sharing idea was implemented by the lower power bound of 75 W:

- no harmonics limits up to this power value; costs only to the supply system;
- existing harmonics limits beyond this power value; costs to both the product and the supply system (because the harmonic currents are not zero!).

This was considered in setting the limits in Table 3.

The limits of Table 1 and Table 2 were taken from the older European standard (EN 50006) into IEC (60)555-2. No definite information on economics is available for the limits in these tables. In the European Standard, the scope was restricted to household appliances, and experts from that sector were actively involved in the work. It might be assumed, therefore, that the economic effects of the introduction of the limits were acceptable at that time, by the parties involved.

During the preparation of the Millennium Amendment, consideration of economic aspects was intensified. As a result, many products were re-allocated from Class D to Class A (see 6.6).

Annex A
(informative)

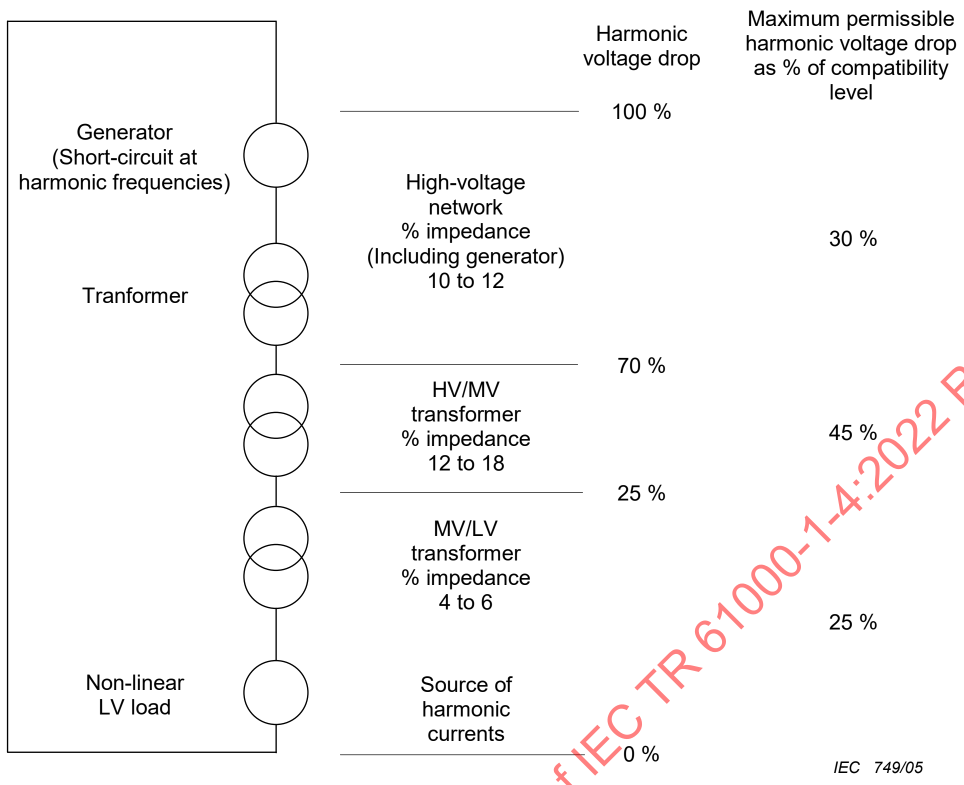
Compatibility level and compensation factor

A.1 Explanation of the allocation of only part of the total compatibility level to the low-voltage network

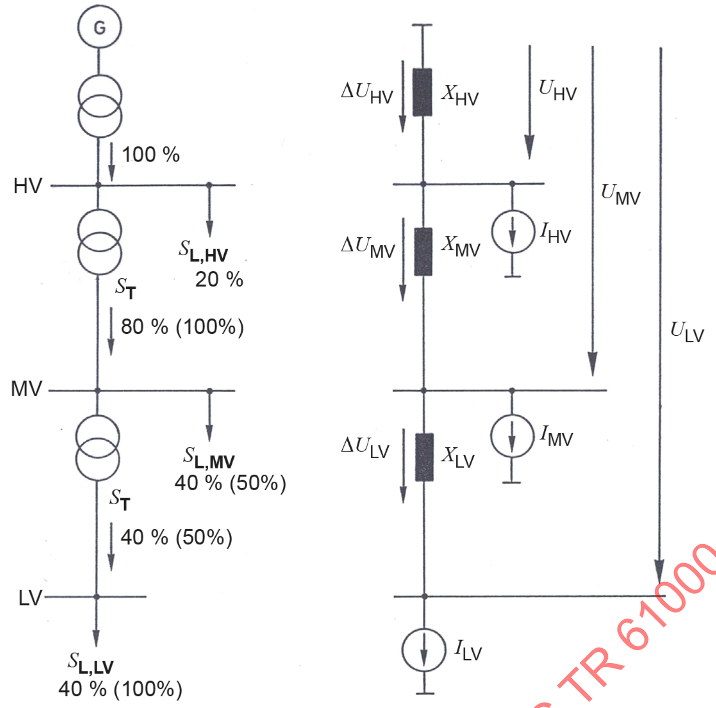
Harmonic distortion at LV-, MV- and HV-levels in the network is mainly produced by harmonic currents of non-linear loads installed in the LV-network. The resulting harmonic distortion in the LV-network is the geometrical sum of the harmonic voltage drops in the LV-network and in all superimposed MV- and HV-systems. According to IEC standards, the harmonic distortion in the LV-network shall not exceed the compatibility level given in IEC 61000-2-2.

Harmonic currents of non-linear loads in the LV-network, in the MV-network and in the HV-network produce harmonic voltage drops at the harmonic impedances of the LV/MV-transformer, of the MV/HV-transformer and of the HV-network including generator, respectively. The percentage harmonic voltage drops correspond approximately to the percentage transformer impedances which are given by the percentage short circuit voltage of each relevant transformer.

The typical percentage impedances in European networks are given in Figure A.1. The partition of the total compatibility level into the parts assigned to each voltage level reflects roughly the relation of these percentage impedances. In order to account for the geometric summation of the voltage drops, the share value of 25 % for the LV-network is increased with respect to the value which can be derived from the ratio of the impedance values. 25 % of the total LV compatibility level is therefore used in IEC 61000-3-2 and IEC 61000-3-12 for the assessment of the maximum harmonic currents from non-linear loads in the LV-network for 230 V 50 Hz systems.



~~**Figure A.1 – Allocation of harmonic voltage drops over the transformer impedances in a typical system**~~



⊚	AC voltage source (infinite power system source)
(transformer symbol)	Transformer symbol
S_G	Global power delivered by the integrated power system
$S_{\mathbf{L,HV}}$	Load power consumed by HV customers
$S_{T,MV}$	Transferred power from HV to MV
$S_{\mathbf{L,MV}}$	Load power consumed by MV customers
$S_{T,LV}$	Transferred power from MV to LV
$S_{\mathbf{L,LV}}$	Load power consumed by LV customer

Bold/Italic numbers show percent of global power

(Parentheses show percent of power from previous nearest bus)

IEC

Figure A.1 – Harmonic voltage drops and harmonic current injections in a typical system

NOTE The shares allocated to the three voltage levels are summed geometrically on the assumption that the phase angles are random.

A.2 Compensation factor

A.2.1 ~~Derivation from the model in Figure A.1~~ Maximum permissible current emission – original approach

~~From the model,~~ The maximum permissible current emission from equipment at each harmonic frequency can be shown to be:

$$i_{h,\mathrm{eq}} = u_{h,\mathrm{CL}} k_{N,\mathrm{LV}} / Z_{\mathrm{LV},h} k_{p,h}$$

where

h is the harmonic order;

$i_{h,\mathrm{eq}}$ is the maximum permissible current emission from equipment at harmonic h;

$u_{h,\mathrm{CL}}$ is the compatibility level for voltage distortion at harmonic h;

$k_{N,\mathrm{LV}}$ is the sharing factor for the LV network;

$Z_{\mathrm{LV},h}$ is the network impedance at harmonic h;

$k_{p,h}$ is the compensation factor for harmonic h.

A.2.2 Detailed consideration

$k_{N,\mathrm{LV}}$ is the value applicable in principle to very low-order harmonics, and its value is set at 25 % of the LV compatibility level, based on theoretical studies and measurements. $k_{p,h}$ is a compensation factor, which takes into account a certain probability of phase diversity for higher-order harmonics. For the lower-order harmonics, $k_{p,h}$ is only slightly less than 1 for supplies with low values of short-circuit current rating.

$k_{p,h}$ is composed of many sub-factors, and there is no generally-applicable analytic method for determining its values. The values used in the preparation of IEC 61000-3-2:1995 [1] (first edition) were as shown in Table A.1. The chance of compensation between different harmonic currents increases if the power drawn by the equipment emitting harmonic currents is small compared to the short circuit power R_{sc}. Therefore, $k_{p,h}$ depends on the factor R_{sce} (R_{sc} divided by the rated apparent power of the equipment, see IEC 61000-3-12) as given in Table A.1. R_{sce}= 33 is also taken to apply to IEC 61000-3-2.

Table A.1 – Compensation factors $k_{p,h}$ considered valid in 1995 (IEC 61000-3-2:1995 [1] (first edition))

R_{sce}	h = 3	h = 5	h = 7	h = 11	h = 13
33	0,9	0,85	0,75	0,65	0,65
66	0,8	0,75	0,6	0,5	0,5
120	0,68	0,65	0,45	0,35	0,35
175	0,62	0,55	0,35	0,25	0,25
200	0,6	0,5	0,3	0,2	0,2
250	0,55	0,45	0,28	0,18	0,18

NOTE 1 ~~The above values were taken from Table 3 of IEC 61000-3-6 and were assumed to apply in the general case, being derived in part from published papers.~~ For concentrations of equipment of the same type that produce harmonic currents with only small differences in phase (such as uncontrolled rectifiers with capacitive smoothing), values of $k_{p,h}$ nearer to 1,0 apply for low-order harmonics. See IEC TR 61000-3-6:1996, Table 4 (first edition) (This table does not exist in the 2008 edition (second edition)). ~~New investigations are in progress to verify the above values or to improve them.~~

NOTE 2 The tabled values in IEC 61000-3-2:1995 (first edition) were taken from Table D.1 in the extensive rationale in document 77A/164/CD. In other documents, the values were said to be derived from IEC TR 61000-3-6:1996, Table 3 (first edition) (not in the 2008 edition (second edition)) and were assumed to apply in the general case, being sourced in part from published papers. However, the "indicative"' values in that table have just one decimal place, and the dependencies on the R_{sce} values cannot be represented with sufficient accuracy by any reasonable function, making interpolation between the ($1/R_{\mathrm{sce}}$) values to determine the $k_{p,h}$ values for the R_{sce} values in Table A.1 very problematical. The values for R_{sce} = 32 were probably determined by negotiation. See 6.9.2.

If, in an individual case study, proper account for actual system impedances is made, $k_{N,\mathrm{LV}}$ can be calculated, so that $k_{p,h}$ becomes the only term subject to estimation. The root cause for any discrepancies between modelling and survey results ~~must~~ are then ~~be~~ isolated to this term alone. Table A.2, derived from [32], describes what might be considered a relatively complete set of sub-factors although it is possible to suggest others. Table A.2 also shows plausible ranges of values for these sub-factors, as well as for the composite compensation factor, $k_{p,h}$, which follows from combination of the individual sub-factors. As a first approximation, for Table A.2, the sub-factors are multiplied together to obtain the composite factor.

It should be clearly understood that, for some equipment and configurations, the listed factors ~~may~~ are not ~~be~~ always independent. The multiplication of the sub-factors to obtain the value of the composite factor is still valid if all but one member of a non-independent set of factors is set to the value 1.

Table A.2 – Sub-factors of $k_{p,h}$

Sub-factor	Estimated values for 5th harmonic factors		
	Low estimate	Typical value	High estimate
Non-linear load penetration factor [a]	0,1	0,14	1
Triplen factor [b]	1	1	1
System de-rating factor	0,75	1	1,5
Load diversity factor	0,5	1	1
L-L and L-N 3-phase factor [c]	0,23	1	1
Load phase diversity factor	0,4	0,44	1
System phase diversity factor	0,5	0,62	1
Voltage THD factor	0,85	1	1
Current division factor [d]	0,76	1	1
Resonance factor	1	1,6	4
Three-phase unbalance factor	1	1,1	1,25
Composite factor $k_{p,5}$	0,01	0,64	7,5

[a] The mix of linear and non-linear loads is not considered for calculation of composite $k_{p,h}$.

[b] Triplen cancellation in Δ-connected transformers is only applicable to the medium-voltage network.

[c] This factor ~~may~~ can result in significant cancellation for the 5th and 7th harmonics, but ~~may~~ can also be as high as 3,0 for triplen harmonics to account for summation in neutral conductors if all loads are connected L-N.

[d] This factor accounts for division of harmonic currents between the mains system impedance and the aggregate impedance of connected linear loads including capacitor banks.

Several conclusions ~~may~~ can be immediately drawn from Table A.2. First, wide swings in the value of $k_{p,h}$ follow from reasonable selections of values for included sub-factors. At the extremes, substitutions of apparently defensible values for $k_{p,h}$ result in estimates for permissible 5th harmonic emissions ranging from greater than 400 % of the fundamental current at one extreme to less than 0,7 % at the other. Both results are clearly absurd. Secondly, a decision to ignore a particular sub-factor (i.e. to set the sub-factor to 1,0) can significantly impact the value derived for $k_{p,h}$. The fact that several ways of combining many sub-factors, especially simple multiplication, contributes greatly to the possibility of wide swings in the value of $k_{p,h}$ might tempt the dismissal of concerns that only a subset is typically considered, but this conclusion can be shown to be unrealistic.

Work is on-going to develop formally-defined sub-factors (which ~~may~~ might or ~~may~~ might not be those in Table A.2). ~~The results of this work are intended to be reported in IEC 61000-1-X (to be published).~~

A.2.3 New work prompted by the preparation of this document

A.2.3.1 Rationale

Discussions have highlighted some issues with the text of the first edition of IEC TR 61000-1-4. Also, new documents concerning the subject of partitioning acceptable voltage distortion levels between LV, MV and HV have been discovered.

It should be clearly understood that this new work does not justify a widespread reconsideration of emission limits. Emission levels are approaching compatibility levels at some (but by no means all) locations. However, the work might help to resolve some specific issues that are at present under discussion.

A.2.3.2 Compensation factors – a simpler approach

Referring to the text and formula in A.2.1, $k_{N,\mathrm{LV}}$ is set to 25 % of the total LV compatibility level and is used in IEC 61000-3-2 and IEC 61000-3-12 for the assessment of the maximum harmonic currents from non-linear loads in the LV-network for 230 V 50 Hz systems.

The formula includes "$k_{N,\mathrm{LV}}$", a constant for all harmonics, which seems counterintuitive. Also, it is derived from a very greatly simplified model of a complete HV-MV-LV distribution system, and thus includes numerous assumptions. Different, justifiable assumptions can result in very different values of $k_{N,\mathrm{LV}}$.

The subject is in fact very confusing, because there are two linked quantities, $k_{N,\mathrm{LV}}$ and $k_{p,h}$, which modifies $k_{N,\mathrm{LV}}$ for every harmonic, according to the values in Table A.1. It is really more clear to define a "compensated sharing factor", $C_{\mathrm{LV},p,h} = k_{N,\mathrm{LV}}/k_{p,h}$, which does vary with the harmonic order, as would be expected.

The justifications for reconsidering sharing are based on the following reasoning: even and triplen order harmonics are normally very small on European HV- and MV-systems and are not problematic, except in the case of neutral currents in four-wire three-phase networks.

Reasons for not considering the partition of even orders (see [17] and [18]):

- equipment directly connected to MV-/HV-systems is normally of the symmetrical three-phase type which does not produce these harmonics, except in rare failure cases;
- since unsymmetrical controls and half-wave rectification are normally not allowed for LV-system appliances, the upstream even order currents are small;
- on the MV-level, there is a good chance of compensation of even order harmonics originating from half-wave rectification since a lot of LV-systems are connected and, therefore, the polarity of these rectifiers comes close to 50 %:50 %.

Reasons for not considering the partition of triplen orders:

– low triplen order harmonics (3rd and 9th) regularly exist as zero-sequence systems and are not transferred by star/delta-transformers which are typical in European distribution networks (neither upstream the currents nor downstream the voltages);

– irregular triplen order harmonics which exist in positive- and negative-sequence systems are normally small.

From the known tolerable voltage distortion and the effective supply impedance, the resultant current limit can be determined for each harmonic order. The effective supply impedance cannot be strictly calculated, because it is affected by every load connected to a feeder, so it varies with location and time. The LV-system supply impedance at the supply frequency can be taken as the reference value from IEC TR 60725 [10]. For the lower order harmonics, the inductive component is found to be proportional to frequency, but above the 10th harmonic it tends to be proportional to the square root of the frequency, due to the resistive components of other loads on the same feeder. See [19] and [20]. The resistive component of the impedance is small compared with the inductive component, except for the very low-order harmonics.

Loads that include large contributions from switching power supplies with regulated DC outputs have input impedances with incremental negative resistance (since if the supply voltage falls, the input current increases to keep the DC power output constant). The presence on a feeder of several lightly-loaded switch-mode power supplies (stand-by operation) leads to a significant capacitive component of the impedance, reducing its value at high harmonic frequencies still further.

Recent large-scale data collection in Germany, the results of which were analysed in Canada, indicates that the new values of the compensated sharing factor given in Table A.3 are admissible.

Table A.3 – Compensated sharing factors

Harmonic	Compensated sharing factor %	Harmonic	Compensated sharing factor %
5	20	23	51
6	22	24	53
7	23	26	56
8	25	27	58
10	29	28	59
11	30	29	61
12	32	31	65
13	34	32	66
16	39	33	68
17	41	34	70
18	42	36	73
19	44	37	75
21	47	38	77
22	49	40	80

For odd-order triplen harmonics a compensated sharing factor of 45 % is admissible.

A.2.3.3 Comparison of compatibility levels and Class A emission limits

NOTE 1 The Class B limits are simply derived from the Class A limits, but this theoretical basis does not apply to the Class C and Class D limits.

Historically, the logical starting point would have been immunity data of existing products and distribution system components, which in turn would have allowed compatibility levels of voltage distortion, for each voltage level and each harmonic order, to be determined. But insufficient data were available. Instead, higher statistical values of the existing voltage distortion levels were assumed to be generally tolerable and were adopted as compatibility levels. See [19].

It should be clearly understood that compatibility levels are set by considering the voltage distortions that can be tolerated, not by a calculation process. For current and future studies, the standardized compatibility levels are taken as the starting point. However, each LV compatibility level can incorporate contributions from MV and HV voltage distortions, so only a share of the LV compatibility level can be taken up by LV products.

NOTE 2 The shares allocated to the three voltage levels are summed geometrically on the assumption that the phase angles are random.

From the known tolerable voltage distortion and the effective supply impedance, the resultant current limit can be determined for each harmonic order. The effective supply impedance cannot be strictly calculated, because it is affected by every load connected to a feeder, so it varies with location and time. The LV-system supply impedance at the supply frequency can be taken as the reference value from IEC TR 60725. For the lower order harmonics, the inductive component is found to be proportional to frequency, but above the 10th harmonic it tends to be proportional to the square root of the frequency, due to the resistive components of the other loads on the same feeder. See [20] and [21]. The resistive component of the impedance is small compared with the inductive component, except for the very low-order harmonics.

However, very recent analysis of data from real networks, which has never been available in such detail before, indicates that the above reasoning cannot be fully accepted as its conclusions differ somewhat from measured values. Because both the sharing factor and the supply impedance vary with time and place, only "typical values" can be used, with no claim to represent the situation at any particular place or time.

A.2.3.4 Effective supply impedance at harmonic frequencies

The original rationale connecting current emission limits with tolerable voltage distortions was in IEC (60)555-2:1982, IEC (60)555-2:1982/Amd1:1985, and IEC (60)555-2:1982/Amd2:1988: Clause 4 and Annex A.

Annex A includes the following text:

> In preliminary work, the interference level of a piece of equipment and the corresponding limits were expressed as voltage harmonic ratios. These voltage harmonic ratios are those produced by a single piece of equipment supplied at rated voltage at the terminals of a conventional network presenting specific internal impedances, called reference impedances.
>
> At a later date, current limits were adopted in order to simplify and clarify the presentation of this standard.
>
> For single-phase equipment with 200 V to 260 V, 50 Hz, rated voltage, the current limits of this standard are in accordance with the following voltage harmonic ratio limits [now included in the more comprehensive Table 1 below] if the reference impedance at each harmonic frequency is equal to (0,4+ j n 0,25) Ω (n being the order of the harmonic).
>
> The values of reference impedances and voltage harmonic ratios indicated above should in no way be considered as typical values or guideline values for low-voltage distribution systems. They are solely used for the appreciation of disturbances due to equipment.

However, loading of the feeder by other equipment than that being measured should obviously be taken into account. It is reasonable to take near-worst-case conditions, i.e. a very light additional load on the feeder, and a value of 10 Ω resistive is adopted.

The results of the comparison of the Class A emission limits with the supply impedance including an additional 10 Ω parallel load are shown in Figure A.2. The additional 10 Ω represents only 5,29 "average" consumers at 1 kW each. For fewer such loads, the number of Class A loads that can be connected falls to zero at the 27th, 33rd and 39th harmonics, but this is likely to be a very rare occurrence.

NOTE 1 It is reasonable to consider the parallel load as purely resistive because of the modern emphasis on high power factor. Also, some loads are capacitive, therefore opposing the phase-shift due to inductive loads.

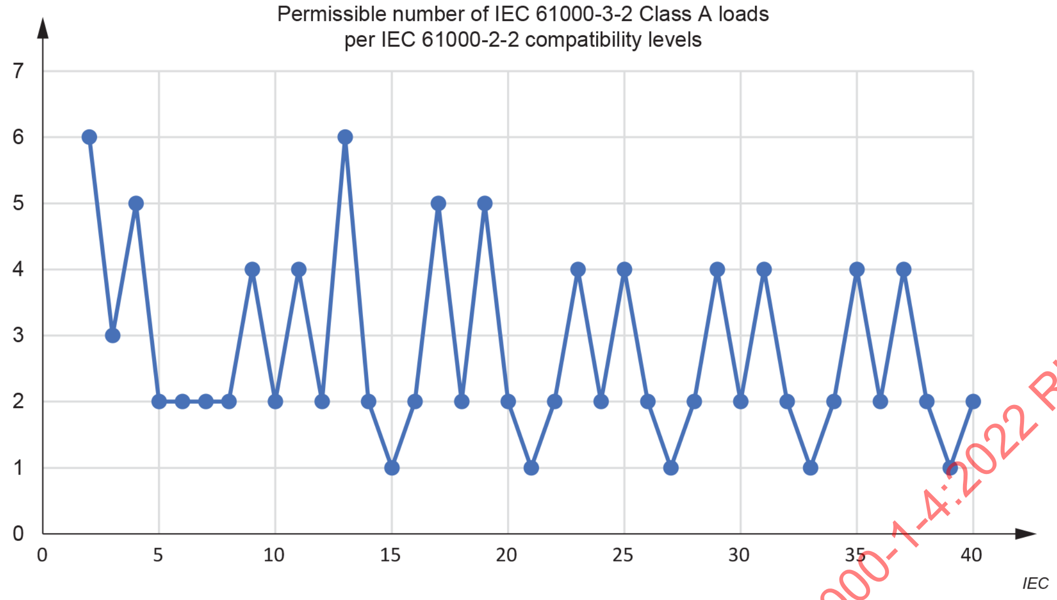


Figure A.2 – Permissible number of Class A loads versus harmonic order, with an additional 10 Ω load on the feeder

NOTE 2 The assumed load is deliberately not realistic, since it just meets the Class A limit for every harmonic.

Annex B
(informative)

Comparison of Class A limits and the harmonic spectra of phase-controlled dimmers of incandescent lamps at 90° firing angle

NOTE Although incandescent lamps are now used only if no practical alternative exists, Annex B is retained as a historical record.

The harmonic spectra of phase-controlled dimmers of incandescent lamps at 90° firing angle (at which the harmonic current emissions are greatest) vary very little from one product to another, and the Class A limits are specified as currents. It is therefore possible to deduce from each limit value the corresponding value of fundamental current. It can be shown (see Figure B.1) that the lowest fundamental current is determined by the limit for the 15th harmonic, and this corresponds to a full-load power of 745 W. Limits for the lowest harmonics are less stringent, no doubt due to changes to accommodate non-linear loads other than dimmers.

Figure B.1 illustrates this relationship, using a logarithmic vertical scale to show the high-order harmonic limits and levels clearly. For comparison, the measured spectrum of a typical dimmer of 1970s design (before conformity with EMC standards was mandatory) is shown, the load being a 230 V 150 W lamp and the firing angle 90°. It can be seen that for harmonics above the 13th, the correspondence between limit values and spectrum levels is quite good. The slightly higher levels of 19th and 27th harmonics from the measured dimmer ~~may~~ can be due to distortion of the supply voltage or perhaps resonance between the "rise-time" inductor in the dimmer and the capacitor for attenuating conducted emissions.

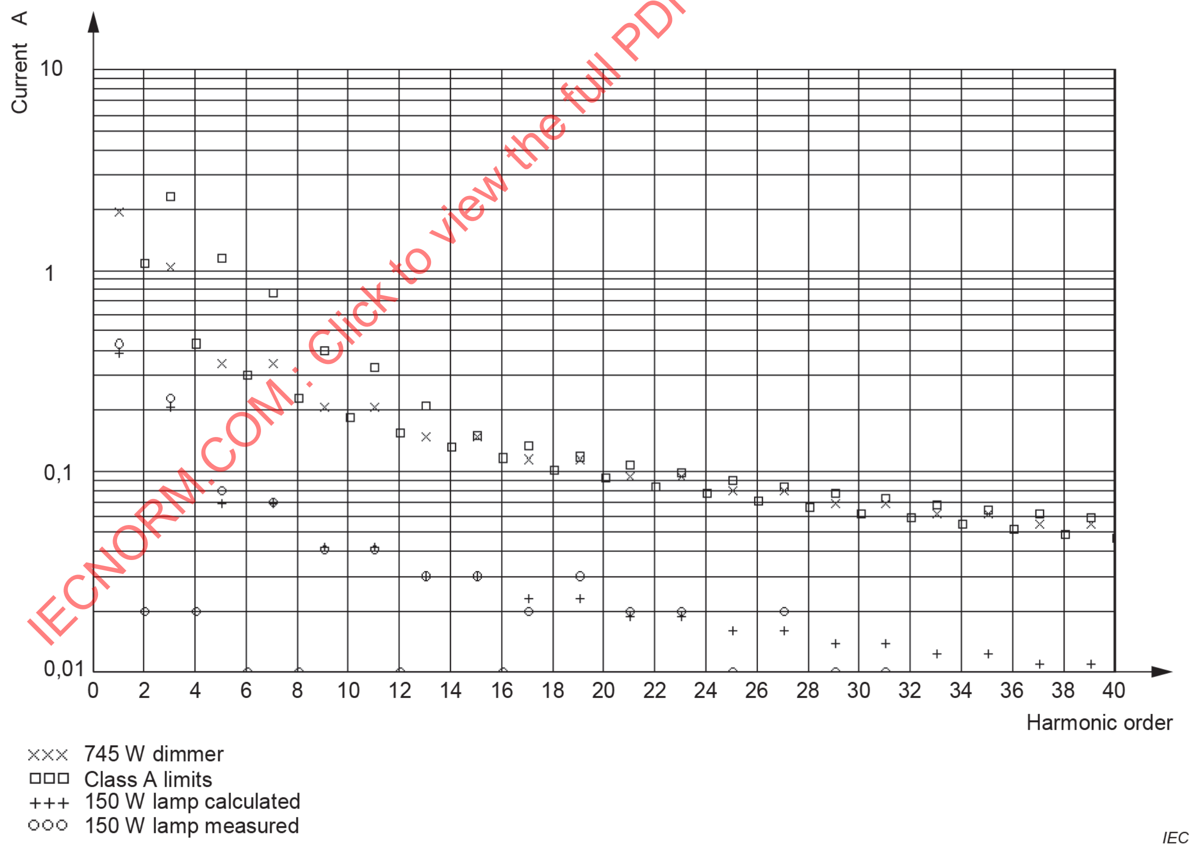


Figure B.1 – Comparison of Class A limits and spectra of dimmers

Annex C
(informative)

Comparison of Class C (IEC 61000-3-2:2018 and IEC 61000-3-2:2018/AMD1:2020, Table 2) limits and the harmonic spectrum of a discharge lamp with inductive ballast

NOTE Although this technique is no longer widely used, Annex C is retained as a historical record.

Figure C.1 is self-explanatory.

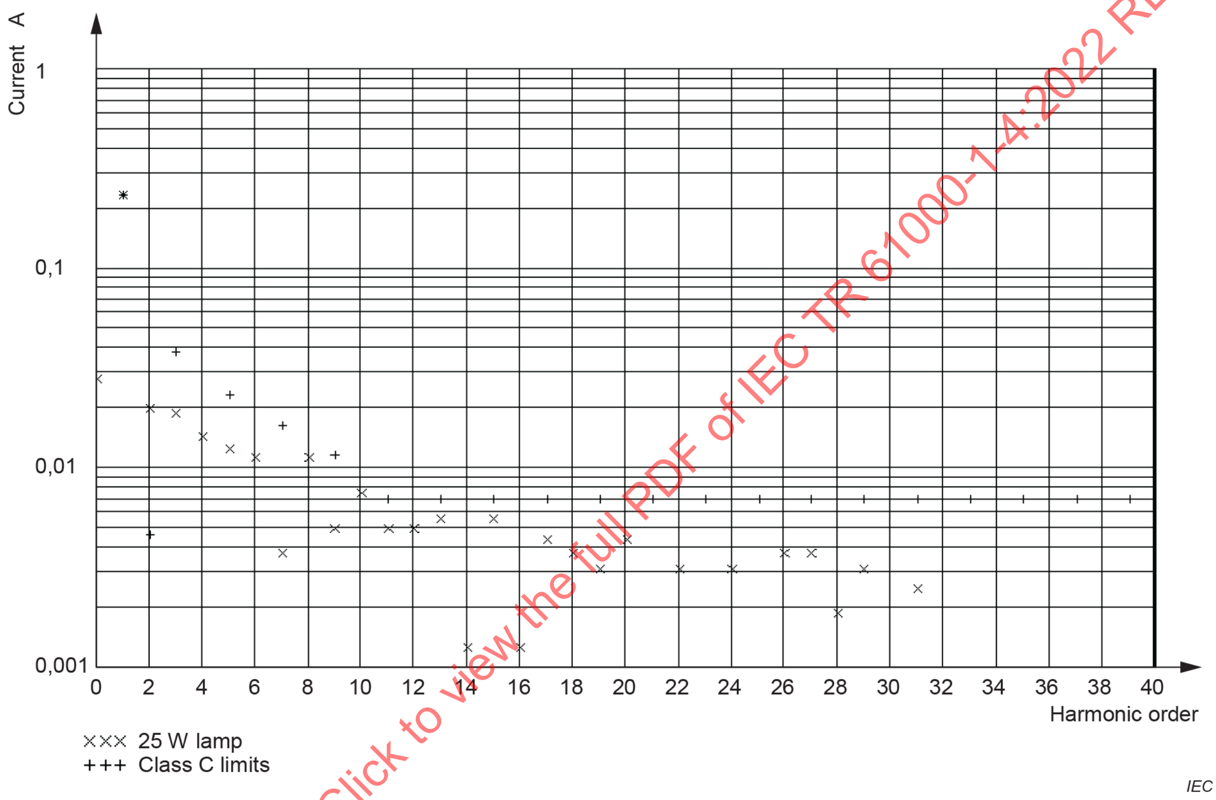


Figure C.1 – Comparison of Class C limits and the harmonic spectrum of a discharge lamp

Annex D
(informative)

Comparison of Class D limits and the harmonic spectra of capacitor-filtered single-phase rectifiers with 35° and 65° conduction angles

NOTE Although this technique has largely fallen out of use, Annex D is retained as a historical record.

Figure D.1 is largely self-explanatory. Note that the 3rd and 5th harmonic levels for the 65° conduction angle coincide with the limits.

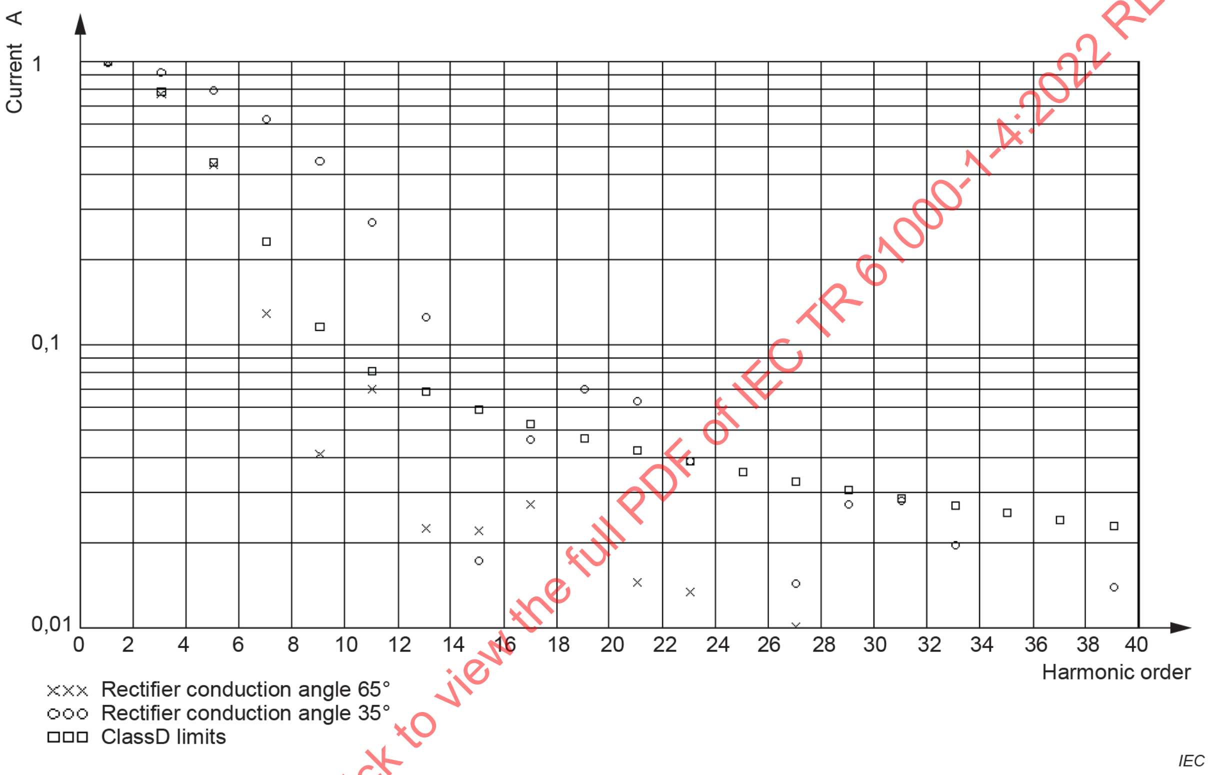


Figure D.1 – Comparison of Class D limits and harmonic spectra of single-phase 230 W rectifiers with capacitor filters

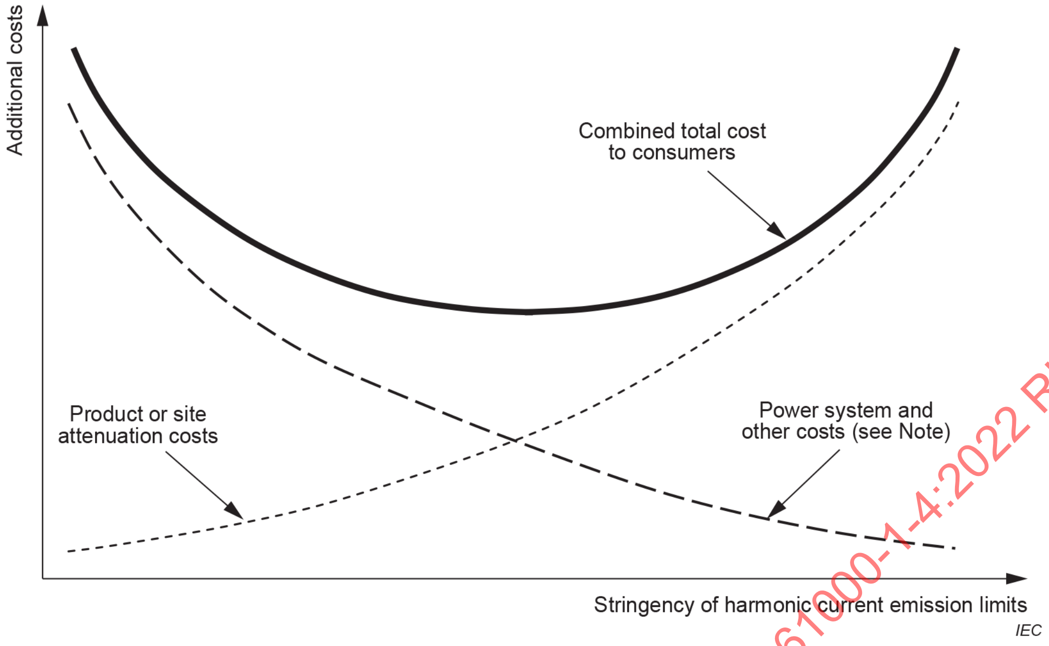
Annex E
(informative)

Economic considerations taken into account in setting limits, before finalization of the text of the Millennium Amendment to IEC 61000-3-2

Passive mitigation techniques typically yield less complete mitigation of harmonic emissions, but generally are less costly to implement compared with active methods. Until very recently, passive filtering was the only feasible method for high-power applications from a cost standpoint. Recent advances in power semiconductor devices and digital signal processing have made the use of active mitigation techniques more cost effective. Considered in aggregate, the average cost for implementing high performance, active mitigation using present-day techniques in a wide variety of high volume products (except low-cost products such as lamps) is estimated to be between 1 % and 2 % added to the end user's purchase price. It is not expected that these percentages will change substantially in the foreseeable future. Actual costs vary widely by product type. For example, incremental costs are a small percentage added to the purchase price for personal computers, but 60 % or more added to the purchase price of three-phase variable speed drives.

Experts from the product manufacturing sector estimate aggregate costs for implementing high performance active mitigation for all electrical and electronic products to be a very large sum annually. The consequence of this would be that harmonic voltage level be reduced very significantly. Experts from the electricity supply industry, for their part, have estimated that annual costs attributed to the effects of harmonic emissions would be comparable in future, if there were no harmonic emission limits at equipment or site level. With substantial sums at stake, it becomes very desirable to carefully consider how best to optimise the selection of mitigation options in order to rationally minimise total aggregate costs. Figure E.1 captures the basic concept of optimising a trade-off between excessive costs arising from attempts to address the problem in a single dimension. It is widely recognized that it is inappropriate to rely entirely on product mitigation or, conversely, on making the supply system capable of sustaining any level of emissions from equipment by, for example, reducing the system impedance to a negligible level. It is also widely recognized that it is inappropriate to attempt to reduce a phenomenon, for example voltage distortion, to an unnecessarily low level. In some countries, due to problems related to fair cost-sharing, the incremental cost associated with system-level mitigation is accepted only if it enables a much greater reduction in incremental costs which would otherwise be associated with mitigation at the equipment or site level.

NOTE In some countries, the electricity supply industry places reliance on IEC 61000-3-2 to control emissions at the equipment level. This is said to eliminate a need to install mitigation equipment at the site or system level, thus allocating the cost of mitigation to the origin of the harmonic distortion.



NOTE Most of the “power system and other costs” are power system costs.

Figure E.1 – Illustration of the concept of total aggregate cost trade-offs for meeting compatibility levels

Annex F
(Informative)

Concept plan for a full revision of IEC 61000-3-2

NOTE This concept plan is intended to be used also for a future edition of IEC 61000-3-12.

F.1 ~~Introduction~~ Rationale

~~NOTE The rationale for the full revision of IEC 61000-3-2 is given in IEC 61000-1-X (to be published).~~

It was agreed to base the study on the allocation of limits based on a composite "impact factor" of a product on the voltage distortion of the supply network. A number of components of this factor were identified and are listed below. This is not a new concept; a "saturation factor" and a "simultaneity factor" were used in [22].

F.2 Density

The density impact factor is intended to take into account the equipment impact related to the total number of pieces of equipment that are in the field. The density impact factor is assessed for each type of equipment. It is defined as the ratio of the number of pieces of equipment to the number of households.

NOTE Consideration of density allows the burden of strict limits to be removed from rare equipment.

F.3 Usage factor

The usage impact factor is intended to take into account differences of the impact on the network, related to the usage of equipment. Basically it can be calculated from the ratio of the electrical energy consumed per year to the maximum active power during normal use.

Additional correction factors consider the simultaneity of use, for example per day or per season of the year.

NOTE Consideration of usage allows the burden of strict limits to be removed from little-used equipment.

F.4 Contribution

The harmonic contribution factor attempts to capture the potential impact of the entire spectrum of the harmonic emissions from a particular type or general class of equipment. The ratio of the non-linear portion to the fundamental current is used to define the harmonic "contribution" factor with sufficient accuracy to define the potential impact of a particular type or general class of equipment.

For the purposes of assessing the impact of harmonic "contribution" where measurements are employed, any reasonably accurate and repeatable method should be suitable. However, it is generally preferred that methods as defined in IEC 61000-3-2:2018 (second edition) are employed to obtain average emission values.

F.5 Phase angle factor

The phase angle of the harmonic current has been selected as a relevant impact factor, because this has an influence on the network voltage distortion. For example, considering two pieces of equipment connected on the same network, there is a cumulative or a cancellation effect on the distortion of the network voltage, depending on the relative phase angles of their harmonic currents.

Equipment with a phase angle factor less than 1 should have more relaxed limits, as their impact on the network distortion is lower.

F.6 System and site mitigation

In order to achieve an optimum economic accommodation of non-linear loads on the low-voltage electricity supply network, all possible technical measures should be assessed. Mitigation of the effects of harmonic currents at system level is technically very complex and can involve high capital costs, but some measures (such as the reduction of system impedance) are employed where justified. Mitigation at site level, where the interface with the public electricity supply is a medium- or high-voltage, ~~may~~ can have economic advantages over mitigation at equipment level, but its introduction depends on the practicability of ensuring that agreed emission limits are respected, and the co-operation of electricity suppliers and government agencies. It has been introduced in some countries. Site level mitigation is extremely unlikely to be practicable for small and residential sites.

F.7 Network factors

Network factors are included within the impact factor assessment to take into account the electrical characteristics of the network, operation of the network, and the interaction of the loads on the network. Network factors are a function of the network design, network operation, interaction of the network loads, and the restraints imposed upon the network operators.

NOTE Consideration of these factors allows the burden of strict limits to be removed from some types of equipment.

Annex G
(informative)

Derivation of the limits in IEC 61000-3-12

G.1 Formulae connecting the voltage drop and the short-circuit ratio

In this document, the rated single phase voltage U_p is written V, and the rated interphase voltage U_i is written U. The line impedance Z of the network is written Z_L and the neutral impedance of the network is written Z_N.

Short-circuit power:

$$S_{sc} = \frac{U^2}{Z}$$ (U = phase to phase voltage; Z = network phase impedance)

Short-circuit ratio:

Single phase: $R_{sce} = \frac{S_{sc}}{3.S_{equ}}$ with: $S_{equ} = V.I_{equ}$

Three phase: $R_{sce} = \frac{S_{sc}}{S_{equ}}$ with: $S_{equ} = \sqrt{3}.U.I_{equ}$

Voltage drop per phase:

Single phase: $$\Delta V \leq \left|\overline{Z}_L + \overline{Z}_N\right|.I_{equ} = \left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot Z_L \cdot I_{equ} = \left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot \frac{U^2}{S_{sc}}.I_{equ}$$

$$\Delta V \leq \left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot \frac{U^2}{3.S_{equ}.R_{sce}}.I_{equ} = \left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot \frac{V}{R_{sce}}$$

$$\boxed{\frac{\Delta V}{V} \leq \left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot \frac{1}{R_{sce}}}$$

Three phase: $$\Delta V \leq Z_L \cdot I_{equ} = \frac{U^2}{S_{sc}} \cdot I_{equ}$$

$$\Delta V \leq \frac{U^2}{S_{equ}.R_{sce}}.I_{equ} = \frac{U^2}{\sqrt{3}.U.I_{equ}.R_{sce}}.I_{equ}$$

$$\frac{\Delta V}{V} \leq \frac{1}{R_{sce}}$$

It is assumed that the maximum voltage drop at the fundamental frequency is 3 %.

For single phase equipment $\Delta V/V \leq 3$ % if $R_{sce} \geq 55$ (assuming that $\left|\overline{Z}_L + \overline{Z}_N\right| / Z_L = 5/3$).

For three phase equipment, $\Delta V/V \leq 3$ % if $R_{sce} \geq 33$.

As most of equipment with input current above 16 A is three phase equipment, the minimum R_{sce} value is chosen equal to 33.

G.2 Approximate formula connecting harmonic current, harmonic voltage and short-circuit ratio R_{sce} at the PCC level

Assuming that Z_L or Z_N is purely inductive: $Z_5 = 5.Z_1$

For single phase:

The 5th harmonic voltage (per phase) is:

$$V_5 = 5.\left|\overline{Z}_L + \overline{Z}_N\right|.I_5$$

$$V_5 = 5 \cdot \left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot Z_L \cdot I_5 = 5.\left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot \frac{U^2}{3.S_{equ}.R_{sce}}.I_5 = 5.\left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot \frac{3.V^2}{3.V.I_{equ}.R_{sce}}.I_5$$

$$\frac{V_5}{V} = \left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot \frac{5}{R_{sce}} \frac{I_5}{I_{equ}}$$

Using percentages: $v_5(\%) = \frac{V_5}{V}$ $i_5(\%) = \frac{I_5}{I_1}$

And assuming $I_{equ} \approx I_1$, we obtain:

$$v_5(\%) = \left|\frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L}\right| \cdot \frac{5}{R_{sce}}.i_5(\%)$$

For three-phase:

The 5th harmonic voltage (per phase) is:

$$V_5 = 5.Z_L.I_5$$

$$V_5 = 5.\frac{U^2}{S_{equ}.R_{sce}}.I_5 = 5.\frac{U^2}{\sqrt{3}.U.I_{equ}.R_{sce}}.I_5 = 5.\frac{V}{R_{sce}}.\frac{I_5}{I_{equ}}$$

With the same assumptions as for single phase, we obtain: $v_5(\%) = \frac{5}{R_{sce}} . i_5(\%)$

For any harmonic order h:

Single phase: $v_h(\%) = \left| \frac{\overline{Z}_L + \overline{Z}_N}{\overline{Z}_L} \right| \cdot \frac{h}{R_{sce}} . i_h(\%)$

Three phase: $v_h(\%) = \frac{h}{R_{sce}} . i_h(\%)$

G.3 Total and partial weighted harmonic distortion

These concepts are used in IEC 61000-3-12. For an explanation of their purpose, see Annex H.

G.4 Emission limits for R_{sce} = 33

The limits have been established using the following assumptions:

a) proportional limits are adopted;

b) ¼ of the compatibility level is not exceeded when one single piece of equipment is connected;

c) consequently, the maximum value for the 5th harmonic voltage v5 is 1,5 % (compatibility level = 6 %);

d) for three phase equipment, using the above formula with R_{sce} = 33 gives a limit for i5 equal to 9,9 %;

e) in order to avoid discontinuity with the existing standards, the limit for the 5th harmonic has been aligned with the class B limit of IEC 61000-3-2 at 16 A, which is 10,7 %;

f) the limits for single phase equipment have been aligned on those for three phase equipment;

g) the limits for all harmonic orders for R_{sce} = 33 have been aligned on the class B limits of IEC 61000-3-2 at 16 A (see Tables G.4 to G.6).

G.5 Emission limits for R_{sce} greater than 33

G.5.1 Assumptions for the LV-system

a) A transformer feeds into a busbar with n outgoing identical feeders of the same length.

b) The feeders have the same cross section over the total length; the feeder impedance increases linearly with the distance from the busbar.

c) The maximum 3-phase impedance is that at the far end of each feeder. It corresponds to the minimum short circuit ratio $R_{sce,min}$ = 33. Loads with higher power may not be connected at this "far end" point. The "far end" impedance may be considered as the 3-phase reference impedance: $Z_{ref,3p}$ = |0,24 + j 0,15| Ω = 0,283 Ω.

d) The "far end" impedance for the harmonic order h is $Z_{max,h}$ =|0,24 + jh 0,15| Ω, e.g. 0,79 Ω for h = 5.

e) The harmonic impedance at the busbar, $Z_{B,h}$, corresponds to h times the transformer short circuit impedance. Example: h = 5, transformer data: $U_{n,Tr}$ = 400 V; $S_{n,Tr}$ = 400 kVA; Z_{Tr} % = 4 %, $Z_{B,h} = Z_{Tr,h} = h\ Z_{Tr}\ U_n^2 / S_{n,Tr}$ = 5 × 0,04 x (400V)²/(400kVA) = 0,08 Ω.

f) The busbar impedance, $Z_{B,h}$, is the fraction x_{min} of the "far end" impedance: $x_{min} = Z_{B,h} / Z_{max\ h} \approx 0{,}1$. The same fraction x_{min} is assumed to be valid also for the fundamental, i.e. the busbar impedance corresponds to $R_{see,max} = R_{see,min} / x_{min} \approx 330$.

g) The busbar is considered as a node on a fictitious feeder at the distance x_{min} from an ideal source with Z_{se} = 0, see Figure H.1b. The total length of the fictitious feeders is "1". The total length of the real feeders corresponds to $(1 - x_{min})$ on the fictitious feeder. The node at x_{min} is common for all fictitious feeders and represents the busbar.

h) A disturbing load is connected to one of the fictitious feeders at the point x ($x_{min} \le x \le 1$) and injects a constant harmonic current I_h at this point.

i) Customers installations are connected in uniform distribution along each feeder.

G.5.2 Description of the physics

The caused harmonic voltage increases linearly from the ideal source ($U_{x=0}$ = 0) up to the connection point "x" (U_x) and remains then constant up to the end "1" of the fictitious feeder to which the load is connected, see Figure H.1b. The highest voltage U_{max} is reached if the load is connected at the far end. The voltage at the point "x" is $U_x = x\ U_{max}$, and the busbar voltage is $U_B = x_{min}\ U_{max}$. The busbar voltage is impressed to the remaining $(n - 1)$ feeders and remains constant along these feeders.

G.5.3 Total distorting weight (TDW)

The following equations are used in order to calculate the "total distorting weight (TDW)" of the disturbing load depending on the point "x" where it is connected. The TDW describes the total impact of the disturbing load to all installations in the network. The TDW can be considered as the sum of all "voltage • length" – areas over all feeders in the network, see Figure H.2. Three areas of different shape exist (see Figure H.1b):

– Identical area for each of the n fictive feeders:

$A_1 = U_B \bullet (1 - x_{min}) = x_{min} \bullet U_{max} \bullet (1 - x_{min})$

– Area of linear increase from x_{min} to x on the feeder with the load:

$A_2 = (x - x_{min}) \bullet U_{max} \bullet (x - x_{min}) / 2 = U_{max} \bullet (x - x_{min})^2 / 2$

– Area of constant voltage from x to "1" on the feeder with the load:

$A_3 = (x - x_{min}) \bullet U_{max} \bullet (1 - x)$

The TDW as a function of x is given by

$$\mathrm{TDW}(x) = n \bullet A_1 + A_2 + A_3$$

$$= U_{max} \bullet [n \bullet x_{min} (1 - x_{min}) + (x - x_{min})^2 / 2 + (x - x_{min}) \bullet (1 - x)]$$

$$= U_{max} \bullet [n \bullet x_{min} (1 - x_{min}) + (x - x_{min}) \bullet (1 - (x + x_{min}) / 2)] \quad (1)$$

The maximum value of $\mathrm{TDW}_{x=1}$ is reached if the load is connected to the far end x = 1:

$$\mathrm{TDW}_{x=1} = U_{max} \bullet [n \bullet x_{min} (1 - x_{min}) + (1 - x_{min})^2 / 2] \quad (2)$$

The TDW_x at the point x can be related to the maximum $TDW_{x=1}$ and gives the relative $tdw(x) = TDW_x / TDW_{x=1}$:

$$tdw(x) = \frac{n \bullet x_{\min} + \frac{x - x_{\min}}{1 - x_{\min}} \bullet (1 - (x + x_{\min})/2)}{n \bullet x_{\min} + \frac{1 - x_{\min}}{2}} \tag{3}$$

The parameter x can be expressed by R_{sce} using the following equation if always the same load at different points x is considered:

$$R_{sce} = 33 / x \tag{4}$$

The relative total distortion weight "tdw", depending on the connection point x, is calculated for $x_{\min}$ = 0,1 and n = 3, 4 and 5 feeders in the following Table G.1 and shown in Figure H.2.

Table G.1 – Relative total distortion weight depending on the point x where the distorting load is connected

x	R_{sce}	tdw		
		n = 3	n = 4	n = 5
0,1	330	0,400	0,471	0,526
0,2	165	0,526	0,582	0,626
0,3	110	0,637	0,680	0,713
0,5	66	0,815	0,837	0,854
0,7	47	0,933	0,941	0,947
1,0	33	1,000	1,000	1,000
x = 0,1: connection at the busbar; x = 1: connection at the far end of a feeder R_{sce} is valid for the point x n: number of feeders outgoing from the busbar				

G.5.4 Approximation for the relative total distortion weight

The curves in Figure H.2 can be approximated by the function

$$tdw = 1 / (R_{sce} / 33)^{\alpha} \tag{5}$$

The exponent α depends on the number n of the feeders:

- α = 0,40 for n = 3
- α = 0,33 for n = 4
- α = 0,28 for n = 5

G.5.5 Relation between the relative total distortion weight and the limits

The distortion in a total LV system, produced by a load, is proportional to the harmonic current of the load, I_h, and to the relative total distortion weight tdw_x depending on the connection point

x. Two loads at different connection points x_1 and x_2 should not exceed the same "total distortion":

$$I_{h,x1} \bullet tdw_1 = I_{h,x2} \bullet tdw_2$$

The equation can be rewritten into:

$$I_{h,x2} / I_{h,x1} = tdw_1 / tdw_2 \qquad (6)$$

If $I_{h,x1}$ denotes the harmonic current limit for a load connected to the „far end" (x_1 = 1 or R_{sce} = 33) then the harmonic current limit for a load connected to a point $x_2 = x < 1$ (or R_{sce} /x > 33) is given by:

$$I_{h,\lim,x} = (tdw_{x=1} / tdw_x) \bullet I_{h,\lim,x=1} = (1 / tdw_x) \bullet I_{h,\lim,x=1} \qquad (7)$$

Using the approximation (5), the equation (7) can be rewritten into:

$$I_{h,\lim,x} = (R_{sce} /33)^{\alpha} \bullet I_{h,\lim,x=1} = (R_{sce} /33)^{\alpha} \bullet I_{h,\lim,Rsce = 33} \qquad (8)$$

Equ. (8) relates the limits of the harmonics, depending on R_{sce}, to the limit value at R_{sce} = 33.

G.5.6 Limits in IEC 61000-3-12, Table 2 depending on R_{sce}

The limits in IEC 61000-3-12 related to single-phase equipment are taken for comparison with Equation (8). Table G.2 contains, as an example, the limits for the orders 5 and 7 and the result of Equation (8) for α = 0,3.

This value α = 0,3 is the average for LV-systems having 4 or 5 main feeders which reflects the reality. Original limits and approximated limits fit well together, see Table G.2.

Table G.2 – Comparison of limit values of IEC 61000-3-12 (columns 2 and 4) with the approximation by equation (8) (columns 3 and 5)

R_{sce}	I_5 Table 2	I_5 Equ.(8) α = 0,3	I_7 Table 3	I_7 Equ.(8) α = 0,3
33	10,7	10,7	7,2	7,2
66	13	13,2	8	8,9
120	15	15,8	10	10,6
250	20	19,6	13	13,2
350	24	21,7	15	14,6

The higher exponent α for higher harmonic orders takes the phase angle diversity between different loads into account; the limits for high R_{sce} values increase stronger. This is especially true for balanced three phase equipment where the phase angles normally differ from those of single-phase equipment.

G.5.7 Summary

It is shown that the assumed condition 'equal total distortion weight in a LV-system' leads to a relation between limit values and R_{sce} values which can be found in the existing report IEC 61000-3-4 and IEC 61000-3-12.

The limits have been established using the other following assumptions:

a) proportional limits are adopted;

b) higher limits are admissible for three-phase equipment than for single phase equipment (see tables G.4 and G.5), as the network impedance is lower for three phase equipment (Z_L) than for single phase equipment ($Z_L + Z_N$);

c) higher limits are admissible for special types of three-phase equipment (see tables G.5 and G.6), to take into account the compensation effect due to these types of equipment;

d) for simplification, linear functions of R_{sce} with rounded numbers have been adopted.

G.6 Voltage distortion

G.6.1 Voltage distortion produced by one piece of equipment at the PCC level:

In Tables G.4 to G.6, all the harmonic voltages are given, calculated from the formulas given in G.2, for different values of R_{sce}.

For single phase equipment, it is assumed that: $\left|\overline{Z_L} + \overline{Z_N}\right| / Z_L = 5/3$

G.6.2 Voltage distortion produced by *n* pieces of equipment at the LV busbar level (transformer level)

Two cases are considered:

- linear addition of harmonic currents;
- quadratic addition of harmonic currents.

It is assumed that:

- the MV/LV transformer is fully loaded by *n* identical non-linear loads;
- all non-linear loads comply with emission limits related to the R_{sce} value;
- the short-circuit voltage u_{sc} of the MV/LV transformer is equal to 5 %.

Only the harmonic voltage drop across one phase of the MV/LV transformer is considered here. Harmonic voltage drops due to harmonic currents flowing trough LV feeder impedances are not taken into account.

Notations:

I_1: fundamental current of one piece of equipment;

I_h: harmonic current produced by one piece of equipment;

n: number of pieces of equipment;

S_{equ}: power of one piece of equipment;

V_{Th}: harmonic voltage across one phase of the MV/LV transformer;

S_T: transformer power;

I_T: nominal transformer phase current;

Z_L: fundamental impedance of one phase of the transformer;

Z_h: harmonic impedance of one phase of the transformer.

•

Linear addition:

All the harmonic currents are in phase and add linearly.

Then: $V_{Th} = Z_h.(n.I_h) = (h.Z_L).(n.I_h)$

And: $u_{sc} = \dfrac{Z_L.I_T}{V}$ with: $I_T = n.I_1$

So: $u_{sc} = \dfrac{Z_L.n.I_1}{V}$ => $Z_L = u_{sc}.\dfrac{V}{n.I_1}$

$V_{Th} = h.\left(u_{sc}.\dfrac{V}{n.I_1}\right).(n.I_h) = h.u_{sc}.V.\dfrac{I_h}{I_1}$ => $\dfrac{V_{Th}}{V} = h.u_{sc}.\dfrac{I_h}{I_1}$

Using percentages: $v_h(\%) = h.u_{sc}.i_h(\%)$

With u_{sc} = 5 %, the general formula for linear addition is:

$$\boxed{v_h(\%) = 0{,}05.h.i_h(\%)}$$

See Tables G.7 to G.9.

- Quadratic addition:

For n pieces of equipment, the total harmonic current of order h is: $\sqrt{n}.I_h$

Then, $V_{Th} = Z_h.\left(\sqrt{n}.I_h\right)$

$$V_{Th} = h.\left(u_{sc}.\dfrac{V}{n.I_1}\right).\left(\sqrt{n}.I_h\right)$$

$$v_h(\%) = \dfrac{h}{\sqrt{n}}.u_{sc}.i_h(\%)$$

The MV/LV transformer is fully loaded by the non-linear loads, so:

$$n = \dfrac{S_T}{S_{equ}}$$

$n = \dfrac{S_T}{S_{sc}}.\dfrac{S_{sc}}{S_{equ}} \approx u_{sc}.R_{sce}$ if the short-circuit power is almost similar at the Pcc and at the transformer level.

Then:

$$v_h(\%) = \frac{h}{\sqrt{(u_{sc}.R_{sce})}}.u_{sc}.i_h(\%) = \frac{h.i_h(\%)}{\sqrt{\frac{R_{sce}}{u_{sc}}}}$$

With u_{sc} = 5 %, the general formula for quadratic addition is:

$$v_h(\%) = \frac{h}{\sqrt{(20.R_{sce})}}.i_h(\%)$$

See Tables G.10 to G.12.

G.7 Voltage distortion produced by one piece of equipment at the PCC level

Table G.3 – Compatibility levels

n	3	5	7	9	11	13
Compatibility level (%)	5	6	5	1,5	3,5	3
1/4 of compatibility level (%)	1,25	1,5	1,25	0,375	0,875	0,75

Table G.4 – Maximum harmonic currents and voltages for one piece of single phase equipment (from Table 2 of IEC 61000-3-12)

R_{sce}	i_3	i_5	i_7	i_9	i_{11}	i_{13}
33	21,6	10,7	7,2	3,8	3,1	2
66	24	13	8	5	4	3
120	27	15	10	6	5	4
250	35	20	13	9	8	6
350	41	24	15	12	10	8
R_{sce}	v_3	v_5	v_7	v_9	v_{11}	v_{13}
33	3,27	2,70	2,55	1,73	1,72	1,31
66	1,82	1,64	1,41	1,14	1,11	0,98
120	1,13	1,04	0,97	0,75	0,76	0,72
250	0,70	0,67	0,61	0,54	0,59	0,52
350	0,59	0,57	0,50	0,51	0,52	0,50

Table G.5 – Maximum harmonic currents and voltages for one piece of balanced three phase equipment (from Table 3 of IEC 61000-3-12)

R_{sce}	i_3	i_5	i_7	i_9	i_{11}	i_{13}
33		10,7	7,2		3,1	2
66		14	9		5	3
120		19	12		7	4
250		31	20		12	7
350		40	25		15	10
R_{sce}	v_3	v_5	v_7	v_9	v_{11}	v_{13}
33		1,62	1,53		1,03	0,79
66		1,06	0,95		0,83	0,59
120		0,79	0,70		0,64	0,43
250		0,62	0,56		0,53	0,36
350		0,57	0,50		0,47	0,37

Table G.6 – Maximum harmonic currents and voltages for one piece of balanced three phase equipment (from Table 4 of IEC 61000-3-12):

R_{sce}	i_3	i_5	i_7	i_9	i_{11}	i_{13}
33		10,7	7,2		3,1	2
120		40	25		15	10
R_{sce}	v_3	v_5	v_7	v_9	v_{11}	v_{13}
33		1,62	1,53		1,03	0,79
120		1,67	1,46		1,38	1,08

G.8 Voltage distortion produced by n pieces of equipment at the LV busbar level (Linear addition)

Table G.7 – Maximum harmonic currents and voltages for n pieces of single phase equipment (from Table 2 of IEC 61000-3-12)

R_{sce}	i_3	i_5	i_7	i_9	i_{11}	i_{13}
33	21,6	10,7	7,2	3,8	3,1	2
66	24	13	8	5	4	3
120	27	15	10	6	5	4
250	35	20	13	9	8	6
350	41	24	15	12	10	8
R_{sce}	v_3	v_5	v_7	v_9	v_{11}	v_{13}
33	3,24	2,68	2,52	1,71	1,71	1,30
66	3,60	3,25	2,80	2,25	2,20	1,95
120	4,05	3,75	3,50	2,70	2,75	2,60
250	5,25	5,00	4,55	4,05	4,40	3,90
350	6,15	6,00	5,25	5,40	5,50	5,20

Table G.8- Maximum harmonic currents and voltages for *n* pieces of balanced three phase equipment (from Table 3 of IEC 61000-3-12):

R_{sce}	i_3	i_5	i_7	i_9	i_{11}	i_{13}
33		10,7	7,2		3,1	2
66		14	9		5	3
120		19	12		7	4
250		31	20		12	7
350		40	25		15	10
R_{sce}	v_3	v_5	v_7	v_9	v_{11}	v_{13}
33		2,68	2,52		1,71	1,30
66		3,50	3,15		2,75	1,95
120		4,75	4,20		3,85	2,60
250		7,75	7,00		6,60	4,55
350		10,00	8,75		8,25	6,50

Table G.9 – Maximum harmonic currents and voltages for *n* pieces of balanced three phase equipment (from Table 4 of IEC 61000-3-12):

R_{sce}	i_3	i_5	i_7	i_9	i_{11}	i_{13}
33		10,7	7,2		3,1	2
120		40	25		15	10
R_{sce}	v_3	v_5	v_7	v_9	v_{11}	v_{13}
33		2,68	2,52		1,71	1,30
120		10,00	8,75		8,25	6,50

G.9 Voltage distortion produced by *n* pieces of equipment at the LV busbar level (Quadratic addition)

Table G.10 – Maximum harmonic currents and voltages for *n* pieces of single phase equipment (from Table 2 of IEC 61000-3-12):

R_{sce}	i_3	i_5	i_7	i_9	i_{11}	i_{13}
33	21,6	10,7	7,2	3,8	3,1	2
66	24	13	8	5	4	3
120	27	15	10	6	5	4
250	35	20	13	9	8	6
350	41	24	15	12	10	8
R_{sce}	v_3	v_5	v_7	v_9	v_{11}	v_{13}
33	2,52	2,08	1,96	1,33	1,33	1,01
66	1,98	1,79	1,54	1,24	1,21	1,07
120	1,65	1,53	1,43	1,10	1,12	1,06
250	1,48	1,41	1,29	1,15	1,24	1,10
350	1,47	1,43	1, 25	1, 29	1, 31	1, 24

~~Table G.11- Maximum harmonic currents and voltages for *n* pieces of balanced three phase equipment (from Table 3 of IEC 61000-3-12):~~

R_{sce}	i_3	i_5	i_7	i_9	i_{11}	i_{13}
33		10,7	7,2		3,1	2
66		14	9		5	3
120		19	12		7	4
250		31	20		12	7
350		40	25		15	10
R_{sce}	v_3	v_5	v_7	v_9	v_{11}	v_{13}
33		2,08	1,96		1,33	1,01
66		1,93	1,73		1,51	1,07
120		1,94	1,71		1,57	1,06
250		2,19	1,98		1,87	1,29
350		2,39	2,09		1,97	1,55

~~Table G.12 – Maximum harmonic currents and voltages for *n* pieces of balanced three phase equipment (from Table 4 of IEC 61000-3-12):~~

R_{sce}	i_3	i_5	i_7	i_9	i_{11}	i_{13}
33		10,7	7,2		3,1	2
120		40	25		15	10
R_{sce}	v_3	v_5	v_7	v_9	v_{11}	v_{13}
33		2,08	1,96		1,33	1,01
120		4,08	3,57		3,37	2,65

Annex H
(informative)

Explanation of the reasons for using the concepts of total harmonic distortion (THD) and partial weighted harmonic distortion (PWHD)

Two main impacts of harmonics on the supply system should be considered:

a) Harmonic currents produce additional ohmic losses e.g. in lines, cables and in the windings of transformers and generators. The total losses consist of one part due to the fundamental current and another part (the additional losses) due to the harmonic currents:

$$P_{loss} = R\,I^2 = R\,I_1^{\,2} + R\,\Sigma\,I_h^{\,2} = R\,I_1^{\,2}\,(1 + \mathrm{THD}i^2),$$

where R is the resistance of the conductor, I is the total r.m.s. current, I_1 its fundamental component, $\Sigma\,I_h^{\,2}$ the harmonic content and THD_i the total harmonic current distortion.

It is obvious that the THD is an appropriate measure in order to evaluate the additional losses due to current harmonics.

b) Harmonic currents injected in a supply system produce harmonic voltages according to

$$U_h = Zh\,I_h,$$

where I_h is the harmonic current of order h and Z_h the system impedance at the frequency of the harmonic order h. For low order harmonics, the impedance may be approximated by $Z_h = h\,Z_1$, but for higher orders the impedance may increase less than linearly with the harmonic order. An approximation by $Z_h \sim \sqrt{h}\,Z_1$ is more realistic (see Note).

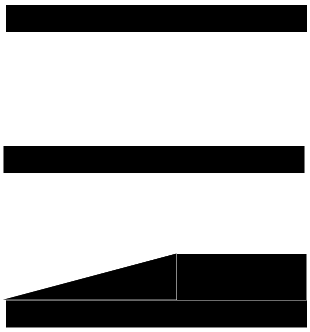
The comparison of each individual voltage harmonic U_h with the relevant compatibility or planning level may be replaced for high order harmonics by comparing only a global value with the relevant levels. Such a global value may be the partial harmonic distortion of the voltage, PHD_u, for high order ($h \geq h_{min}$) voltage harmonics

$$\mathrm{PHD}_u = [\Sigma\,(U_h/U_1)^2]^{1/2} \sim [\Sigma\,(Zh/Z_1 \cdot I_h/I_1)^2]^{1/2} \sim [\Sigma\,h\,(I_h/I_1)^2]^{1/2} = \mathrm{PWHD}_i \text{ for } h \geq h_{min},$$

NOTE The harmonic order h is thus not squared in the third summation.

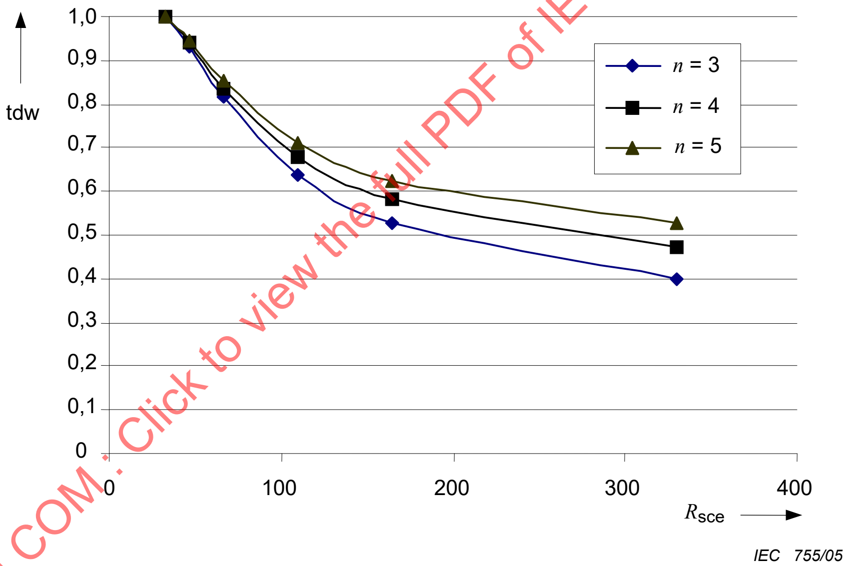
where PWHD_i is the partial weighted harmonic distortion of the current.

The factor PWHD_i takes the realistic frequency dependent system impedance characteristic into account and reduces considerably the necessary effort to compare measured values with limits.



~~**Figure H.1a – Diagram of a LV system consisting of a transformer, a busbar and *n* equal feeders**~~

~~**Figure H.1b – Equivalent circuit for the LV system with "fictitious" feeders**~~



~~**Figure H.2 – Relative total distortion weight "tdw" as a function of the short-circuit ratio R_{sce}**~~

Annex G
(informative)

Histories of IEC 61000-3-2 and IEC 61000-3-12 and related standards

EN 50006:1975 is the ancestor of IEC (60)555-2, IEC 61000-3-2, IEC TR 61000-3-4, IEC 61000-3-12 (and of IEC (60)555-3, IEC 61000-3-3, IEC TS 61000-3-5 and IEC 61000-3-11).

IEC (60)555-2:1982 was amended twice, greatly. Amendment 1 is dated 1985 and Amendment 2 is dated 1988. Amendment 1 introduced modified text on limits for television receivers, which seem to have been determined by measurements of emissions, rather than calculation. Amendment 2 included extensive text on lighting equipment, the treatment of fluctuating harmonics, especially in the context of analogue analysers, and conditions of measurement for television receivers.

IEC (60)555-2 is the ancestor of IEC 61000-3-2, IEC TR 61000-3-4, IEC 61000-3-12 and IEC 61000-4-7.

Table G.1 to Table G.3 give the detailed histories which are recorded by IEC.

Table G.1 – Publication history of IEC 61000-3-2

Date	Publication	Edition	Status
2020-07-14	IEC 61000-3-2:2018/AMD1:2020	5.0	Valid
2018-01-26	IEC 61000-3-2:2018 RLV	5.0	Valid
2018-01-26	IEC 61000-3-2:2018	5.0	Valid
2014-05-26	IEC 61000-3-2:2014	4.0	Revised
2009-08-12	IEC 61000-3-2:2005+AMD1:2008+AMD2:2009 CSV/COR1:2009	3.2	Revised
2009-04-20	IEC 61000-3-2:2005+AMD1:2008+AMD2:2009 CSV	3.2	Revised
2009-02-05	IEC 61000-3-2:2005/AMD2:2009	3.0	Revised
2008-03-11	IEC 61000-3-2:2005/AMD1:2008	3.0	Revised
2005-11-28	IEC 61000-3-2:2005	3.0	Revised
2004-11-10	IEC 61000-3-2:2000+AMD1:2001+AMD2:2004 CSV	2.2	Revised
2004-10-12	IEC 61000-3-2:2000/AMD2:2004	2.0	Revised
2001-10-18	IEC 61000-3-2:2000+AMD1:2001 CSV	2.1	Revised
2001-08-28	IEC 61000-3-2:2000/AMD1:2001	2.0	Revised
2000-08-30	IEC 61000-3-2:2000	2.0	Revised
1998-04-23	IEC 61000-3-2:1995+AMD1:1997+AMD2:1998 CSV	1.2	Revised
1998-02-06	IEC 61000-3-2:1995/AMD2:1998	1.0	Revised
1997-12-17	IEC 61000-3-2:1995+AMD1:1997 CSV	1.1	Revised
1997-09-26	IEC 61000-3-2:1995/AMD1:1997	1.0	Revised
1997-02-01	IEC 61000-3-2:1995/COR2:1997	1.0	Revised
1995-04-01	IEC 61000-3-2:1995/COR1:1995	1.0	Revised
1995-03-13	IEC 61000-3-2:1995	1.0	Revise

Table G.2 – Publication history of IEC 61000-3-12

Date	Publication	Edition	Status
2012-09-18	IEC 61000-3-12:2011/ISH1:2012	2.0	Valid
2004-11-29	IEC 61000-3-12:2004	1.0	Revised

Table G.3 – Publication history of IEC 61000-4-7

Date	Publication	Edition	Status
2008-06-11	IEC 61000-4-7:2002/AMD1:2008	2.0	Valid
2004-07-21	IEC 61000-4-7:2002/COR1:2004	2.0	Valid
2002-08-08	IEC 61000-4-7:2002	2.0	Valid
1994-11-01	IEC 61000-4-7:1991/COR1:1994	1.0	Revised
1991-08-28	IEC 61000-4-7:1991	1.0	Revised

Bibliography

[1] IEC 61000-3-2:2018[7], *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*
IEC 61000-2-2:2018/AMD 1: 2020

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

[3] EN 50006:1975, *The Limitation of Disturbances in Electricity Supply Networks Caused by Domestic and Similar Appliances Equipped with Electronic Devices*

[4] IEC (60)555-2:1982[8], *Disturbances in supply systems caused by household appliances and similar electrical equipment – Part 2: Harmonics*
IEC 60555-2:1982/AMD1:1988
IEC 60555-2:1982/AMD2:1988

[5] IEC TR 61000-3-4:1998, *Electromagnetic compatibility (EMC) – Part 3-4: Limits – Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A*

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

[7] IEC 61000-2-2:2002[9], *Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*
IEC 61000-2-2:2002/AMD 1:2017
IEC 61000-2-2:2002/AMD 2:2018

[8] IEC 61000-4-13:2002, *Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques — Harmonics and interharmonics including mains signalling at AC power port, low frequency immunity tests*
IEC 61000-4-13:2002/AMD1:2009
IEC 61000-4-13:2002/AMD2:2015

[9] IEC TR 61000-3-6:2008, *Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems*

[10] IEC TR 60725:1981[10], *Considerations on reference impedances for use in determining the disturbance characteristics of household appliances and similar electric equipment*

[11] IEC 61000-3-3, *Electromagnetic compatibility (EMC) - Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems,*

[7] Previous editions of IEC 61000-3-2 are also referred to in this document.

[8] This publication has been withdrawn.

[9] Previous editions of IEC 61000-2-2 are also referred to in this document.

[10] This publication has been withdrawn and was replaced by a new edition in 2012.

for equipment with rated current ≤16 A per phase and not subject to conditional connection

[12] IEC 61000-3-11, *Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subject to conditional connection*

[13] IEC 60082:1984[11], *Ballasts for tubular fluorescent lamps*

[14] Harmonic limits for household and similar equipment, Rapport LABORELEC 3/3/1328/G1/RVD, May 1984

[15] A. Mansoor, J. McKim, An Examination of the Rationale for Limiting Harmonic Emissions from Low-Voltage Equipment, Symposium Record of the 1999 IEEE International Symposium on Electromagnetic Compatibility; Seattle, WA; Volume 2, pp 934-939.

[16] IEC 61000-4-30:2015, *Electromagnetic compatibility (EMC) – Part 4.30: Testing and measurement techniques – Power quality measurement methods*

[17] R. Gretsch, 171204_Gr_Remarks to 77AWG1-Woodgate57.doc

[18] R. Gretsch, short private communication. November 2017

[19] Harmonics, characteristic parameters, methods of study, estimates of existing values in the network, Electra No. 77 pp 35 – 55.

[20] R. Gretsch, short private communication. November 2017

[21] R. Gretsch, short private communication. December 2017 [12]

[22] R. Gretsch, M.Neubauer: System Impedances and Background Noise in the Frequency Range 2 kHz to 9 kHz. ETEP Vol.8, No.5, 1998, pg. 369-374

[23] Harmonics, characteristic parameters, methods of study, estimates of existing values in the network, M A Personen et al, CIGRE WG36-05 Electra No. 77 pp 35 – 54

[24] IEC (600)82:1973[13], *Ballasts for tubular fluorescent lamps*

[25] Kloss, A., Statistische Betrachtungen zur Oberschwingungsproblematik in Anlagen der Leistungs-elektronik; Bull. SEV/VSE 66 (1975) 8, S. 437-433.

[26] EMC-Guide for Public Power Supply Networks – Compatibility Levels and Permissible Emission; VDEW, 1992 (ISBN 3-8022-0311-9)

[27] Report on EMC Co-ordination in Electricity Supply Systems – Electricity Product Characteristics and Electromagnetic Compatibility; UNIPEDE, 230.02 NORMCOMP, Oct. 1994

[28] E. Wargowski: Harmonic currents in controlled three-phase rectifier installations; CIRED 1981, IEE 197, pg. 91-95

11 This publication has been withdrawn.

12 The relevant texts of references a), b), d) and 9e) have been largely incorporated in this document.

13 This publication has been withdrawn.

[29] R. Gretsch, G. Krost; Th. Stiller: Network Disturbances Caused by Transient Harmonics; CIRED 1985, IEE 250(1985), pg. 333-338

[30] R.Gretsch, W.Gunselmann: Harmonic Distortion of the Mains Voltage by Switched-Mode Power Supplies – Assessment of the Future Development and Possible Mitigation Measures. EPE'89, Aachen, Vol.III, S. 1255

[31] R. Gretsch, G. Krost: Measurement and Calculation of Harmonic Impedance of Loads, LV and MV Networks. CIRED 1983, Liege, c.02. 1-7

[32] R. Gretsch, W.Gunselmann: Harmonics in Low- and Medium-Voltage Systems – Analysis of the Disturbing Sources and Measures for a Limitation of the Emission. CIRED 1991, Vol.1: Reports, Sess. 2, Paper 2.01

[33] X.Dai, R.Gretsch: A Fast and Accurate Method to Measure Interharmonics in Power Systems. ETEP 6(1996), pg.169-174

[34] T. Goeke, R. Gretsch et al.: Central Compensation of Harmonics – Legal Aspects, System Requirements and Technical Solutions. CIGRE-Conf.Publ. 36-304, Paris, Sept. 1996

[35] Combinaison des harmoniques dus aux appareils perturbateurs basse tension – Etude théorique. Rapport LABORELEC 3/3/1266/G1/RVD, September 1983

~~CISPR 14, *Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus*~~

IEC TR 61000-1-4

Edition 2.0 2022-06

TECHNICAL REPORT

colour inside

Electromagnetic compatibility (EMC) –
Part 1-4: General – Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz

IEC TR 61000-1-4:2022-06(en)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 1-4: General – Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz

FOREWORD

IEC TR 61000-1-4 has been prepared by subcommittee 77A: EMC – Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility. It is a Technical Report.

This second edition cancels and replaces the first edition published in 2005. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) relation between compatibility levels, emission limits and immunity requirements clarified;

b) sharing of emission levels between LV, MV and HV clarified;

c) new historical information added.

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

Draft	Report on voting
77A/1136/DTR	77A/1141/RVDTR

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

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

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

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

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

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

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

INTRODUCTION

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

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description 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 product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

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

IEC TR 61000-1-4:2005 (first edition) gave a historical rationale for the emission limits for equipment up to 2005. Since there is new historical material available about the developments in the past several years, SC77A is adding this new historical material as a revision of IEC TR 61000-1-4. The revision also clarifies and amends some existing statements that are now known not to report the history until 2005 correctly.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 1-4: General – Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz

1 Scope

This part of IEC 61000, which is a technical report, reviews the sources and effects of power frequency conducted harmonic current emissions in the frequency range up to 2 kHz on the public electricity supply, and gives an account of the reasoning and calculations leading to the existing emission limits for equipment in the editions of IEC 61000-3-2 [1][1], up to and including the fifth edition (2018) with Amendment 1 (2020), and in the second edition of IEC 61000-3-12 (2011) [2].

The history is traced from the first supra-national standard on low-frequency conducted emissions into the public electricity supply, EN 50006:1975 [3] and its evolution through IEC (60)555-2 [4] to IEC 61000-3-2 [1], IEC TR 61000-3-4 [5] and IEC 61000-3-12 [2]. To give a full picture of the history, that of the standard for the measuring instrument IEC 61000-4-7 [6] is mentioned as well.

NOTE All IEC standards were renumbered starting from 60000 from 1998-01-01. To indicate the references of standards withdrawn before, or not reprinted after, that date, the "60x" prefix is here enclosed in parentheses. Hence "IEC (60)555-2".

Some concepts in this document apply to all low voltage AC systems, but the numerical values apply specifically to the European 230 V/400 V 50 Hz system.

2 Normative references

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

IEC 61000 (all parts), *Electromagnetic compatibility (EMC)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61000 (all parts) apply.

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

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

1 Numbers in square brackets refer to the Bibliography.

4 General appraisal

The electricity supply industry intends to supply electric power with a sinusoidal voltage waveform, and customers' equipment is designed to operate correctly on such a supply. However, because the internal impedance of the supply system is not zero, a non-linear load connected by one customer produces distortion of the voltage waveform that can adversely affect another customer's equipment, as well as equipment in the supply system itself. There is no type of load or supply system equipment that is totally immune to distortion of the voltage waveform, and “natural” immunity levels (those achieved by customary designs without special attention to improving immunity) vary greatly. Based largely on experience of the amounts of voltage distortion that give rise to evidence of malfunction of, or damage to, equipment, compatibility levels of voltage distortion for the low-voltage (LV) public supply system have been determined and are given in IEC 61000-2-2 [7]. The correspondences between these levels and other values are shown schematically in IEC 61000-2-2:2002, Figure A.1. Compatibility levels are set as an acceptable compromise between immunity to harmonics and reduction of emissions. Methods to check that the immunity of equipment to voltage distortion is adequate are given in IEC 61000-4-13 [8].

NOTE 1 Logically, compatibility levels would be set somewhat below the lowest acceptable immunity levels, but those data were hard to come by in the past. Recommended immunity levels were first established in IEC 61000-4-13.

The intention of applying limits on the harmonic current emissions of equipment connected to the public low-voltage (LV) system is to keep the actual levels of voltage distortion on the system below the compatibility levels for a very large proportion of the time, and below lower levels, known as planning levels, for a lesser but still large proportion of the time.

NOTE 2 Emissions into the medium-voltage (MV) and high voltage (HV) systems can be controlled by other methods and procedures. See IEC TR 61000-3-6. [9]

NOTE 3 In some countries, the electricity supply industry places reliance on IEC 61000-3-2 [1] to control emissions from portable equipment, whether the point of common coupling is at LV, MV or HV.

Emissions from equipment are expressed as currents, because these are largely, but not completely, independent of the source impedance of the supply system, whereas the voltage distortion produced by the equipment is almost proportional to the supply-system impedance and therefore has no definite value. A product that draws a non-linear current from the supply system can alternatively be regarded as drawing a sinusoidal current, while emitting into the supply system harmonic currents of the opposite polarity to those that it actually draws.

Compatibility levels are set, using system disturbance data and standardized immunity levels, so that the probability of the system disturbance level exceeding the lowest immunity test level is acceptably low, and at present is set at 5 %.

NOTE 4 Because the system disturbance level is an aggregate of the emissions of very many loads, the emission limits for equipment are set at quite low disturbance levels.

NOTE 5 For system design, planning values of disturbance levels are adopted unilaterally by distribution system operators; these are not expected to be exceeded but are not subject to standardization.

5 Acceptable provisions in standards related to regulatory legislation

The equipment manufacturing industry can accept requirements in a voluntary standard, whose application can be determined by custom or moderated during individual contract negotiations, that would be unacceptable in a standard backed by regulatory enforcement. For example, a standard can contain provisions that, if fully applied, would result in very long test times. Parties to a contract might waive these provisions, wholly or partly (calculation or simulation might be employed, for example) whereas in an enforcement situation, no deviation from the provisions might be allowed.

Both EN 50006:1975, 7.1 and IEC (60)555-2:1988, IEC (60)555-2:1988/AMD1:1988 and IEC (60)555-2:1988/AMD2:1988[2],5.3.1 [4], required the test operator to search for worst-case conditions using the controls of the equipment under test, and in IEC (60)555-2, this was required for each harmonic in turn. Such a test might well take many days, with no assurance that another test operator might not find a different worst-case condition for just one harmonic. Such a provision was also contained in IEC 61000-3-2:1995 (first edition), Clause C.1 and was not removed until the publication of IEC 61000-3-2:2000/AMD1:2001 (second edition) [1].

A standard must not include regulatory requirements: it is concerned only with the procedures necessary to determine whether a product within its scope meets its requirements.

6 History of IEC 61000-3-2 and its predecessors

6.1 History table

The revision histories of IEC 61000-3-2 and IEC 61000-3-12 are given in Annex G (informative).

An up-to-date table of the entire publication history of each IEC publication can be obtained via the IEC webstore at https://webstore.iec.ch.

6.2 Before 1960

The most numerous non-linear loads were television receivers with half-wave rectifiers. Because most of these had mains connectors of reversible polarity, the DC components approximately cancelled. The number of receivers installed was insufficient to create any significant system problems due to harmonic current emissions, but there is evidence that there was enough random unbalance of polarity of connection in some countries for the resultant DC component to cause corrosion problems in underground cables.

6.3 1960 to 1975

Phase-controlled dimmers for household lighting began to be marketed. These created high-frequency conducted emissions, thus initially drawing the attention of radio-spectrum protection authorities. Measures to limit these emissions could be made mandatory, but it was also noted that the dimmers produced harmonic currents and there was no practicable way of reducing the ratios of harmonic to fundamental current.

A system survey in Europe determined the 90th percentile value for supply impedance for residential customers (who were mostly fed by overhead LV distribution) as (0,4 + j0,25) Ω, and this value was included in IEC TR 60725:1981 [10]. In addition it was determined that without some control of emissions from dimmers, the voltage distortion might grow to exceed acceptable levels (later to be called “compatibility levels”).

NOTE In IEC (60)555-2:1982, Annex A [4], the supply impedance was regarded as purely resistive and inductive ((0,4 + jh0,25) Ω, where h is the harmonic order number). However, evidence was later presented that showed that the impedance rises above 500 Hz more nearly proportional to the square root of frequency, rather than proportional to frequency. The impedance presented to a particular load at the interface with the network (which is what determines the voltage distortion produced by the current emissions from that load) includes the effect of the impedances of other loads on the feeder. Even a light 10 kW load due to other equipment considerably lowers the impedance at high-order harmonic frequencies. See 6.9.

The first standard on this subject (according to its own text it is not based on any previous standard) was the European standard EN 50006:1975, implemented as various national standards, including BS 5406:1976. This standard took burst-firing techniques into account and also covered voltage fluctuations, now the subject of IEC 61000-3-3 [11] and IEC 61000-3-11 [12]. Limitation of harmonic current emissions was achieved by:

2 IEC (60)555-2 was withdrawn in 1995 and replaced by IEC 61000-3-2.

- prohibiting the use of phase control for heating loads over 200 W;
- applying limits for odd-harmonic emissions;
- applying limits for even-harmonic emissions to both symmetrical and asymmetrical control techniques.

The limits were expressed as voltage-harmonic percentages, produced with a supply system whose impedance (for single-phase loads) was (0,4 + jh0,25) Ω. However, the test procedure actually required measurement of the harmonic currents, from which the voltage distortions were calculated.

EN 50006 [3] does not include any explanation of the derivation of the limits, which are preserved as the Class A limits in IEC 61000-3-2, up to the 2000 edition (second edition). In fact, the numerical values were undoubtedly established piecemeal by negotiation between supply industry and equipment manufacturer experts. The retention of a strict mathematical rule for determining the values would not have been a priority for either group.

There was a study that led to an approximate algorithm for determining the cumulative contribution of many dimmers set at different firing angles to a net voltage distortion level at the terminals of the LV transformer feeding the final distribution. (See also Annex A.)

6.4 1975 to 1982

During this period, a more comprehensive standard, IEC (60)555-2 (published in 1982), was developed. Still effectively restricted to 220 (380) V to 240 (415) V 50 Hz European systems, it was adopted by CENELEC as EN (60)555-2 in 1987. It introduced three sets of limits; the original current limits unchanged from EN 50006, limits 1,5 times greater for products used only for short periods, such as portable tools, and special limits for television receivers, although an exemption for receivers whose input power was less than 165 W caused the limits to apply only to a small proportion of the receivers manufactured. The limits were expressed directly as currents, even for television receivers.

Although IEC (60)555-2 included an annex that claimed to explain the derivation of the original current limits, in fact, it did not do so, merely citing the voltage distortion limits that were included in EN 50006 without explanation.

6.5 1982 to 1995

This period saw three profound changes; the great expansion of the use of switch-mode power supplies, both in business and in the home, the intimation that mandatory regulation of the electromagnetic compatibility (EMC) characteristics of electronic products would be introduced in Europe, and the further intimation that the European public electricity supply would be subject to "product quality" requirements.

The early standards, EN 50006 [3]and IEC (60)555-2, did not apply to professional equipment, but there is no relevant definition in either standard, although EN 50006 cites "office machinery" as an example. Thus it was unclear whether the standards applied to desktop computers. This was clarified in Europe by a decision that such computers were "household appliances", so that the original current limits applied. However the great expansion of single phase consumer electronics using direct on line switch mode DC power units, such as television receivers and desktop computers, led to significant peak flattening of the supply voltage waveforms due to near coincidence of the large current pulses drawn by these products. Although direct-on-line switch mode DC power units provided technology advantages (higher efficiency, lighter weight, smaller size), the near coincidence of the large current pulses being drawn can result in significant distortion of the supply voltage waveform. (Products with transformer-fed non-switching supplies have proportionally lower emissions because the series impedance of the transformer results in a larger conduction angle of the rectifiers.)

As a result, the development of the successor to IEC (60)555-2 was extremely controversial. It has been suggested that while the electricity supply industry continued to work in depth on the development of IEC 61000-3-2, the involvement of the equipment manufacturing industry was less structured. This could be true, but should be seen in the context that "equipment manufacture" is a very diverse industry sector, whose sub-sectors have very different priorities in considering harmonic current emissions, while the supply industry has very little diversity in priorities, mainly deriving from differing infra-structure configurations in different countries.

IEC 61000-3-2:1995 (first edition) introduced many new features. Most notably, it applies to "[all] electrical and electronic equipment having an input current up to and including 16 A per phase and intended to be connected to public low-voltage distribution systems." (However, "professional equipment", as defined in the standard, enjoys exemption from some requirements.)

IEC 61000-3-2:1995 thus includes requirements and limits that apply to several different types of product, grouped into four classes. It effectively applies only to European systems, as for previous standards.

NOTE 1 It is still not known whether the characteristics of 220 V to 240 V, 50 Hz supply systems in other countries are sufficiently similar to the European for the standard to be applied, while it has been shown that "scaling" operations, intended to make the provisions applicable to systems of other voltages and frequencies, are rather unreliable. Different distribution system configurations affect the effective supply impedance and the propagation of harmonic currents through the system. The characteristics of electricity supplies world-wide are under study in SC77A.

Class A is a general class, applying to products within the scope that are not specifically included in another class. The limits are derived from the original voltage limits, dating effectively from before 1975, and the assumed supply impedances at the fundamental and harmonic frequencies. The limits are related to the current emissions of dimmers for incandescent lamps. See Annex B.

Class B is a specific class, applying to portable tools, which are assumed to be used for short periods only (a few minutes). The limits are 1,5 times the Class A limits. As far as can be determined, this factor of 1,5 is purely heuristic, although for the third harmonic, one piece of equipment that just meets the third-harmonic limit of 3,45 A thereby takes up almost all the allowable fraction (0,25) of the compatibility level of 5 % that can be allocated to the low-voltage network.

NOTE 2 For an explanation of the "allowable fraction of the compatibility level", see Annex A.

Class C is for lighting equipment, which has to be carefully defined. There is not a single set of limits for this class, and the limits are quite stringent. Some of these originally appeared, with similar values, in the product standard IEC (600)82 [24], now withdrawn. See Annex C.

Class D applied originally to products drawing a current pulse from the supply that lay within a specified mask centred on the peak of the current waveform. The rectifier conduction angle of a typical high-efficiency direct-on-line DC power unit is 35°. The individual low-order odd harmonic currents emitted by a group of such products add nearly arithmetically, producing peak-flattening of the voltage waveform of single-phase supplies. This class was intended to apply to DC power units, separate or built into products, and was based, after considerable study (including the effect of supplying the rectifier with already peak-flattened sine waves), on a rectifier conduction angle of approximately 65°, with some heuristic adjustments to accommodate other products. See Annex D.

The Class D limits, which are proportional to the active power drawn and are thus expressed in mA/W, were nominally aligned with the (fixed current) Class A limits at a power of 600 W, but because of rounding errors, the limits of the two classes for each harmonic become equal at significantly different powers, which caused some confusion initially. It was possible to determine that the expected effect on the supply system was that the compatibility limits would not be exceeded with these limits applied. The details of this prediction are given in [31] and [22].

It was also agreed that there should be a lower bound to Class D below which no limits would apply, because the impact on the network of a large variety of such products would be acceptable. The lower bound was set at 75 W, with a provision to reduce to 50 W "after four years". It was not realised that this is not a provision that could actually be implemented as stated. Consequently, those who relied on this provision have been disappointed that it has not been implemented.

NOTE 3 There is no definite date from which to count the period of four years, because IEC standards are voluntary and can be applied, or not, at any time. Furthermore, IEC standards can only be amended by a voting process, which is contemporaneous; National committees cannot determine which way they will vote on a provision that would become effective many years in the future.

Unfortunately, the conduction angle of 65° required to meet the limits of Class D results in a rather unacceptably low efficiency of the power unit, manifesting as heat emission or the need for the inclusion of an inductor or an active power-factor correction circuit, at extra cost. This requirement was introduced on the grounds that statistical evidence showed a rising level of voltage distortion on European networks, together with daily variations in the 5th harmonic levels that tracked with television viewing habits. The rate of rise determined in several European countries was about 1 % over ten years, although not all the data were measurements at the same sites or at the same times over the ten-year period. But the "background" level due to miscellaneous sources was about 3 % in some places and the compatibility level was 5 % for the 5th harmonic at that time, so an unchecked rise could have had serious consequences in about ten years. Considering the service lifetimes of the products concerned (3 years to 10 years), it was clearly necessary to forestall any close approach to the compatibility level some years before it was forecast to occur.

A principle known as "equal rights" was applied in the setting of limits at that time. This can be simply stated as, "any product consuming x watts has an equal right to produce y % of harmonic currents". Consequently, the classification and limits derived for television receivers were applied to all products with a DC power unit. However, this principle does not allow for the fact that there are, for example, far more television receivers in use than, say, some rare piece of scientific equipment, of which there might be only ten in any one country. So applying the limits to the ten rare units, at a cost, achieves nothing of any significance to the well-being of the supply network or its load equipment.

NOTE 4 "Equal rights" also suggests that the allowable harmonic emissions would be proportional to the power drawn by the product. From the equipment design point of view, this is entirely logical. Fixed current limits are very lax for low-power equipment and can be very stringent indeed for higher-power equipment.

The introduction in Europe of mandatory control of EMC characteristics effectively turned IEC 61000-3-2 into a quasi-legal document, although it was not editorially suited to such a role.

6.6 1995 to 2000

Amendment 1 to IEC 61000-3-2:1995 (first edition) was issued in 1997. It introduced the following changes:

- "The designation shall be specified by the manufacturer" was added to the definition of "professional equipment". (Unfortunately, a definition is not allowed to contain a requirement, so other committees have not been allowed to adopt this definition verbatim.)
- Test conditions for vacuum cleaners and air-conditioners were added to Annex C.

Amendment 2 was issued in February 1998. This introduced requirements for lighting equipment with active input power not greater than 25 W. The limits applying to Class D, without the lower bound of 75 W, can be applied, or, in addition to limits for low-order harmonic currents, the current waveform can meet shape requirements. In setting these requirements, note was taken of the fact that there can be partial cancellation of the 5th harmonic current produced by discharge lamps by the 5th harmonic current produced by DC power units with capacitive filter, such as in television receivers.

Amendment 3 resulted from a proposal to amend the CENELEC version of the standard unilaterally, which was changed to a request for IEC to prepare it. Additional amendments were consolidated with it, resulting in a combined text dealing with:

– limits for motor driven equipment with phase angle control;
– test conditions for kitchen machines;
– asymmetrical control methods;
– symmetrical control methods;
– test condition for arc welding equipment intended for non-professional use.

None of these involved fundamental changes to the standard.

In accordance with IEC publication procedures, this third amendment resulted in a second edition, dated August 2000.

6.7 The "Millennium Amendment"

An initiative in CENELEC led to a reappraisal of the standard, with much discussion in a working group. The output document was referred to IEC SC 77A, and this resulted in further very extensive discussions. During this time, economic considerations were introduced as a specific subject (see Annex E). By the end of 1999, a somewhat reluctant consensus had been achieved, mainly on the grounds that further discussion would not produce significant improvement, and it had been agreed to begin work, immediately after finalizing the amendment, on a full revision of the standard, with documented rationales for all provisions. The resulting amendment became known as the 'Millennium Amendment', because it was substantially finalized at the beginning of 2000.

Unfortunately, Amendment 3 was also in process in IEC during 1998 and 1999, and the IEC procedures resulted in a divergence of the editions of the IEC standard from those of CENELEC, which implemented the Millennium Amendment, but not the third IEC amendment, in a consolidated edition, creating confusion that might have been avoided.

The Millennium Amendment eliminated many of the ambiguities and uncertainties that made the 1995 edition difficult to use in a regulatory situation. It also abandoned the mask for determining Class D membership, on the technical grounds that for some products it was impossible to be sure whether they should be in Class D or not. Instead, it substituted what was finally a rather short list, of high-volume products with high simultaneity of use, which contribute (in the absence of built-in mitigation measures) to odd harmonic currents of little phase diversity (rather than the overall harmonic content of the system voltage): personal computers, personal computer monitors and television receivers.

The amendment also included a clarification of the requirements for lighting equipment.

6.8 2000 to 2019

The second edition of IEC 61000-3-2 was issued in 2000, followed by Amendment 1 in 2001 and Amendment 2 in 2004. The third edition followed in 2005 and was amended in 2008 and 2009. In 2006, a new concept, "impact factor approach", was introduced, but after very long discussions, it did not achieve consensus. However, it has not been completely abandoned. See 6.9.1.

In 2005, SC77A became aware that the use of APC reduced inrush current in on-line rectifiers and allowed more active power to be drawn from the supply. These are direct benefits to product specifications, thus providing economic justification for the additional cost of APC. Consequently, the low-frequency conducted emissions of many types of product were greatly reduced.

The fourth edition was published in 2014. This edition includes the following significant technical changes with respect to the previous edition:

a) a clarification of the repeatability and reproducibility of measurements;
b) a more accurate specification of the general test conditions for information technology equipment;
c) the addition of optional test conditions for information technology equipment with external power supplies or battery chargers;
d) the addition of a simplified test method for equipment that undergoes minor changes or updates;
e) an update of the test conditions for washing machines;
f) a clarification of the requirements for Class C equipment with active input power ≤ 25 W;
g) an update of the test conditions for audio amplifiers;
h) a clarification of the test conditions for lamps;
i) an update of the test conditions for vacuum cleaners;
j) the addition of test conditions for high pressure cleaners;
k) an update of the test conditions for arc welding equipment;
l) the reclassification of refrigerators and freezers with variable-speed drives into Class D;
m) the addition of test conditions for refrigerators and freezers.

The fifth edition was published in 2018 as a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

a) an update of the emission limits for lighting equipment with a rated power ≤ 25 W to take into account new types of lighting equipment;
b) the addition of a threshold of 5 W under which no emission limits apply to all lighting equipment;
c) the modification of the requirements applying to the dimmers when operating non-incandescent lamps;
d) the addition of test conditions for digital load side transmission control devices;
e) the removal of the use of reference lamps and reference ballasts for the tests of lighting equipment;
f) the simplification and clarification of the terminology used for lighting equipment;
g) the classification of professional luminaires for stage lighting and studios under Class A;
h) a clarification about the classification of emergency lighting equipment;
i) a clarification for lighting equipment including one control module with an active input power ≤ 2 W;
j) an update of the test conditions for television receivers;
k) an update of the test conditions for induction hobs, taking also into account the other types of cooking appliances;
l) for consistency with IEC 61000-3-12, a change of the scope of IEC 61000-3-2 from "equipment with an input current ≤ 16A" to "equipment with a rated input current ≤ 16A".

6.9 2020 to 2022

6.9.1 Impact factor approach

A different approach to conducted emissions and their limits might be considered in future editions of IEC 61000-3-2. Initial considerations are described in Annex F. This approach has been extensively discussed in committee (see 6.8), but so far no consensus has been achieved.

6.9.2 Effect of the coronavirus pandemic from 2020 to 2022

The restriction to on-line meetings of necessarily short duration caused the maintenance of standards, and other subjects needing extensive discussion, to be postponed until face-to-face meetings resume.

7 History of IEC 61000-3-12 and its predecessor

7.1 Origin

IEC 61000-3-12 was adapted from IEC TR 61000-3-4 with the following changes:

- IEC 61000-3-12 is limited to equipment rated ≤ 75 A per phase. IEC TR 61000-3-4 can be applied by the distribution system operators (DSOs) for equipment rated > 75 A per phase.
- The IEC TR 61000-3-4 assessment stages were not kept in IEC 61000-3-12 since the DSO is not required to decide whether the equipment can be connected to the public low-voltage network if the harmonic current emission limits in the relevant tables are met.
- IEC TR 61000-3-4:1998, Table 1, Table 2, and Table 3 are slightly modified and included in IEC 61000-3-12:2004 (first edition). Table 4 is also added for balanced three-phase equipment under specified conditions and given relaxed limits that account for the 5th harmonic current phase angle diversity compared to single-phase equipment.
- Table 5 is added for C-less drives in IEC 61000-3-12:2011 (second edition). All the tables undergo changes.
- The reference fundamental rated equipment current I_1 is replaced by the reference current I_{ref} for the calculated emission limits. I_{ref} is the average RMS input line current that is measured during test.
- THD and $PWHD$ are replaced by THC/I_{ref} and $PWHC/I_{\text{ref}}$, respectively.

IEC 61000-3-12:2011 has type test conditions for some types of equipment in Annex A. Annex B has an illustration of linear interpolation of the 5th harmonic current values based on R_{sce}.

7.2 1989 to 1998

IEC 61000-3-2 deals with equipment rated at up to 16 A/phase. A complementary document, dealing with equipment rated at over 16 A/phase, was prepared as IEC TR 61000-3-4, a Technical Report type 2 ("prospective standard for provisional application"), by a team comprising experts from ES, FR, DE, IE, IT, GB and US. Some conclusions of the team were recorded:

- an arithmetic superposition law was used for harmonics up to the 5th and a geometric law for higher orders;
- approximately 75 % of the compatibility level for low-order non-triplen harmonics is transmitted from the MV level and is present as a background disturbance throughout the LV network. Hence only 25 % of the compatibility level is left for the admissible additional voltage distortion due to non-linear loads connected to a specific LV supply. For harmonic orders above approximately the 13th, phase diversity allows a higher percentage of the compatibility level to be allocated to the LV network. See Annex A.

Rough calculations, depending on different assumptions on the partition of distorting loads, yielded:

- $I_5/I_1 \leq 11$ % (GB)
- $I_5/I_1 \leq 15$ % (IT)
- $I_5/I_1 \leq 16$ % (CH)
- $I_5/I_1 \leq 9$ % to 16 % (DE)

It was decided that the limits should depend on the short-circuit ratio R_{sce}, with higher limits with higher R_{sce}, but remain in principle in the range of the rough calculations.

Further studies were made to find a justified relation between the R_{sce} values and the limits. The detailed calculations are lost. An attempt to “recover” the basis of these studies, and relate it to the limits in IEC 61000-3-12, is presented in Annex G.

This rationale does not consider the provisions of IEC TR 61000-3-4 in detail, since all but one (relating to equipment rated at over 75 A/phase) have been superseded by provisions of IEC 61000-3-12.

7.3 After 1998

As was expected, experience gained from applying IEC TR 61000-3-4 led to proposals for changes to be incorporated in IEC 61000-3-12. After a very great deal of discussion, a first voting document was circulated in 2003.

8 History of IEC 61000-4-7 up to 2008

8.1 First edition in 1991

As the title indicates, this was a “general guide” (but it was not a Technical Report of any kind). It allowed analogue measurements as well as digital, the latter only recently becoming possible due to improvements in low-cost computer hardware. Analogue methods can work for harmonic spectra with near-stable harmonic amplitudes, but much equipment produces fluctuating harmonic amplitudes. The measurement bandwidth was nominally set at 3 Hz. (At that time, IEC 61000-3-2 did not exist: emission limits were specified in IEC (60)555-2, which was under revision in 1991.)

An editorial correction was published in 1994.

8.2 Second edition in 2002

This edition is very different from the first edition. Only digital methods are specified, and the scope was greatly changed. Instead of a “guide” the document is a “standard” and it is a complete and normative specification of a measuring instrument for testing individual items of equipment in accordance with emission limits (such as in IEC 61000-3-2), as well as for measurements in supply systems (see IEC 61000-4-30 [16]).

In spite of this profound change, the title of the document was not changed.

The basic measurement bandwidth was set at 5 Hz, but this was profoundly modified by the controversial introduction of “grouping” – summation of the measured values over 50 Hz (in 50 Hz systems) centred on each harmonic frequency. This effectively increases the measurement bandwidth from 3 Hz to 50 Hz, but there was no corresponding change of the emission limits in IEC 61000-3-2. This “grouping” change allows interharmonic emissions to be taken into account, but whether they should be summed with harmonic emissions is still a matter of debate. To resolve this issue on a temporary basis, a concession to use an instrument complying with the first edition was introduced, provided that its use was reported with the results.

An editorial correction was published in 2004.

8.3 Amendment 1 to the second edition

This very large amendment was published in 2008 after several years work in the responsible committee. Amendment 1 includes corrections to several mathematical expressions and symbols, new and revised definitions and many changes to the text and some figures.

The major changes and additions are:

- Various definitions are added, such as the group and sub-group total harmonic distortion $THDG_y$, and $THDS_y$.
- The partially weighted harmonic distortion is added – $PWHD_{h,y}$.
- Inter-harmonics measurements and inter-harmonic grouping are defined. Technical considerations for grouping are explained in an informative Annex C.
- A measurement window of 200 ms allows the same processing of 50 Hz and 60 Hz signals, with a 5 Hz spectral resolution. The digital 1,5 s LP filtering for 50 Hz and 60 Hz is defined.
- A transitional period that permits the use of instruments that adhere to the older 1991 version of IEC 61000-4-7 is included in the second edition with Amendment 1.

An informative Annex B explains the measurement methods up to 9 kHz, with grouping in 200 Hz intervals. Annex B also includes information on an artificial mains network (AMN) to facilitate measurements up to 9 kHz.

8.4 Developments since 2008

Various developments in the emission standards IEC 61000-3-2 and IEC 61000-3-12, require amendments and updates to the second edition with Amendment 1. The responsible committees have been working on various topics. Some of the work on a new edition was delayed due to ongoing discussion on what is called “grouped limits” for IEC 61000-3-2 [1], and possible impact on IEC 61000-4-7 (mainly whether or not IEC 61000-4-7:2002 and IEC 61000-4-7:2002/AMD1:2008, Clause 7, allowing the use of “edition 1” instruments can be deleted).

In summary, the agreed upon changes/additions include:

- A change in title of the standard to better reflect its content.
- Adding definitions for POHC (partial odd harmonic current) and POHV (partial odd harmonic voltage).
- Clear definition of the phase angle measurement and evaluation to support IEC 61000-3-12:2011, Table 4 and Table 5, and for general purposes of harmonic current assessment. Application examples are detailed in a new Annex D.
- Measurement methods of the partial odd harmonic current (POHC) which is specified in IEC 61000-3-2 for Class-A evaluations.
- Various editorial matters, some proposed by National Committees, and some required as IEC guidelines have changed or have been updated.
- Given the extensive changes, a new edition 3 of IEC 61000-4-7 will be published.

9 Economic considerations taken into account in setting limits in IEC 61000-3-2 before publication in 1995, and before the finalization of the text of the Millennium Amendment

Only passive mitigation was considered by IEC as economically practicable at that time, and only for single-phase equipment. Approximately €1 or $1 would be added to the production cost (not selling cost) for a TV-set, i.e. approximately 1 % to 2 % for high volume, not low-price products (a self-ballasted lamp is a typical low-price product).

The cost-sharing idea was implemented by the lower power bound of 75 W:

- no harmonics limits up to this power value; costs only to the supply system;
- existing harmonics limits beyond this power value; costs to both the product and the supply system (because the harmonic currents are not zero!).

This was considered in setting the limits in Table 3.

The limits of Table 1 and Table 2 were taken from the older European standard (EN 50006) into IEC (60)555-2. No definite information on economics is available for the limits in these tables. In the European Standard, the scope was restricted to household appliances, and experts from that sector were actively involved in the work. It might be assumed, therefore, that the economic effects of the introduction of the limits were acceptable at that time, by the parties involved.

During the preparation of the Millennium Amendment, consideration of economic aspects was intensified. As a result, many products were re-allocated from Class D to Class A (see 6.6).

Annex A
(informative)

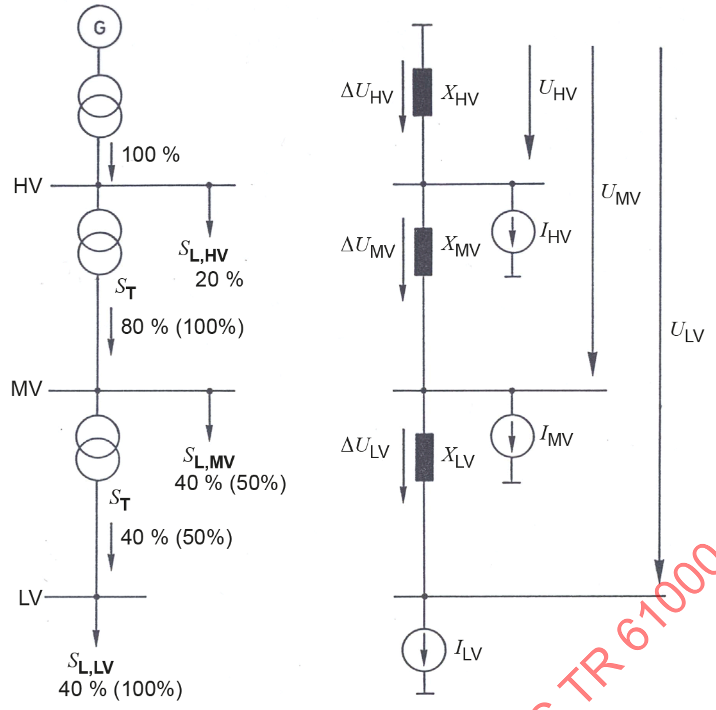
Compatibility level and compensation factor

A.1 Explanation of the allocation of only part of the total compatibility level to the low-voltage network

Harmonic distortion at LV-, MV- and HV-levels in the network is mainly produced by harmonic currents of non-linear loads installed in the LV-network. The resulting harmonic distortion in the LV-network is the geometrical sum of the harmonic voltage drops in the LV-network and in all superimposed MV- and HV-systems. According to IEC standards, the harmonic distortion in the LV-network shall not exceed the compatibility level given in IEC 61000-2-2.

Harmonic currents of non-linear loads in the LV-network, in the MV-network and in the HV-network produce harmonic voltage drops at the harmonic impedances of the LV/MV-transformer, of the MV/HV-transformer and of the HV-network including generator, respectively. The percentage harmonic voltage drops correspond approximately to the percentage transformer impedances which are given by the percentage short circuit voltage of each relevant transformer.

The typical percentage impedances in European networks are given in Figure A.1. The partition of the total compatibility level into the parts assigned to each voltage level reflects roughly the relation of these percentage impedances. In order to account for the geometric summation of the voltage drops, the share value of 25 % for the LV-network is increased with respect to the value which can be derived from the ratio of the impedance values. 25 % of the total LV compatibility level is therefore used in IEC 61000-3-2 and IEC 61000-3-12 for the assessment of the maximum harmonic currents from non-linear loads in the LV-network for 230 V 50 Hz systems.



AC voltage source (infinite power system source)

Transformer symbol

S_G Global power delivered by the integrated power system

$S_{L,HV}$ Load power consumed by HV customers

$S_{T,MV}$ Transferred power from HV to MV

$S_{L,MV}$ Load power consumed by MV customers

$S_{T,LV}$ Transferred power from MV to LV

$S_{L,LV}$ Load power consumed by LV customer

Bold/Italic numbers show percent of global power

(Parentheses show percent of power from previous nearest bus)

IEC

Figure A.1 – Harmonic voltage drops and harmonic current injections in a typical system

NOTE The shares allocated to the three voltage levels are summed geometrically on the assumption that the phase angles are random.

A.2 Compensation factor

A.2.1 Maximum permissible current emission – original approach

The maximum permissible current emission from equipment at each harmonic frequency can be shown to be:

$$i_{h,\mathrm{eq}} = u_{h,\mathrm{CL}} k_{N,\mathrm{LV}} / Z_{\mathrm{LV},h} k_{p,h}$$

where

h is the harmonic order;