

TECHNICAL SPECIFICATION

**Electromagnetic compatibility (EMC) –
Part 3-16: Limits – Limits for harmonic currents produced by the inverter of
inverter-type electrical energy-supplying equipment with a reference current less
than or equal to 75 A per phase connected to public low-voltage systems**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 3-16: Limits – Limits for harmonic currents produced by the inverter of inverter-type electrical energy-supplying equipment, with a reference current less than or equal to 75 A per phase, connected to public low-voltage systems

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IEC 61000-3-16 has been prepared by subcommittee 77A EMC – Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility. It is a Technical Specification.

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

Draft	Report on voting
77A/1167/DTS	77A//RVDTS

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 Specification 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/standardsdev/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.

This document has the status of a product family standard.

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

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- withdrawn,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

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INTRODUCTION

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

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits

(in so far as they do not fall under the responsibility of product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

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

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 3-16: Limits – Limits for harmonic currents produced by the inverter of inverter-type electrical energy-supplying equipment, with a reference current less than or equal to 75 A per phase, connected to public low-voltage systems

1 Scope

This part of IEC 61000 deals with the limits for harmonic (including grouped interharmonic) currents produced by the inverter of inverter-type electrical energy-supplying equipment (ESE) as defined in 3.2, but which does not include energy storage. The limits given in this document are applicable to inverters with a reference current as defined in 3.3 (see also 5.2.3) less than or equal to 75 A per phase, intended to be connected to public low-voltage AC distribution systems of the following types:

- single-phase, two or three wires; nominal voltage up to 240 V
- three-phase, three or four wires; nominal voltage up to 690 V
- nominal frequency of 50 Hz or 60 Hz.

This document specifies:

- a) requirements and emission limits for equipment;
- b) methods for type tests and simulations.

Tests in accordance with this document are type tests of complete pieces of equipment.

Equipment which mainly absorbs energy but which is capable of supplying energy to the public supply as a secondary function is out of the scope of this document.

EXAMPLE An elevator motor drive returning energy during braking.

This document provides limits and testing procedures for equipment in the range up to harmonic order 40 (h_{40}), i.e. 2 000 Hz or 2 400 Hz depending on line frequency.

NOTE 1 It is possible that limits for frequencies in the range from 2 kHz to 9 kHz will be added in a future edition of this document.

NOTE 2 It is possible that limits and procedures for storage systems will be added in a future edition of this document.

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 60038:2009, *IEC standard voltages*

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

IEC 61000-2-2:2002 AMD1:2017

IEC 61000-2-2:2002 AMD2:2018

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

IEC TR 60725:2012, *Consideration of reference impedances and public supply network impedances for use in determining the disturbance characteristics of electrical equipment having a rated current ≤ 75 A per phase*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

3.1 electrical energy-supplying equipment ESE

equipment or system whose main function is to supply electrical energy into public power supply systems

Note 1 to entry: An ESE can also include an energy storage system.

3.2 inverter-type electrical energy-supplying equipment

ESE that includes an inverter taking a DC supply from an energy source but does not include an energy storage system

3.3 reference current

I_{ref}

RMS output current stated in the equipment specification

Note 1 to entry: See 5.2.2 and 5.2.3 for the conditions for determining I_{ref} .

3.4 short-circuit power

S_{sc}

value of the three-phase short-circuit power calculated from the nominal interphase system voltage U_n and the line impedance Z of the system at the point of connection of the ESE:

$$S_{\text{sc}} = U_n^2 / Z$$

3.5 rated apparent power

S_{equ}

<of the ESE inverter> apparent power value calculated from the reference output current I_{ref} of the ESE inverter stated by the manufacturer and the rated voltage U_p (single phase) or U_i (interphase) as follows:

- a) $S_{\text{equ}} = U_p I_{\text{ref}}$ for single-phase equipment;

b) $S_{\text{equ}} = \sqrt{3}U_i I_{\text{ref}}$ for three-phase equipment;

Note 1 to entry: In the case of a voltage range, U_p or U_i is a nominal system voltage according to IEC 60038 (for example: 120 V or 230 V for single-phase or 400 V line-to-line for three-phase).

**3.6
short-circuit ratio**

R_{sce}
characteristic value of a piece of ESE defined as follows:

$$R_{\text{sce}} = S_{\text{sc}} / (3 S_{\text{equ}}) \text{ for single-phase ESE}$$

$$R_{\text{sce}} = S_{\text{sc}} / S_{\text{equ}} \text{ for three-phase ESE}$$

**3.7
partial harmonic current**

PHC
total RMS value of the harmonic current components of orders 14 to 40

$$PHC = \sqrt{\sum_{h=14}^{40} I_h^2}$$

**3.8
total harmonic current**

THC
total RMS value of the harmonic current components of orders 2 to 40

$$THC = \sqrt{\sum_{h=2}^{40} I_h^2}$$

**3.9
partial triplen harmonic current**

PHC_{triplen}
total RMS value of the harmonic current components of the 15th, 18th, 21st, 24th, 27th, 30th, 33rd, 36th and 39th harmonic

$$PHC_{\text{triplen}} = \sqrt{\sum_{h=15,18\dots}^{39} I_h^2}$$

**3.10
partial zero-sequence harmonic current**

PHC_{zero}
total RMS value of the modulus of the harmonic zero-sequence current components of orders 14 to 40

$$PHC_{\text{zero}} = \sqrt{\sum_{h=14}^{40} \left(\frac{I_{h,L1} + I_{h,L2} + I_{h,L3}}{3} \right)^2}$$

where $I_{h,L1}$, $I_{h,L2}$ and $I_{h,L3}$ are the complex vectors of the harmonic phase currents

Note 1 to entry: PHC_{zero} is only applicable to three-phase equipment.

Note 2 to entry: $I_{h,L1} + I_{h,L2} + I_{h,L3}$ is typically identical to the harmonic current in the neutral conductor.

Note 3 to entry: For equipment without connection to a neutral conductor, PHC_{zero} is typically zero.

4 General

4.1 Emissions for electrical ESE unable to cancel harmonics at the grid side

The performance of a piece of ESE depends on its design and configuration (filter type, pulse width modulation technique, control algorithm and switching frequency), thus a piece of ESE that cannot generate harmonics above 1 % does not affect the power quality of the network. Three sets of limits are specified in Table 1, Table 2 and Table 3 in Clause 6 for harmonic emissions of ESE inverters. The permitted PHC depends on the value of R_{sce} .

4.2 Emissions for electrical ESE which can cancel harmonics at the grid side

If a piece of ESE can compensate harmonics at the grid side, then a system test, in addition to the product test, is required to be performed in order to validate the quality and the performance of the ESE inverter. System testing will be addressed in a future version of this document.

Further analysis and development are required in order to define suitable limits for harmonic current emissions to validate both harmonic cancellation and ESE performance under distorted network voltage conditions. This will be addressed in a future edition of this document.

5 Measurement and simulation conditions

5.1 General conditions for test and simulation

Conformity with this document may be determined by either of the two methods as follows:

- a) direct measurement (see 5.2);
- b) calculation by validated simulation (see 5.3).

Direct measurement or simulation shall be conducted with the user's operation controls or automatic programs set to the mode expected to produce the maximum total harmonic current (THC) under normal operating conditions. This defines the equipment set-up during emission tests and not a requirement to conduct searches for worst-case emissions.

The ESE inverter is tested as presented, and in accordance with information provided by the manufacturer.

5.2 Requirements for measurement

5.2.1 Supply of the ESE inverter

The inverter of the ESE shall be supplied with DC power from a power source that does not contribute to current emissions, for all load conditions presented by the ESE.

NOTE The inverter can be designed to accept input from a current source, such as a solar photo-voltaic array, or from a voltage source.

5.2.2 Supply into which the ESE inverter feeds energy

As a first step in the measurement process, the manufacturer shall choose a trial value of R_{sce} , (symbol $R_{sce\ min}$), based on knowledge of the product design, expected to allow the ESE inverter to comply with the requirements in Table 1 or Table 2, and Table 3.

The supply source shall then meet the following requirements:

- a) the supply voltage U shall be equal to the rated output voltage of the ESE inverter. In the case of a voltage range, the output voltage shall be a nominal system voltage in accordance with IEC 60038 (for example: 120 V or 230 V for single-phase or 400 V line-to-line for three-phase);
- b) while the measurements are being made, the output voltage shall be maintained within $\pm 2,0\%$ and the frequency within $\pm 0,5\%$ of the nominal value;
- c) in the case of a three-phase supply, the voltage unbalance shall be less than 2% ;
- d) the harmonic ratios of the supply voltage U shall not exceed:
 - $1,5\%$ for harmonics of order 5;
 - $1,25\%$ for harmonics of order 3 and 7;
 - $0,7\%$ for harmonics of order 11;
 - $0,6\%$ for harmonics of order 9 and 13;
 - $0,4\%$ for even harmonics of order 2 to 10;
 - $0,3\%$ for harmonics of order 12 and 14 to 40;
- e) the impedance of the supply source is lower than the reference impedance given in IEC TR 60725; moreover, for the application of Table 1, the impedance of the supply source is such that the R_{sce} is higher than or equal to 33, and for the application of Table 2, the R_{sce} is equal to or higher than $R_{sce\ min}$, the value expected to allow the compliance of the ESE inverter;
- f) the impedance of the current-sensing part and the wiring is included in the impedance of the supply source.

NOTE The limit for the voltage unbalance in 5.2.2 c) corresponds to the compatibility level given in IEC 61000-2-2:2002, 4.6, which is also 2% .

5.2.3 Determination of the reference current I_{ref}

The reference current shall be measured using the averaging method specified in 5.2.4 for harmonic currents. The measurement shall be made under the conditions specified in 5.1.

5.2.4 Measurement of harmonic currents

5.2.4.1 General

The ESE inverter output shall be connected to the supply source and the inverter DC input current or voltage set so that, after a waiting time of at least 10 s, the reference current I_{ref} flows into the supply source. The currents shall then be measured in accordance with 5.2.4.2 for an observation period of 1 min.

Measurements shall be made at the point of connection between the source and the ESE inverter. For ESE connected to a single-phase supply, it is permitted to measure the current in the neutral conductor instead of the current in the line.

The requirements for the measurement instrumentation are given in IEC 61000-4-7. The current limits for ESE inverters as specified in this document apply to each of the line currents.

5.2.4.2 Measurement procedure

The measurement of currents shall be performed as follows:

- for each harmonic order, measure the 1,5 s smoothed RMS current in each discrete Fourier transform (DFT) time window as defined in IEC 61000-4-7:2002 and IEC 61000-4-7:2002/AMD:2008, Figure 1, OUT 2b. For the purpose of testing ESE, grouping as described in IEC 61000-4-7:2002 and IEC 61000-4-7:2002/AMD:2008, 5.5.1, shall be active, with the following exception:

- for the calculation of the PHC, the ungrouped values of harmonic currents may be used. A comparison to the limit fails, if the ungrouped value fails the limit. A comparison to the limit passes, if either the grouped or the ungrouped value passes. The chosen calculation shall be stated in the test report;
- for each harmonic order, calculate the arithmetic average of the measured values from the DFT time windows, over the entire observation period.

If compliance is not achieved with the trial value $R_{sce\ min}$ for the application of Table 1, Table 2 or Table 3, a higher value of $R_{sce\ min}$ shall be chosen and the test repeated, until a value of $R_{sce\ min}$ is found that achieves compliance. This final value shall be used as the “minimum value of R_{sce} ” in Clause 7.

5.3 Requirements for simulation

Assessment of current emissions and the corresponding minimum value of R_{sce} can be made by computer simulation of the equipment considered. This procedure may be used when the requirements given in 5.2 concerning the supply source cannot be met. In order to validate the results, the following steps shall be performed:

- a) Measurement of the type of equipment under normal laboratory conditions as described in 5.2, with possible higher voltage distortion, provided that harmonic levels do not exceed the compatibility levels given in IEC 61000-2-4, class 3. These measurements shall show that the equipment complies with the relevant limits.
- b) The voltage spectrum during the test as well as the supply impedance (value at fundamental frequency, either directly as such or indirectly in terms of short-circuit power, including the impedance of the current-sensing part and the wiring) shall be recorded.
- c) Simulation of the equipment with the manufacturer's software and procedures:
The measured values of the voltage spectrum and supply impedance are taken as input parameters into the simulation. The harmonic currents calculated by this simulation are compared to the results of the measurement under item a). The simulation is considered validated if the results from simulation do not differ from the results of measurement by more than the following values:
 - either $\pm 2\%$ of the maximum output current or the reference current for Table 1 or Table 2, or
 - $\pm 10\%$ of the result of measurement,
 whichever is larger for each harmonic current ($h \leq 13$).

NOTE Simulation technology for higher orders can have some variability, and therefore harmonic orders h_{14} and above are not compared against measurement results.

Measured harmonics less than 1 % of the maximum output current or the reference current for Table 1 or Table 3 are not compared as part of the validation.

It is not necessary to repeat the validation of the simulation for each product in a range of products with a reference current less than or equal to 75 A per phase based on the same technology and topology. The simulation is considered to be valid if it is validated for one product at or near each end (within the range 0 A to 75 A) of the product range.

- c) the simulation is repeated with a pure sinusoidal, balanced supply voltage and low output impedance.

For the application of Table 1, the impedance of the supply source shall be lower than the reference impedance given in IEC TR 60725 and correspond to an R_{sce} value higher than or equal to 33,

For the application of Table 3, the impedance of the supply source shall be lower than the reference impedance given in IEC TR 60725 and correspond to an R_{sce} value higher than or equal to the trial value $R_{sce\ min}$ (see 5.2) expected to allow the compliance of the equipment.

The results of this second simulation are considered to be the relevant harmonic currents to check the compliance with this document. However, if compliance is not achieved with the trial value $R_{sce\ min}$ when applying Table 3, a higher value of $R_{sce\ min}$ shall be chosen and the simulation repeated, until a value of $R_{sce\ min}$ is found that achieves compliance. This final value shall be used as the “minimum value of R_{sce} ” in Clause 7.

6 Emission limits

NOTE A rationale for the limits is given in Annex A (informative).

The average value for each individual harmonic current, taken over the entire test period (see 5.2), shall be less than or equal to the applicable limits in Table 1. The PHC and the $PHC_{triplen}$ (for single-phase inverters) or the $PHC_{triplen}$ (for three-phase inverters), shall be less than or equal to the applicable limits in Table 3. For each harmonic order, all 1,5 s smoothed RMS harmonic current values, as defined in 5.2.4.2, shall be less than or equal to 150 % of the applicable limit.

Table 1 defines individual limits for the harmonic orders of 2 to 13. Table 1 is applied to single-phase or three-phase ESE with a reference current up to 75 A per phase. Table 2 presents the same data in an alternative format.

Table 3 defines partial harmonic current (PHC) limits for ESE with single-phase and three-phase configurations and reference current of 0 A to 16 A and 16 A to 75 A.

Table 1 – Individual current harmonic limits for all ESE inverters up to 75 A per phase

Individual harmonic orders	Individual harmonic current $I_{og,h}/I_{ref}$ ^a %	
	$R_{sce} = 250$	$R_{sce} = 33$
h_2	1	1
h_3	4	3
h_4	1	1
h_5	4	3
h_6	2	2
h_7	4	3
h_8	2	2
h_9	1,5	1
h_{10}	1	1
h_{11}	2	1,5
h_{12}	1	1
h_{13}	2	1,5

^a I_{ref} = reference current
 $I_{og,h}$ = current component of smoothed harmonic group of order h
 Linear interpolation between R_{sce} values of 33 and 250 is permitted.

Table 2 – Alternative presentation of individual current harmonic limits for all ESE inverters up to 75 A per phase

R_{sce}	Individual harmonic orders and Individual harmonic current $I_{og,h}/I_{ref}^a$ %											
	h_2	h_3	h_4	h_5	h_6	h_7	h_8	h_9	h_{10}	h_{11}	h_{12}	h_{13}
33	1	3	1	3	2	3	2	1	1	1,5	1	1,5
250	1	4	1	4	2	4	2	1,5	1	2	1	2

^a I_{ref} = reference current
 $I_{og,h}$ = current component of smoothed harmonic group of order h
 Linear interpolation between R_{sce} values of 33 and 250 is permitted.

Table 3 – PHC limits for all ESE inverters up to 75 A per phase

	Single-phase 0 A to 16 A	Single-phase > 16 A and ≤ 75 A	Three-phase 0 to 16 A	Three-phase > 16 A and ≤ 75 A
$PHC I_{ref}$	1,30 %	1,30 %	1,30 %	1,90 %
$PHC_{triplen} I_{ref}$	0,70 %	0,90 %	n.a.	n.a.
$PHC_{zero} I_{ref}$	n.a.	n.a.	0,30 %	0,60 %

Individual currents below 1 % of the reference current are considered for the calculation of the PHC limits and the measured PHC .
 I_{ref} = reference current

7 Product documentation

7.1 Test report

The report shall include, as a minimum, all the following relevant information, showing conformity of the EUT with the requirements of this document:

- test conditions;
- observation time;
- value of the reference current I_{ref} ;
- short-circuit ratio R_{sce} used for the test;
- required minimum short-circuit ratio $R_{sce,min}$;
- statement as to whether grouped or ungrouped values were used for calculating PHC .

7.2 Instruction manual

For ESE inverters complying with the requirements of this document, the manufacturer shall state in the instruction manual supplied with the equipment:

“Equipment complying with IEC 61000-3-16”

For ESE not complying with Table 1, the manufacturer shall

- determine the minimum value of $R_{s_{ce}}$ for which the limits given in relevant Table 1 are not exceeded;
- declare the value of the short-circuit power S_{sc} corresponding to this minimum value of $R_{s_{ce}}$ (see 3.6) in the instruction manual; and
- instruct the user to determine, in consultation with the distribution system operator if necessary, that the ESE is connected only to a supply of that S_{sc} value or more. For that purpose, the statement in the instruction manual shall be:

“This equipment complies with IEC 61000-3-16 provided that the short-circuit power S_{sc} is greater than or equal to xx at the interface point between the user's supply and the public system. It is the responsibility of the installer or user of the equipment to ensure, by consultation with the distribution system operator if necessary, that the equipment is connected only to a supply with a short-circuit power S_{sc} greater than or equal to xx.”

where xx is the value of S_{sc} corresponding to the minimum value of $R_{s_{ce}}$ for which the limits given in the relevant Table 1 are not exceeded.

Annex A (informative)

Rationale for the limits in this document

A.1 General

The connection of inverter-type electrical energy-supplying equipment with a reference current less than or equal to 75 A per phase to public low-voltage systems is a developing technology, as can be seen from the dates of the papers mentioned in the Bibliography. These papers themselves have extensive further bibliographic information. Manufacturers of the equipment have been optimising system designs for better efficiency, EMC and cost performances and distribution service operators (DSOs) are evaluating the complex effects of added inverter-type generation on the networks. Proposed limits have therefore been subject to quite considerable discussions as a result of these activities.

A.2 History

Initially in 2016, limits were derived, as a first proposal, from IEC 61000-3-12 and IEC TR 61000-3-15. Radical new proposals were presented in 2018, with much lower limits. Whereas the maximum permitted voltage distortion of the supply source requirements were initially different and followed IEC 61000-3-2 for < 16 A, and IEC 61000-3-12 levels for up to 75 A, the proposed IEC 61000-3-16 has only the IEC 61000-3-12 requirements. Due to concerns about increased harmonic levels with the addition of new electrical energy-supplying equipment, based on inverter technology, to the networks, a lower emission limit for inverter-type electrical energy-supplying equipment was sought. As a future technology, the introduction of active harmonic compensation was also considered, but it was premature.

Neither the justification for lower limits, nor the changes in permitted voltage distortion of the supply source are minuted, but they were based on actual measurements of the output of typical equipment. The standard IEEE Std 1547TM-2018 was mentioned in discussions. New information was presented in February 2019, tending to support low limits, comprising limits for individual low-order harmonics and combined partial harmonic current limits for harmonics above order 13.

All the numerical values in this document are based on measurements and negotiations, taking into account the overall need to preserve compatibility levels; there are no simple mathematical bases for them. These limits were finalized by agreement between manufacturer and DSO experts in August 2019. Subsequently, the requirements for P_{HC} were simplified.

In order to formally register the work, a New Work Proposal was circulated in November 2019 and attracted some National Committee comments, which were considered but did not result, after discussions and negotiations, in any changes to the limits. Further explanations are included in Clause A.4.

A.3 Technology

A.3.1 Basic technology

An inverter for energy-supplying equipment consists of a controlled DC bridge of switching devices, metal-oxide semiconductor field-effect transistors (MOSFETs) or insulated-gate bipolar transistors (IGBTs), which typically operate in the frequency range above 10 kHz to produce a nearly sinusoidal current waveform. One well-known control method, among others, uses a pulse-width modulated (PWM) signal derived from a reference source. Such a configuration is capable of producing very low levels of harmonic output currents into a load or a network, but it also emits currents at the switching frequency, its sidebands and its integer multiples. Inverters of higher power rating use lower switching frequencies, even in renewable energy applications, down to the frequency range below 10 kHz. These currents are at present not within the scope of this document. The emissions at the switching frequency and its sidebands are typically attenuated by a T-type LCL filter at the output of the inverter. This presents a high impedance to higher-frequency signals both from the inverter and from the grid. It requires carefully-designed damping, in order to minimise the effects of resonances, because the filter cannot be terminated in the optimum resistances and the unknown network impedance has an impact on the filter transfer function.

For a grid-tied inverter, the near-sinusoidal signal is derived from the grid via a phase-locked loop (PLL), in order to synchronize the inverter and grid voltages. Distortion of the grid voltage can have a very large effect on the current emissions of the inverter, depending on the overall system control. These emissions can be helpful (mitigating the network distortion) or unhelpful (neutral to or even increasing the network distortion), depending on the control loops inside the controller of the inverter.

Inverter emissions can also be caused by ripple on the DC supply; this does not occur with photovoltaic sources, but can occur with, for example, wind generator sources. These emissions are not synchronized with the grid voltage and thus represent interharmonics, which can be of varying frequency.

A.3.2 Coping with grid voltage distortion

Grid voltage distortion can produce inverter harmonic emissions via two routes:

- by producing harmonic currents that flow through the source impedance of the inverter. (It is obvious that the impedance has to be very low at the fundamental frequency, otherwise the power loss in the inverter would be unacceptable.) However, the source impedance of the inverter is frequency-dependent, determined by the converter controller and its output filter parameters,
- by the impression of the distorted waveform on the PLL reference signal.

Complex designs are required in order to reduce these effects to acceptable levels.

Because of this effect, the emissions of inverters for verification of conformity with this document are measured with a very low distortion supply into which the inverter feeds energy.

A.4 Limits

A.4.1 General

Electromagnetic emissions can be cumulative, so it is sensible to set emission limits for each type of equipment as low as can be economically achieved. Although this principle is not formally stated in any IEC or CISPR document, it is established in IEC 61000-3-2 and 61000-3-12, in different ways. In IEC 61000-3-2, equipment is divided into classes, and economically-acceptable limits are set for each class. In IEC 61000-3-12, account is taken of the differing impedances of supplies suitable for the connection of high-power equipment, and economically-acceptable emission limits for currents are set so that the consequent voltage distortion is kept to an acceptable level. The emission limits in this document are based on IEC 61000-2-2:2002 and IEC 61000-2-2:2002/AMD1:2017, Table 1, and the levels of harmonic current emissions that are economically achievable.

There are several “impact factors” that could be taken into account for determining limits. These include the usage over time (per day and per year) and the phase diversity between pieces of the same type of equipment. This is in addition to the relation with the compatibility levels and economic factors. Inverters are permanently connected but supply power only for some hours a day, depending on the time of year and weather conditions. In low latitudes, there is much less variation over a year than there is in higher latitudes. There can be only limited phase diversity.

In an ideal world, the immunity to voltage distortion would be measurable and documented for every type of equipment, but this cannot be achieved. It is impracticable to determine the actual immunity, because it very likely depends on the mix of harmonic voltages presented and their relative amplitudes and phases. All that can be done is to set immunity test levels in product or product-family standards. Consequently, it is practicable only to set compatibility levels in terms of voltage distortion, and this is done in IEC 61000-2-2. As a consequence, current emission limits are set so that the risk of a compatibility level being exceeded somewhere is acceptably low. See IEC TR 61000-1-4:2022, Clause 4. Practical experience over the last decades has shown that most interference cases have been due to low order harmonics ($h < 10$), and extremely few interference cases are reported for higher order harmonics ($h > 20$).

In IEC 61000-2-2, some explanations for compatibility levels are given. See IEC 61000-2-2:2002 and IEC 61000-2-2:2002/AMD1:2017, 4.3 and 4.4. Planned voltage distortion on a network should not exceed some fraction of the compatibility level, to allow for arithmetic addition of in-phase emissions at some sites, and higher system impedances than the reference value of $0,4 \Omega + j0,25 \Omega$ given in IEC TR 60725. Different current emission limits are applied to all equipment for non-triplen odd harmonics, triplen harmonics and even harmonics, following the division for compatibility levels for voltage distortion in IEC 61000-2-2. To explain the differing emission limits, it is necessary to relate them to the different compatibility levels. Those for triplen harmonics and even harmonics are lower than those for other odd harmonics because they have particularly undesirable effects.

Triplen harmonics cause circulating currents in delta transformer windings and unbalanced voltages on three-phase supplies. These effects justify lower current emission limits.

Zero-sequence harmonics add up arithmetically in neutral conductors because of their low phase diversity, causing potentially dangerous overheating. In contrast to classical power systems, PWM inverters can cause zero-sequence harmonics at any frequency.

Even harmonics can cause asymmetrical saturation (saturation on one current peak but not on the next of opposite polarity), for example in transformers. This is in contrast to odd harmonics, which can only cause symmetrical saturation. As asymmetrical saturation has been regarded as more dangerous for the network than symmetrical saturation (probably because it is also caused by direct current), the compatibility levels for even harmonics have been set low.