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

colour inside

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

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.100.10

ISBN 978-2-8322-2263-8

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CONTENTS

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FOREWORD

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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- withdrawn,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 $(0{,}4 + jh0{,}25)\ \Omega$. 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].