IEC TR 61000-1-4

Edition 2.0 2022-06

TECHNICAL
REPORT

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

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.100.10

ISBN 978-2-8322-2263-8

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

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

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

2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.

3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.

6) All users should ensure that they have the latest edition of this publication.

7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.

8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

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 $PWHC/I_{ref}$, 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.

Symbol	Description
$\otimes$	AC voltage source (infinite power system source)
$\ominus$	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
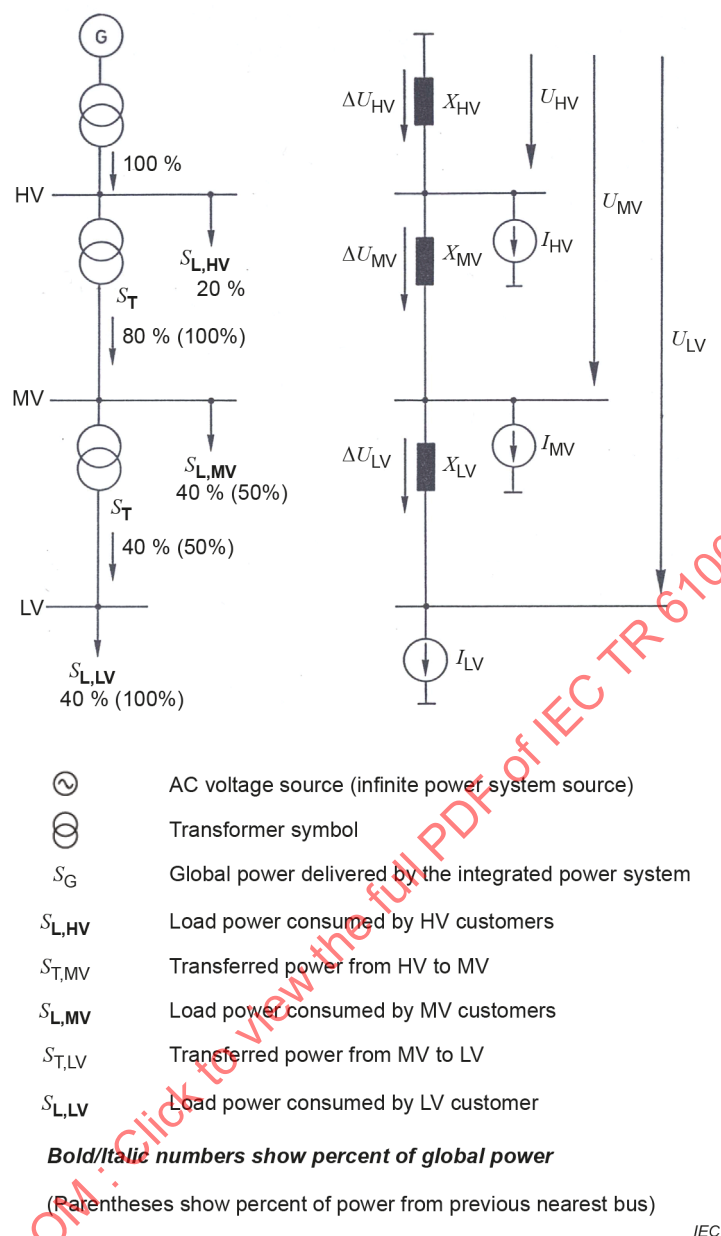
Figure A.1 – Harmonic voltage drops and harmonic current injections in a typical system

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:

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

where

h is the harmonic order;

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

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

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

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

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

A.2.2 Detailed consideration

$k_{N,\text{LV}}$ 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. $R_{\text{sce}}= 33$ 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 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)).

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 ($1/R_{\text{sce}}$) values to determine the $k_{p,h}$ values for the R_{sce} values in Table A.1 very problematical. The values for $R_{\text{sce}} = 32$ were probably determined by negotiation. See 6.9.2.

If, in an individual case study, proper account for actual system impedances is made, $k_{N,\text{LV}}$ 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 are then 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 are not 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 can result in significant cancellation for the 5th and 7th harmonics, but 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 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 might or might not be those in Table A.2).

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, $k_{N,LV}$ 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 "$k_{N,LV}$", 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 $k_{N,LV}$.

The subject is in fact very confusing, because there are two linked quantities, $k_{N,LV}$ and $k_{p,h}$, which modifies $k_{N,LV}$ for every harmonic, according to the values in Table A.1. It is really more clear to define a "compensated sharing factor", $C_{LV,p,h} = k_{N,LV}/k_{p,h}$, 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.
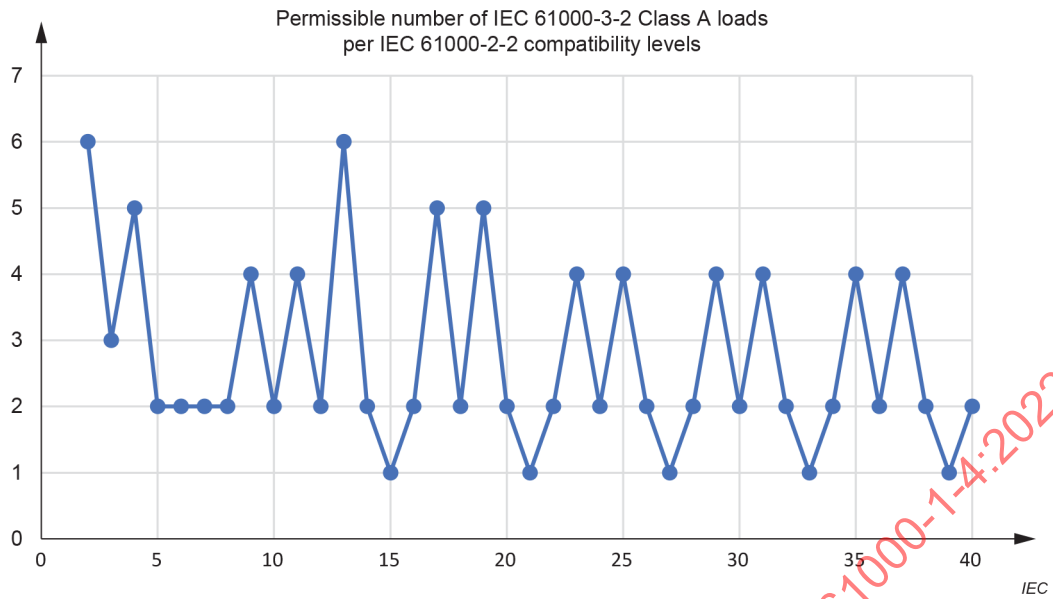
Permissible number of IEC 61000-3-2 Class A loads
per IEC 61000-2-2 compatibility levels

IEC

**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.
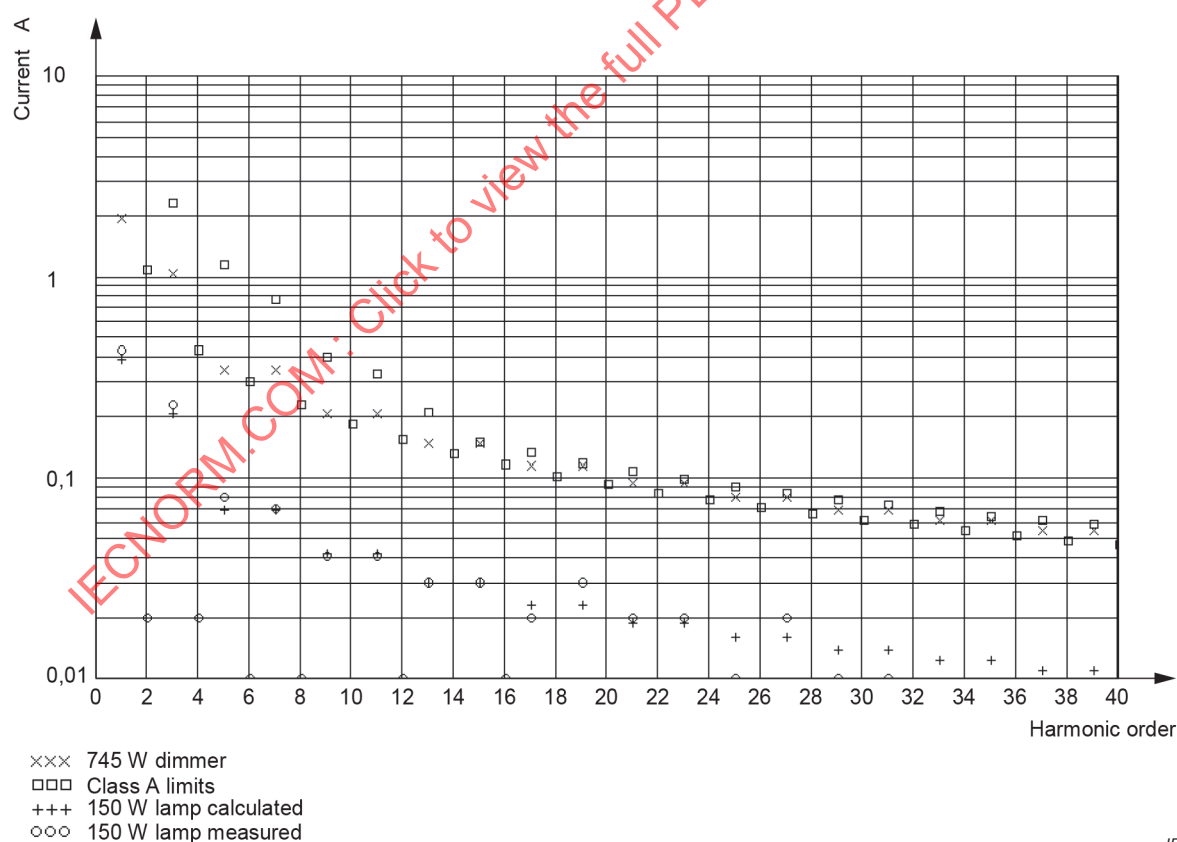
Annex B
(informative)

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 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.


××× 745 W dimmer
□□□ Class A limits
+++ 150 W lamp calculated
○○○ 150 W lamp measured

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.

××× 25 W lamp
+++ Class C limits
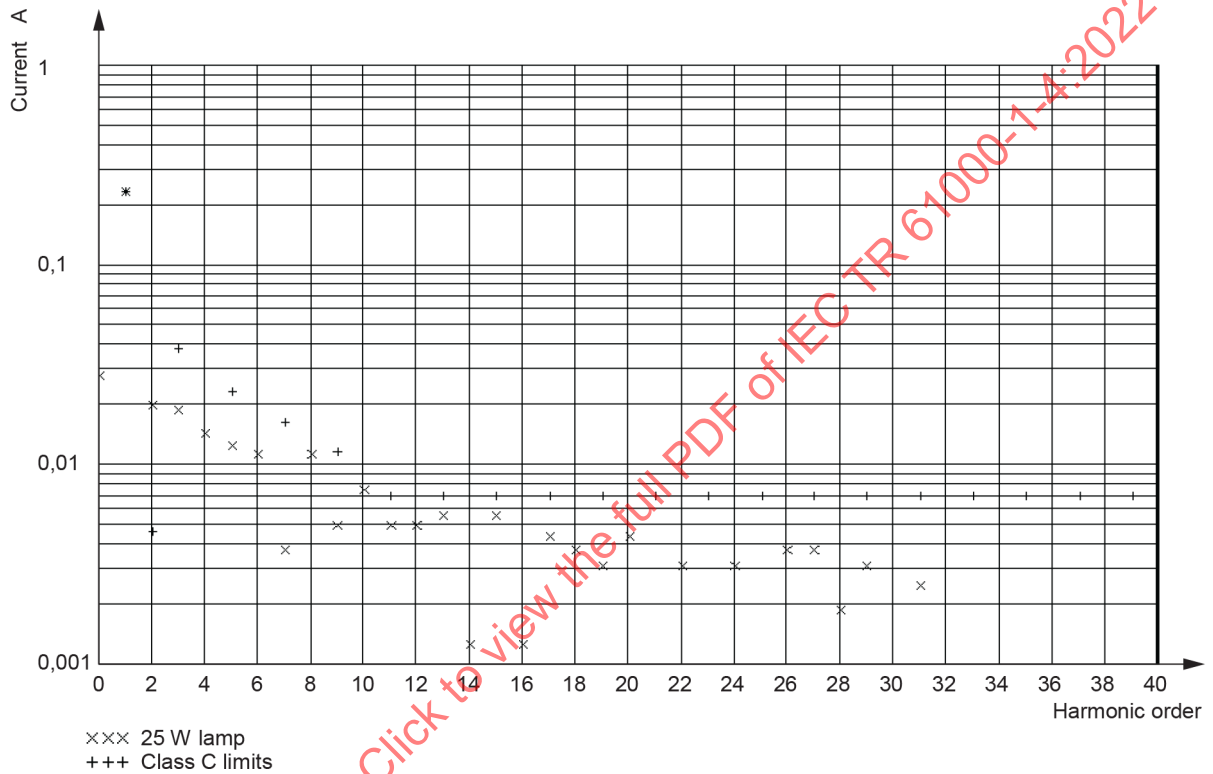
IEC

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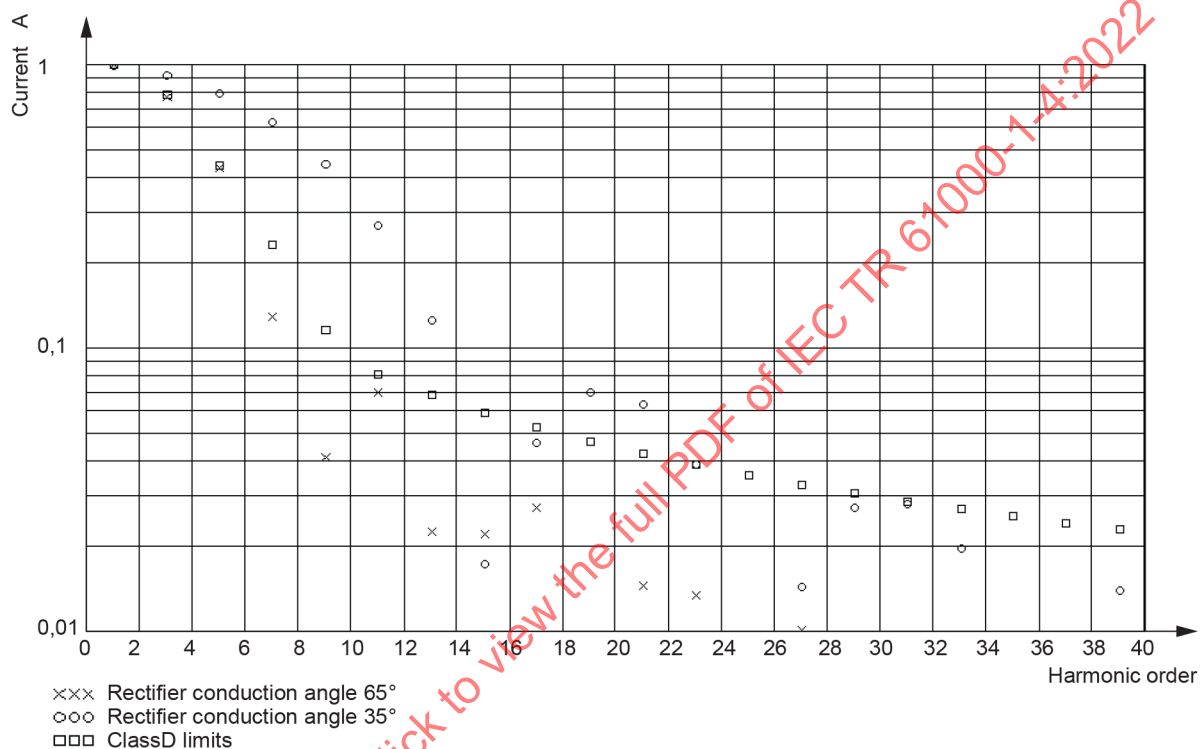
Figure D.1 – Comparison of Class D limits and harmonic spectra
of single-phase 230 W rectifiers with capacitor filters

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.
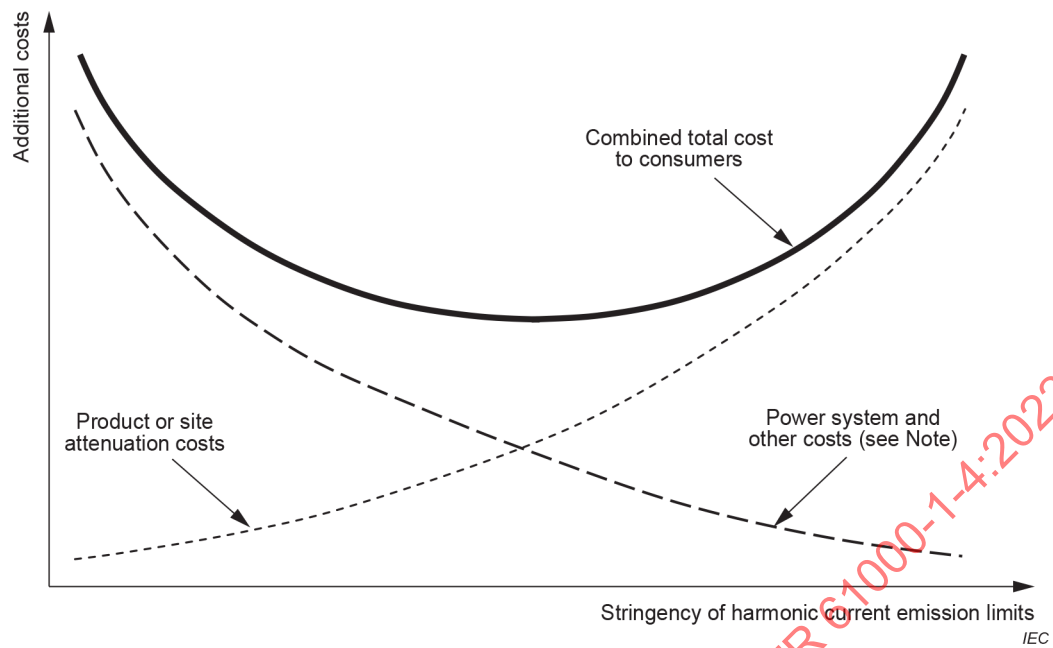
NOTE   Most of the "power system and other costs" are power system costs.

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