PD IEC/TR 61000-3-15:2011

Electromagnetic compatibility (EMC)

Part 3-15: Limits – Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV networks

National foreword

This Published Document is the UK implementation of IEC/TR 61000-3-15:2011.

The UK participation in its preparation was entrusted by Technical Committee GEL/210, EMC - Policy committee, to Subcommittee GEL/210/12, EMC basic, generic and low frequency phenomena Standardization.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Electromagnetic compatibility (EMC) –
Part 3-15: Limits – Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 3-15: Limits – Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network

FOREWORD

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The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a Technical Report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 61000-3-15, which is a technical report, has been prepared by subcommittee 77A: Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
77A/744/DTR	77A/759/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

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

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication 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.

A bilingual version of this publication may be issued at a later date.

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 are 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 3-15: Limits – Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network

1 Scope

This part of IEC 61000 is concerned with the critical assessment of existing and emerging national and international standards for single and multi-phase dispersed generation systems up to 75 A per phase, particularly converters connected to the public supply low voltage network, to serve as a starting point and to ultimately pave the way for the definition of appropriate EMC requirements and test conditions. This Technical Report is limited to EMC issues (immunity and emission) up to 9 kHz and does not include other aspects of connection of generators to the grid.

2 Terms and definitions

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

2.1
electromagnetic compatibility
EMC
ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[IEC 60050-161:1990, 161-01-07]

2.2
distributed generation, embedded generation, dispersed generation
DG
generation of electric energy by multiple sources which are connected to the power distribution system

[IEC 60050-617:2009, 617-04-09]

2.3
current source inverter
stiff current source inverter (inverter operating as an impressed current source)

2.4
voltage source inverter
stiff voltage source inverter with current control (inverter operating as an impressed voltage source)

2.5
low voltage
LV
set of voltage levels used for the distribution of electricity and whose upper limit is generally accepted to be 1 000 V a.c.

[IEC 60050-601:1985, 601-01-26]

2.6
(electromagnetic) emission
phenomenon by which electromagnetic energy emanates from a source

[IEC 60050-161:1990, 161-01-08]

NOTE For the purpose of this report, emission refers to phenomena such as conducted electromagnetic disturbances that can cause distortions, fluctuations or unbalance on the supply voltage.

2.7
emission level (of a disturbing source)
level of a given electromagnetic disturbance emitted from a particular device, equipment, system or disturbing installation as a whole, assessed and measured in a specified manner

2.8
power quality
characteristics of the electric current, voltage and frequencies at a given point in an electric power system, evaluated against a set of reference technical parameters

NOTE These parameters might, in some cases, relate to the compatibility between electricity supplied in an electric power system and the loads connected to that electric power system.

[IEC 60050-617:2009, 617-01-05]

2.9
point of common coupling
PCC
point of a power supply network, electrically nearest to a particular load, at which other loads are, or may be, connected

NOTE 1 These loads can be either devices, equipment or systems, or distinct customer's installations.

NOTE 2 In some applications, the term “point of common coupling” is restricted to public networks.

2.10
emission limit (allowed from a disturbing source)
specified maximum emission level of a source of electromagnetic disturbance (e.g. device, equipment, system or disturbing installation as a whole)

2.11
immunity (to a disturbance)
ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

[IEC 60050-161:1990, 161-01-20]

2.12
immunity level
maximum level of a given electromagnetic disturbance on a particular device, equipment or system for which it remains capable of operating with a declared degree of performance

2.13
fundamental component
sinusoidal component of the Fourier series of a periodic quantity having the frequency of the quantity itself

2.14
harmonic frequency
frequency which is an integer multiple of the fundamental frequency

NOTE The ratio of the harmonic frequency to the fundamental frequency is the harmonic order (recommended notation: “h”).

2.15
interharmonic frequency
frequency which is a non-integer multiple of the reference fundamental frequency

NOTE 1 By extension from harmonic order, the inter-harmonic order is the ratio of an inter-harmonic frequency to the fundamental frequency. This ratio is not an integer. (Recommended notation “m”).

NOTE 2 In the case where $m < 1$, the term sub-harmonic frequency may be used.

2.16
total harmonic distortion
THD
ratio of the r.m.s. value of the harmonic content of an alternating quantity to the r.m.s. value of the fundamental component of the quantity

2.17
voltage unbalance
in a poly-phase system, a condition in which the magnitudes of the phase voltages or the phase angles between consecutive phases are not all equal (fundamental component)

2.18
flicker
impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time

2.19
short-term flicker indicator
P_{st}
measure of flicker evaluated over a specified time interval of a relatively short duration

NOTE The duration is typically 10 min, in accordance with IEC 61000-4-15.

2.20
long term flicker indicator
P_{lt}
measure of flicker evaluated over a specified time interval of a relatively long duration, using successive values of the short-term flicker indicator

NOTE The duration is typically 2 h, using 12 successive values of P_{st}, in accordance with IEC 61000-4-15.

2.21
voltage fluctuation
series of voltage changes or a continuous variation of the r.m.s. or peak value of the voltage

2.22
voltage dip (voltage sag)
sudden reduction of the voltage at a point in an electrical system followed by voltage recovery after a short period of time from a few cycles to a few seconds

2.23
short interruption (of supply voltage)
disappearance of the supply voltage for a time interval whose duration is between two specified limits

2.24
distribution system operator, distribution network operator
DSO
party operating a distribution system

2.25
product test
test which assesses the DG current emissions in worst case conditions

NOTE This test method is based on the test circuits specified in IEC 61000-3-2 (up to 16 A), and IEC 61000-3-12 (up to 75 A).

2.26
system test
test which emulates the DG actual condition in the public supply network

NOTE This test method is based on the test circuits specified in IEC 61000-3-3 (up to 16 A), and IEC 61000-3-11 (up to 75 A), including the impedance, with the addition of a defined load and specified pre-distortion levels.

2.27
islanding protection
protection against the continuous operation of the inverter and part of the utility load once isolated from the remainder of the electric utility system

2.28
active infeed converter
AIC
self commutated electronic power converter of all technologies, topologies, voltages and sizes which are connected between the electrical a.c. power supply system (lines) and a d.c. side (current source or voltage source) and which can convert electrical power in both directions (generative or regenerative) and control the power factor of an applied voltage or current

NOTE Some of them can additionally control the harmonic distortion of an applied voltage or current. Basic topologies may be realized as a Voltage Source Converter (VSC) or a Current Source Converter (CSC).

3 General

This Technical Report applies to DG and primarily concerns the critical assessment of several common low frequency electromagnetic emission and immunity requirements.

It can be considered an initial proposal in order to gain experience toward the definition of appropriate EMC limits and test conditions for the connection of potentially disturbing installations to LV power systems.

This Technical Report focuses on emission caused by DG (mainly harmonics and inter-harmonics, DC emissions flicker, rapid voltage changes and fluctuations), as well as immunity aspects to normally occurring events in the public supply network (voltage dips and short interruptions, frequency variations, harmonics and interharmonics).

In addition, every effort has been made to utilize already existing emission and immunity standards, including the test set-up and existing test equipment in use.

The existing standards, in combination with the requirements of DG equipment, lend themselves to the definition of two types of emission tests:

- the “product test”;
- the “system test”.

The application of these two test methods is believed to meet the demands from both DSO and DG manufacturers and should result in reliable operation of DG equipment up to 75 A when connected under typical network conditions. It should be noted that these tests, although being primarily emission tests, also deal to some extent with the immunity of the DG against normally occurring events in the public supply.

At this time, DG equipment is generally not designed to compensate for current or voltage distortions but this possibility may be evaluated for future developments. For such developments no requirements are included in this Technical Report, but the method of the system test introduced in this report could be used to evaluate compensating behaviour.

The suggested emissions and immunity tests are devised to assure that DG equipment connected to the network may be expected to function acceptably in the EMC environment.

4 Classification of DG generators

4.1 General

The aim of the following short description of different generation systems is to highlight the behavior of static power supplies connected to the electrical network compared with other types of generators.

There are three main types of generation systems that interface to the power system. These include:

- induction (asynchronous) generators;
- synchronous generators;
- static power converters.

Each type has its own specific characteristic regarding synchronization equipment, protective functions, starting practices, and electrical operating behavior. The primary energy source of generating plant can be internal or external combustion, wind, fuel cells, electrochemical accumulators flywheel storage systems, small scale hydro and photovoltaic cells.

In this Technical Report both current and voltage source inverters are addressed. Although, most DG inverters might be considered as voltage source inverters based on their topology, they behave with a current source control strategy when viewed from the network integration perspective.

This means that it is generally assumed that the line voltage at the point of DG connection can be regarded as constant, so the desired power injection is achieved by controlling the current injected by the inverter.

4.2 Induction (asynchronous) generators

An induction generator, “asynchronous” generator, operates on the principles of an AC induction motor, except that in normal operation it has a speed of rotation slightly greater than the synchronous speed of the power system. Induction generators, however, are commonly used in power plants that only need to operate in parallel with another source (such as the utility system).

Induction generators take their excitation current via their stators. Thus, they consume reactive power from the system. This causes voltage drop and increased losses in the distribution system. In situations where system losses and voltage drop are significant, the induction generator may need provisions to correct its power factor to near unity.

Induction generators cannot sustain an appreciable fault current at their terminals for a long time due to the collapse of excitation source voltage during the fault. However, they will inject a large amount of current for a short transient period of time and this can impact the power system. Because of the characteristics of the induction generator described above, its protection and interface is somewhat different from that of the synchronous generator.

4.3 Synchronous generators

Synchronous generators (acting as voltage sources) are rotating energy conversion machines capable of operating as stand-alone power sources (running independently of any other source). They also can operate in parallel with other sources (such as a utility distribution system) if they are properly synchronized to those sources and have appropriate protection/controls.

One of the synchronous generator's characteristics is that the integral exciter and exciter controls allow it to operate as a stand-alone source. This is particularly useful for DG installations that can serve the dual function of stand-alone (standby) power unit and also grid parallel operation. Extra care in the anti-island protection is required with these units.

In addition, synchronous generators, unlike induction generators, shall be precisely synchronized with the utility system at the instant of connection and during operation. This means matching the frequency, phase angle and voltage magnitude within certain tight tolerances at the instant of interconnection of the customer's circuit breaker interface between the utility network in order to avoid damage to, or problems with, the generator or utility system equipment.

The unit's load shall be controlled in order to maintain synchronicity. If the unit slips out of synchronism and is not immediately separated from the system equipment, damage or power quality problems are likely to occur.

Synchronous generators, due to their exciters, can sustain fault currents for much longer than an induction generator (assuming the exciter energy source is separately derived). This makes fault protection more critical on a synchronous unit than on an induction unit.

4.4 Static power converters

The static power converter (inverter) provides the interface between direct current (DC) energy sources or variable frequency sources and the power distribution system. Examples of generation systems employing inverter units include photovoltaic arrays, fuel cells, battery storage systems, some types of micro-turbines, and some types of wind turbines.

Unlike an induction or synchronous generator that uses rotating coils and magnetic fields to convert mechanical into electrical energy, the inverter normally converts one form of electricity into another (i.e. DC to AC) using solid state electronics, and it is typically controlled and protected by its internal electronic circuits. The internal controller detects abnormal voltage, current and/or frequency conditions and quickly disables the injection of power into the utility system if maximum tolerances for voltage or frequency deviations are exceeded. It also controls synchronization and start-up procedures.

While most small converter units designed for grid parallel operation can rely totally upon their internal protection functions, larger and special feature inverter units may also require external protection/control functions.

There are differences between inverters and rotating machines. For example, as the inverter has no moving or rotating parts, it utilizes the on/off switching of semiconductor devices to "synthesize" the AC power frequency waveform from the energy source. In addition, due to the fast switching response of solid state switching devices, a converter is usually able to stop producing energy much faster than a typical rotating machine, once the controller protection scheme identifies the need to interrupt flow of energy.

5 Survey of EMC requirements for DG

The need for testing and certification of distributed generation equipment to ensure a compatible, reliable interconnection with the electric power grid and other load equipment is leading research bodies, such as IEEE, EPRI, UL, CIGRE and CIRED to increase the investigations on this matter to arrive at operating guidelines or standards that find widespread acceptance.

Within the framework of international EMC standardization regarding integration of renewable energy sources and distributed energy generation in the electricity supply, the development of common EMC requirements is more and more required.

The most frequently used specifications and emission requirements in different countries are summarized in Table 1.

The aim of Table 1 is mainly to assess how low frequency emission requirements are taken into account in different countries and to summarize the possible national/international standards and common practice specifications that are normally applied to DG and comply with DSOs' restrictions.

In Table 1, data related to voltage fluctuations, harmonics and DC injection were mainly provided by CIGRE TF C6.04.01, a Task Force dedicated to the connection criteria at the distribution network for distributed generation [1][1].

The Table was subsequently updated on the basis of the contributions from National Committees. The last column in Table 1 lists the references to National Specifications.

The proposed emission tests in this Technical Report are derived with these existing standards in mind.

Data on EMC low frequency immunity requirements were insufficient for a dedicated table.

Table 1 – DG specifications and emission requirements applied in different countries

Country	*Voltage fluctuations*	*Harmonics*	*DC injection*	*National specifications*
Austria	P_{lt} = 0,46 Resulting from all the connected generators at the PCC mostly affected	Individual limits based on the available short-circuit power (half of the limits used for loads of the same power)	Systems which inject DC current by design (e.g. half wave operation) are not permitted. (Ref to EN 50438:2007)	TOR D2:2006 Assessment of network interferences for any installation (MV and LV) ÖVE/ÖNORM E 8001-4-172:2009 (for PV installations)
Belgium	informative IEC 61000-3-3, IEC 61000-3-5 to IEC 61000-3-11	informative IEC 61000-3-2, IEC 61000-3-4 IEC 61000-3-12	< 1 % of rated current; if > 1 %, trip after 0,2 s	Synergrid – Specific technical requirements for connection of DG systems operating in parallel on the distribution network (C10/11 – revision 12 May 2009)
Canada	IEEE 519 or IEC 61000 series	IEC 61000 series or IEEE 519	IEEE 1547: < 0,5 % rated current	C22.3 NO. 9.08 Interconnection of Distributed Resources and Electricity Supply systems CAN/CSA-C22.2 NO. 257-06 Interconnecting Inverter Based Micro-Distributed Resources to Distribution Systems

1 Numbers in square brackets refer to the Bibliography.

Country		Voltage fluctuations	Harmonics	DC injection	National specifications
	France	IEC 61000-3-3, IEC 61000-3-11 Limited such that DSO can meet its commitments in terms of power quality. $P_{lt} \leq 1$	IEC 61000-3-2, IEC 61000-3-12 Limited such that DSO can meet its commitments in terms of power quality.		Government decree 2003-229 and Ministerial orders (March and April 2003, November 2006) on the general technical requirements regarding design and operation which installations must fulfill for connection to the public distribution network Distribution Technical Guide (EDF)
	Germany	IEC 61000-3-3, IEC 61000-3-11	IEC 61000-3-2, IEC 61000-3-12	1 A max (not normal operation) trip after 0,2 s	E VDE-AR-N 4105 Guideline for DG connection to the LV grid (draft July 2010) VDE 0126-1-1 Automatic disconnection device between a generator and the public low-voltage grid
	Greece	IEC 61000-3-3, IEC 61000-3-11	IEC 61000-3-2 IEC 61000-3-4	Under consideration; < 1 % of rated current	Technical requirements for the connection of independent generation to the grid Guide for the connection of PV installations to the LV network
	Italy	IEC 61000 series	IEC 61000 series	< 0,5 % rated current	CEI 0-21 (draft) Reference technical requirements for connecting active and passive electrical users to LV networks of electrical supply companies
	Japan	ΔV_{10} shall be ≤ 0,45 in general	Current THD ≤ 5 % each harmonic current ≤ 3 %	1 % of rated current, trip after 0,5s	Interpretation of the Technical Standards for Electrical facilities; Grid interconnection Code
	Korea (Rep. of)	$P_{lt} \leq 0.25$, $P_{st} \leq 0.35$	IEEE 519: TDD = 5 %	IEEE 1547: < 0,5 % rated current	Technical requirement for the connection of distributed generation to the distribution system.
	Malaysia	IEC 61000 series P_{st} = 1; P_{lt} = 0.8	IEC 61000 series	None	Malaysian standards adopted from IEC
	Mexico	IEC 61000-3-3	IEEE1547 IEEE 519 IEC 61000-3-2 IEC 61000-3-6	Under consideration	CFE-L0000-45 Permissible deviations on the wave forms of voltage and current in the power source. CFE-L0000-70 NMX-J-610/3-2-ANCE NMX-J-610/3-3-ANCE NMX-J-610/3-6-ANCE NMX-J-610/3-12-ANCE
	Netherlands	IEC 61000 series	IEC 61000 series	EN 50438	NTA 8494 Qualification measurements for grid-connected (PV)-inverters
	Portugal	IEC 61000 series	IEC 61000 series	EN 50438	Technical requirements needed for the connection of DG systems to the LV EDP Electrical Network (Portuguese Grid)
	Slovenia	IEC 61000-3-3 or P_{lt} = 0,46 at the PCC mostly affected	IEC 61000-3-2, Class A or IEC 60034-1 or individually calculated when inverters are used	0,5 % of rated current and not exceeding 1A	"Guideline for connection and operation of power plants up to 10 MW in the distribution network" (National System operator of distribution network – SODO)

Country		***Voltage fluctuations***	***Harmonics***	***DC injection***	***National specifications***
	Spain	IEC 61000 series	IEC 61000 series	IEC 61000 series Galvanic isolation or any equivalent method is required	Royal decree 1955/200 ORDER 5/9/1985 Administrative and technical rules for the operation and interconnection to the grid of hydroelectric power plants up to 5 MVA and "autogeneration plants" RD 1663/2000 Interconnection of PV installation for the low voltage grid
	Switzerland	P_{lt} = 0,46 at the PCC mostly affected	Individually calculated when inverters are used	1 A max (not normal operation) trip after 0,2 s	VSE/AES 301/006 Technical Rules for the Assessment of Network Disturbances
	Thailand	TIS 1449-2010 TIS 2484-2010 TIS 1450-2010	TIS 1448-2010 TIS 2483-2010 TIS 2485-2010	< 0.5 % of rated inverter current	Thailand's standards adopted from IEC
	United Kingdom	IEC 61000-3-3 IEC 61000-3-11 P_{st} < 0,5 measured at PCC according to ENA ER P28; P_{st} < 1,0 measured at the supply terminals (not applicable to generating plant exporting power to other consumers)	IEC 61000-3-2 (Class A) IEC 61000-3-12 IEC/TR 61000-3-4 Limits implemented through references in ENA ER G59/1, ER G83, ER G5/4-1	20 mA limit recommended in ENA ER G83. DGS < 16A Zero limit recommended in ENA G5/4-1	Compliance with Energy Networks Association (ENA), Engineering Recommendations (ERs) relating to the connection of equipment, mandatory in accordance with the Distribution Code for all DSOs holding Distribution Licenses issued by the Regulatory Authority
	Australia	AS/NZS 61000 series	AS/NZS 61000 series	IEC 61000 series	AS 4777 series: Grid connection of energy systems via inverters; Series AS 4509: Stand alone power systems
	USA	IEEE 519	IEEE 519	Varies among utilities	IEEE Standard 1547 Energy Policy Act of 2005

6 Proposed EMC requirements and tests

6.1 General test requirements

The proposed general test setup for emission and immunity tests for DC supplied inverters is shown in Figure 1.

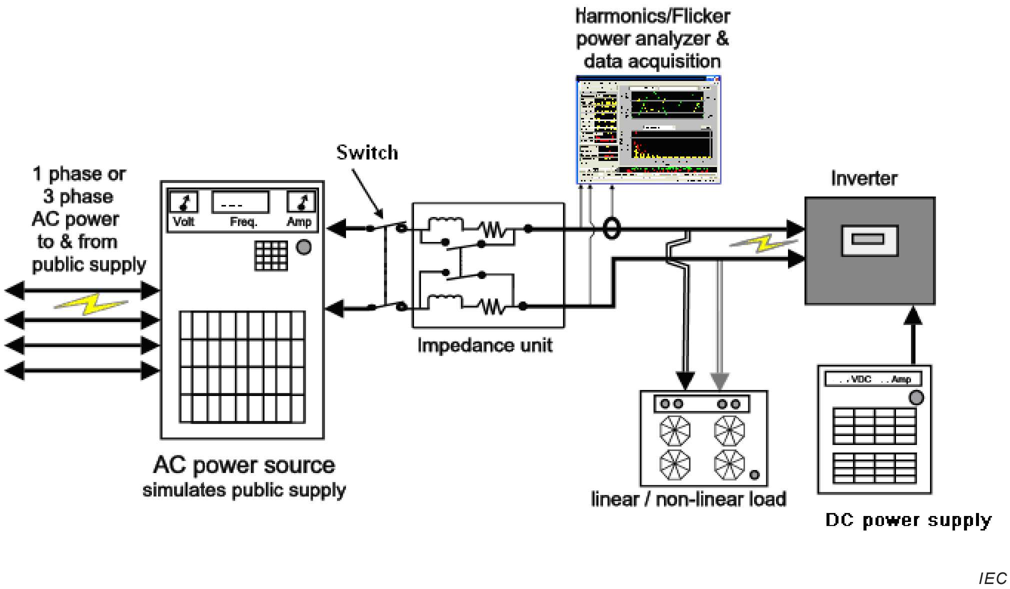


Figure 1 – General test setup for combined emission/immunity tests

The impedance unit shown in Figure 1 can be in-line or by-passed. It simulates the public supply network impedance as specified in IEC 61000-3-3 or IEC 61000-3-11, depending on the DG power. With the impedance in line, any non-linear current flowing to or from the inverter or the load will cause voltage distortion at the inverter side of the impedance. For the purposes of the tests defined in this Technical Report, the Z_{ref} defined in IEC 61000-3-3 and Z_{test} defined in IEC 61000-3-11, 6.3 are suggested.

For current levels up to 16 A, the IEC 60725 Reference Impedance ("Z_{ref}") values are used. The combined resistance plus inductance values for European 230 V – 50 Hz public supply networks are defined as (0,4 Ω + j 0,25 Ω) consisting of (0,24 Ω + j 0,15 Ω) for the phase and (0,16 Ω + j 0,1 Ω) for the neutral. For higher current levels up to 75 A, the suggested "Z_{test}" impedance values are specified in IEC 61000-3-11, 6.3 and result in a combined impedance of (0,25 Ω + j 0,25 Ω). For North American networks, appropriately lower impedance values may be used, when performing the system test.

An appropriate power analyzer/data acquisition unit should be used to measure current emissions, voltage fluctuations and flicker, as well as voltage distortions caused by the inverter.

The AC power source simulates the public supply and can produce distorted voltages, dips and interruptions and frequency variations. The AC power source or the impedance unit has to be able to separate the simulated power supply from the inverter. This may also be accomplished by a separate switch as shown in Figure 1. Opening this switch simulates the circuit breaker tripping, i.e. separating the DG from the public supply at the local level, while programming the voltage to zero simulates the situation when the public supply voltage goes to zero.

If the power source used to simulate the public supply is regenerative, it can feed the (excess) inverter power back into the public supply. If the power source is not regenerative, an additional parallel load unit is necessary, or the power source shall be capable to absorb all of the power produced by the inverter. The load unit shall be capable of producing linear and non-linear current flow, to simulate the typical load pattern such as found in homes and offices.

DC supply shown in Figure 1 provides power to the inverter and can be set to various power levels, so as to operate the inverter at various power generation levels. A standard DC supply, possibly computer controlled or otherwise controllable, with variable voltage is to be used for the tests.

6.2 Proposed tests

The result of the assessment process led to the compilation of the tests shown in Table 2. Successful completion of the tests, some of which are dealt in detail in Clauses 7 and 8, should result in reliable operation of DG equipment up to 75 A when connected under typical network conditions.

It should be noted that these are proposed tests only.

Table 2 – Proposed EMC requirements and tests for DG equipment

Refer to Figure 1 for general test setup and requirements of emission/immunity tests				
DG proposed test	**Test set up configuration**	**Proposed limits**	**Test impedance**	**Test specific notes**
Harmonic emissions	IEC 61000-3-2 IEC 61000-3-12	Modified Class C (≤ 600 W) - Modified Table 2 of IEC 61000-3-12, R_{sce} =33 (> 600 W)	NO	Product test
	IEC 61000-3-3 IEC 61000-3-11 Pre-distorsion < 5 %	If V-THD < 5 %, increase of V-THD < 1 % due to DG	YES	System test
Flicker Voltage fluctuations	IEC 61000-3-3 IEC 61000-3-11	P_{st} = 0,5 ΔU = 4; 6 % d_c = d(t) = 3,3 %	Z_{ref} or Z_{test} depending on DG power	Product test
DC Injection	See harmonic emissions	0,5 A or 1 % I_{rated} whichever is less	NO	Product test
Short and long duration overvoltage emission caused when DG disconnects from the public supply	IEC 61000-3-3 IEC 61000-3-11	Voltage tolerance envelope	YES	Less then 2 cycle test
		Voltage tolerance envelope	YES	Greater then 2 cycle test
Switching frequency emission	Under consideration	Under consideration	----	For emissions from 2 to 9 kHz, work is in progress in IEC 77A WG1
Immunity to voltage dips and short interruptions	IEC 61000-4-11 IEC 61000-4-34	Voltage dip Tolerance Curve	YES	Short dip/interrupt < 100 ms
				Longer duration voltage dips
Immunity to frequency variation	IEC 61000-4-28	± 6 %	NO	
Immunity to harmonics and inter harmonics	IEC 61000-4-13	Class 2 Class 3	NO	Immunity from 2 to 9 kHz is under consideration

7 Emission

7.1 General

Depending on the primary energy source and on the technology used for the conversion process, the connection of DG units to the grid may increase the disturbance level, thus increasing the probability that electromagnetic interference occurs.

The degradation of the power quality may affect the installations of the network users and prevent the network operator from meeting its obligations. The magnitude of DG caused disturbances depends largely on the short-circuit power available at the connection point and on the power level of the DG unit. The phenomena are therefore expected to be more important on weak grids. Hence, the network impedance at the PCC may be one of the limiting factors which determines the number and size of DG units that can be connected. In addition to the size of individual DG units, their parallel operation needs to be considered as well.

The impact on the public supply network also depends on the technology used, especially for the coupling with the grid: for instance, coupling systems making use of an electronic interface may help to limit or even avoid voltage fluctuations or flicker but in some cases they may carry a risk in terms of increased voltage distortion.

Whereas this Technical Report is principally concerned with limiting DG emissions to acceptable levels, it might be possible in the near future to utilize DG to improve power quality. If DG penetration will sufficiently increase, a possible solution to reduce EMC impact on the network could be to adopt a different inverter strategy in order to achieve a behaviour of the inverter emulating synchronous generators [2]. In addition to this type of behaviour, active infeed technology could be used to improve power quality using a compensating behaviour that could be superior to that of synchronous generators.

Thus, improved power quality of the public supply might be achieved either by using inverters with voltage source control strategy or by using a group of devices, which, for instance, could consist of inverters with current source control strategy and an additional compensation system.

Operation of DG equipment, including switching at start up and stopping, power conversion and stochastic output may cause:

- voltage fluctuations;
- flicker;
- harmonic and inter-harmonic emissions;
- unbalance;
- disturbance of network signaling systems (PLC/ripple control).

The following clauses give information concerning possible test methods for the above phenomena as applicable to DG units, taking into account the data collected in Table 1.

7.2 Harmonics

7.2.1 Mechanisms of harmonic current emissions

Many inverters based DG have harmonic currents at the PCC that appear to be significantly dependent on the harmonic voltage content of the AC-system voltage [3]. The impact of harmonic currents produced by the DG on the harmonic voltage distortion also depends on the impedance of the supplying grid at the PCC, the properties of the internal filter of the DG equipment and the characteristics of the control system of the DG.

If the control system takes its current reference waveform from the measured network voltage, the harmonic components in the voltage produce harmonic currents that tend to increase the voltage distortion.

In addition to harmonic currents caused by the supply voltage harmonics, DG equipment generates harmonics of its own due to the switching operation of its solid state devices. These harmonics are usually above 2 kHz but even then small components at lower frequencies exist due to the imperfections in the control and solid state device properties. Naturally the magnitude of the generated harmonics depends on the type of the DG equipment's internal filter and its component values.

Furthermore, the harmonic currents could differ considerably under different generating conditions, e.g. there can be a substantial difference between high and low input power operations of the inverter [4]. The assessment for grid connection of photovoltaic based inverters should take this into account. For example, in case of a solar inverter with DC/AC current control using open-loop control for low-load conditions and closed loop control for higher loading conditions, the harmonics are higher for low power generation conditions and reduced for peak generation conditions (see Annex A). Therefore several load levels are defined in harmonic current emission tests.

Some more details and measurements results are given in Annex A.

7.2.2 Proposed limits and tests for harmonic current emissions

Specific recommendations on harmonic emissions associated with interconnecting distributed resources with electric power systems can be found in IEEE 1547 [5].

Even though the harmonic current emission limits in IEC 61000-3-2 (up to 16 A) and IEC 61000-3-12 (from 16 A to 75 A) were derived with loads in mind and DG was not considered, it can be assumed that there is a substantial degree of commonality between certain loads and dispersed generation as far as emissions are concerned.

In particular, there is commonality between lighting type loads and dispersed generation below 600 W. Both lighting and DG are used for prolonged periods and may also have comparable power levels. The combined lighting products of a home can be comparable to small inverters, while a small office building can have a combined lighting power consumption that is similar to popular inverter types in the low kilowatt range. This is particularly applicable to photovoltaic based inverters. Therefore it can be concluded that lighting and small size inverters generally have a potentially similar impact on the network as far as current emissions are concerned, irrespective of the direction of current flow.

Consequently, it seems to be reasonable to consider a set of limits based on the slightly modified IEC 61000-3-2 Class C (lighting) limit table, as a good guideline for limiting current emissions for DG units below 600 W. The slightly modified proportional limits of IEC 61000-3-12 (Table 2, R_{sce} = 33) are believed to be suitable for DG equipment in the power range above 600 W.

In addition to limiting current emissions, the DG should not significantly increase the voltage distortion on the network. To verify that the DG equipment causes neither current nor voltage distortion to exceed acceptable levels, two test methods are proposed: the first method defines a strongly suggested "product test" and the second method, highly recommended as a supplementary test, defines a "system test" for DG equipment.

The product test method utilizes the test set up specified in IEC 61000-3-2 (up to 16 A), that is similar to the test setup for IEC 61000-3-12 (up to 75 A). The test basically assesses the DG current emissions in worst case conditions: if the DG meets the proposed limits, it is expected to function properly in all but the most exceptional cases.

The current emission limits specified in IEC 61000-3-2 and IEC 61000-3-12 were derived to limit voltage distortion to acceptable levels at the point where the load is connected. The network is not ideal however, i.e. may have significant distortion present. Any added current distortion from the DG can increase the voltage distortion already present in the network, so it is necessary to limit the amount of increased voltage distortion the DG may cause.

For this reason, the system test method is proposed which utilizes the test circuits specified in IEC 61000-3-3 (up to 16 A), and IEC 61000-3-11 (up to 75 A), including the impedance, with the addition of a defined load and specified predistortion levels, in order to emulate the actual condition in the public supply network.

The proposed test methods should enable the user and the manufacturer to assure that DG equipment can function acceptably in the EMC environment commonly found on the network. Provided that the DG meets the product test requirements, it is proposed that an acceptable system behavior is achieved when the DG equipment does not cause local voltage harmonic distortion to increase by more than 1 % absolute, under the assumption that the local voltage distortion is less than 5 % prior to the connection of DG.

7.2.3 Summary of harmonic current emission tests

Table 3 specifies the characteristics of the main instrumentation and lists different suggested product and system tests for harmonic current emissions.

Table 3 – Different suggested product and system tests for harmonic emissions

	Main instrumentation to perform DG tests
POWER SOURCE	– *Regenerative -> the power source feed back the DG power to the public supply* – *NOT regenerative -> the power source or load shall absorb all the DG power plus an acceptable margin*
LOAD	– *linear* – *NOT linear*
DC SUPPLY	– *variable voltage for different DG power levels*

PRODUCT TEST *(ideal network)*

Limits: as proposed in Table 6			
Load	**Power source[a]**	**Reference impedance**	**Pre-distortion level**
None	Regenerative nominal voltage	NO	NO
Power source or linear load	Not regenerative nominal voltage	NO	NO

Product test main features:

DG harmonic emissions measured in a worst case condition. If product test is passed, DG functions properly in public supply network (in all but the most exceptional cases)

[a] maximum allowed voltage distortions according to IEC 61000-3-2 (< 16 A) and IEC 61000-3-12 (> 16 A)

SYSTEM ***TEST*** *(voltage distortion on the network)*

Load	**DG supply**	**Network impedance[b]**	**Pre-distortion level < 5 %**	**Set up**	**DG voltage distortion limit**
linear	100 %	Z_{ref} or Z_{test}	4,0 ± 0,2 % set by source[c]	IEC 61000-3-3/11	V-THD_{DG} increase < 1 %
50 % linear 50 % not linear	100 %	Z_{ref} or Z_{test}	4,0 ± 0,2 % caused by load	IEC 61000-3-3/11	V-THD_{DG} increase < 1 %
25 % linear 25 % not linear	100 %	Z_{ref} or Z_{test}	2,5 ± 0,2 % caused by load	IEC 61000-3-3/11	V-THD_{DG} increase < 1 %
25 % linear 25 % not linear	50 %	Z_{ref} or Z_{test}	4,0 ± 0,2 % caused by load	IEC 61000-3-3/11	V-THD_{DG} increase < 1 %

[b] of the public supply network: Z_{ref} in IEC 60725 = 0,4 Ω + j 0,25 Ω (impedance applied for power levels < 16 A per phase); Z_{test} = 0,25 Ω + j0.25 Ω (impedance applied for power levels > 16 A per phase).

[c] See Table 7.

7.2.4 Product test procedure for harmonic current emissions

Connect the DG as shown in Figure 1 (with impedance by passed) and set the simulated public supply to the nominal voltage.

For DG below 16 A, verify that the simulated public supply has a voltage distortion that is less than the maximum values specified in IEC 61000-3-2, Clause A.2 and illustrated in Table 4.

Table 4 – Voltage distortion of simulated public supply (IEC 61000-3-2)

The harmonic ratios of the test voltage (U) shall not exceed the following values with the EUT connected as in normal operation: 0,9 % for harmonic of order 3; 0,4 % for harmonic of order 5; 0,3 % for harmonic of order 7; 0,2 % for harmonic of order 9; 0,2 % for even harmonics of order from 2 to 10; 0,1 % for harmonics of order from 11 to 40

For DG above16 A, verify that the simulated public supply has a voltage distortion that is less than the maximum values specified in IEC 61000-3-12, 7.1 and illustrated in Table 5.

Table 5 – Voltage distortion of simulated public supply (IEC 61000-3-12)

The harmonic ratios of the output voltage (U) in no load condition shall not exceed the following values: 1,25 % for harmonic of order 3; 1,5 % for harmonic of order 5; 1,25 % for harmonic of order 7; 0,6 % for harmonic of order 9; 0,4 % for even harmonics of order from 2 to 10; 0,7% for harmonic of order 11; 0,6% for harmonic of order 13; 0,3 % for harmonics of order 12 and from 14 to 40

Verify that the DG current emissions remain within the limits specified in Table 6.

The limits reported in Table 6 are defined as a percentage of the average r.m.s. current level (I_{rms}) that the DG unit can be operate on a continuous basis in full load condition.

The method to determine the maximum continuous operating current is the method used in IEC 61000-3-12 (basically the average of the current over the observation period with the inverter operating at maximum power).

The inverter is, at first, operated at the maximum (rated) power it can continuously handle. The current at that level is the basis for limits, even when the unit is tested at 25 % and 50 % power.

Table 6 – Limits for DG up to 75 A/phase (in percent of I_{rms})

Harmonic order	2	3	5	7	9	11	13	Odd harmonics from H_{15} to H_{39}	Even harmonics from H_4 – H_{40}
For DG ≤ 600 W	2 %	30 % x λ	10 %	7 %	5 %	3 %	3 %	3 %	2 %
For DG > 600 W	1 %	21,6 %	10,7 %	7,2 %	3,8 %	3,1 %	2 %	1 %	1 %
NOTE λ is the power factor of the DG, measured under 100 % power generation condition									

7.2.5 System test procedure for harmonic current emissions

In Table 7 are reported the distortion values for a voltage distortion V-THD of 4,0 % based on flat top and peak curve of IEC 61000-4-13.

Table 7 – Distortion values for a flat top and peaky voltage distortion V-THD of 4,0 %

Frequency	Fund.	H3	H5	H7	H9	H11	H13	H15	H17	H19
Amplitude (%)	100	3,3	1,6	1,1	0,8	0,6	0,4	0,2	0,1	0,1
Phase for flat-top wave form	0 °	10 °	210 °	300 °	220 °	20 °	0 °	120 °	180 °	0 °
Phase for peaky wave form	0 °	180 °	0 °	270 °	0 °	180 °	0 °	0 °	0 °	0 °

7.3 Unbalance

Depending on the type of DG units and the connection to the grid, it may increase the unbalance rate and therefore may affect the quality of supply. Even though there is no direct test to establish unbalance caused by a single phase DG, possible flicker/voltage fluctuations may occur and the following considerations apply.

The system voltages at a generation site are generally highly symmetrical due to the construction and operation of synchronous generators used in large centralized power plants. Therefore, the central generation generally does not contribute to unbalance.

However, when small-scale distributed generation, sometimes embedded in energy management systems, is installed at the customer's site and represents a significant share of the electricity production, the situation is different. Many of these relatively small units, such as photovoltaic installations, are usually connected to the grid at LV by means of single-phase power electronic inverter units. The connection point has a relatively high impedance (the short-circuit power is relatively low), leading to a potentially larger unbalance of the voltage compared with connections at higher voltage level.

The impedance of electricity system components is not exactly the same for each phase. The geometrical configuration of overhead lines, possibly asymmetric with respect to the ground for instance, causes a difference in the electrical parameters of the line. Generally, these differences are very small and their effect can be neglected when sufficient precautions, such as the transposition of lines, are taken. In most practical cases, the asymmetry of the loads is the main cause of unbalance.

In IEC 61000-2-2, the standard related to the compatibility levels for low-frequency conducted disturbances, voltage unbalance should be considered in relation to long term effects, i.e. for durations of 10 min or longer and only in relation to the negative phase sequence component, this being the component relevant to possible interference with equipment connected to public low voltage distribution systems. For systems with the neutral point directly connected to earth, the zero-sequence unbalance ratio can be relevant.

The voltage unbalance caused by a single-phase load connected line-to-line is in practice equal to the ratio of the load power to the network three-phase short circuit power. Consequently, unbalance is generally only a concern in larger installations.

7.4 Voltage fluctuation and flicker

7.4.1 General

Distribution networks may suffer an increase in the levels of flicker, voltage fluctuations and rapid voltage changes due to the connection and disconnection of DG units embedded in the networks or in consumers' installations, or due to variable DG power output of a stochastic nature. The last effect is often associated with wind power units sited in remote rural locations having weak supply networks, or photovoltaic units subjected to varying irradiation patterns.

When a supply network is weak, i.e. characterized by a low short circuit current ratio or high network supply impedance, voltage variations due to changes of DG output power may become large enough to cause a rise in consumer complaints. Weak networks are usually operating at the extremes of their statutory supply voltage tolerances.

For DG equipment of limited power and exporting into the public supply at a high short circuit current connection, it is unlikely that the DG will introduce noticeable flicker.

However, with large DG units or several parallel operated photovoltaic units in a localized area, flicker may occur. In winter months, when temperature, cloud and wind conditions may change frequently and suddenly, flicker may occur due to the voltage changes produced by rapid power changes at the DG point of connection.

For DG equipment up to 16 A per phase, IEC 61000-3-3 is applied. IEC 61000-3-11 covers connections of all equipment with input currents up to 75 A per phase and is mainly intended to apply for low impedance connections having a high short circuit current capability.

The flicker level, expressed as P_{st} (short-term flicker indicator) and measured at the supply terminals of the installation containing DG units which do not export power to a public supply network, should not exceed P_{st} = 1,0 under normal load conditions.

When DG equipment exports power to a public supply network, the P_{st} emissions of the DG, measured at the supply terminals of the installation, should not exceed P_{st} = 0,5 when measured under normal load and steady state conditions of the public supply, that is when no flicker contribution from the public supply is present. The contribution to P_{st} and d_{max} (maximum relative voltage change) are the most important parameters when DG equipment exports power to a public supply network as they indicate the amount of disturbance on such a public supply network.

IEC 61000-4-15 specifies how to assess for P_{st}, P_{lt} (long-term flicker indicator), d_{max} and d_c (relative steady-state voltage change) and provides detailed specifications for the evaluation of these directly measured parameters.

Voltage changes are generally associated with the energizing, switching and disconnection of DG equipment and are expressed as a percentage of the steady state supply voltage immediately prior to each type of voltage change event. These voltage fluctuations are linked to the size of the equipment.

Voltage change limits, particularly the parameters d_c, $d(t)$ (relative voltage change characteristics) and d_{max} as specified in IEC 61000-3-3 can be applied to DG equipment operation.

IEC 61000-3-3 establishes a maximum rapid voltage change limit of 4 % without further conditions, but permits 6 % for voltage changes caused by manual switching or automatic switching, provided the latter has a delayed re-start, as for many DG installations. IEC 61000-3-3 allows voltage fluctuations of up to 7 % for equipment that is attended whilst in use, or switched no more than twice per day. This 7 % limit therefore only applies in exceptional cases as far as DG equipment is concerned.

For information, IEC 61000-2-2 specifies a compatibility level of 3 % for the individual voltage variations.

Specific recommendations are not provided in IEEE standards or guides, but individual utilities in USA usually have their own rapid voltage change guidelines in the range 4 % to 7 %.

7.4.2 Flicker test conditions for DG equipment exporting power to the public supply

This test is made to assure that the flicker contribution, as caused by the DG equipment, is limited to acceptable levels.

Configure the DG equipment as shown in Figure 1, with the IEC 60725 Reference Impedance (Z_{ref}) or the Z_{test} (for higher power units) in-line. Set the simulated public supply to the nominal voltage level and verify that it meets the requirements specified in IEC 61000-3-3, 6.3, which are reported below (for a 50 Hz system).

> The test voltage shall be maintained within ± 2 % of the nominal value.
> The frequency shall be 50 Hz ± 0,5 %.
> The percentage total harmonic distortion of the supply voltage shall be less than 3 %.
> Fluctuations of the test supply voltage during a test may be neglected if the P_{st} value is less than 0,4. This condition shall be verified before and after each test.

Perform a 10 min test, as in 6.5 of IEC 61000-3-3. The general test conditions given in 6.6 of IEC 61000-3-3 apply, as there are no specific DG test conditions specified in Annex A of the standard. The test conditions for the measurement of voltage fluctuations and flicker are given below.

> For equipment not mentioned in Annex A, controls or automatic programs shall be set to produce the most unfavorable sequence of voltage changes, using only those combinations of controls and programs which are mentioned by the manufacturer in the instruction manual, or are otherwise likely to be used.

For automatic DG operation, apply the d_{max} limit of 4 %, and for manually controlled DG equipment, a d_{max} limit of 6 % is acceptable.

The P_{st} reading with the DG active and exporting power to the public supply should not increase by more than 0,5 compared to the level that is present before the DG equipment is connected and activated. For the other parameters, the limits are as specified in IEC 61000-3-3.

In addition, it is suggested to evaluate flicker during normal operation (with and without chopper/booster running) but also at derating (fold-back) due to, for example, too high AC or DC power or current.

7.5 DC injection

The injection of DC current by distributed generators into distribution networks has received increasing attention due to the importance of inverter based generators. Therefore the possibility that a DC-component (offset) on voltage or current will appear and flow into the grid has to be considered.

DC injection may result from the circuit design (e.g. asymmetry due to the dispersion of components' characteristics) or DC offset may arise from an internal fault. Different concerns are related to the injection of DC current into the AC network, some of them are described in IEC 61000-2-2.

DC injection can be measured using the test set up for harmonic emission assessment specified in 7.2.4 and 7.2.5.

At the current time there are no worldwide or IEC limits defined for DC current injection (see Table 1). For the USA, IEEE 1547 [5] specifies 0,5 % maximum of the DG rated current. This specification applies also in many countries outside North America. Several other countries permit 1 % of rated current or absolute levels, varying from 0 to 1 A, while the limit in the UK is 0,25% of the rated current per phase.

It should be noted that the above values such as 0,5 % represent a small portion of the total load of the distribution transformer. Moreover, multiple DG units may compensate any DC injection from each other.

Laboratory tests [6] have shown that inverters do not seem to produce relevant DC components, even in presence of even harmonics in the voltage. Levels lower than 100 mA have been measured for most of the tested inverters and, except for a few cases, the presence of relatively high levels of even voltage harmonics did not have any noticeable effect on the DC component level.

In those European countries where EN 50438 [7] is law, systems which inject DC into the network by construction are prohibited, with the aim to lead to a minimal impact on the network. This requirement implies that, for inverter based systems, only symmetrical control is permitted, while systems which inject DC current by design (e.g. half wave operation) are not permitted.

Such requirement can be fulfilled with reasonable effort for a broad range of technologies. Another possible solution is the use of an isolation transformer, which guarantees a null emission of DC components to the distribution network.

7.6 Short duration over voltages

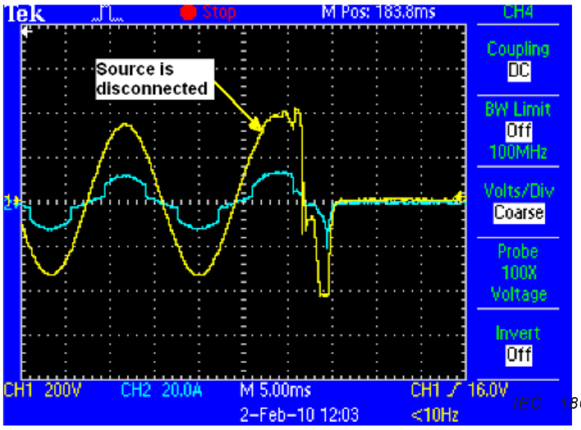
7.6.1 General

Short duration over voltages lasting from 8 ms to several hundred milliseconds have been observed when the network part, having the DG equipment, is disconnected from the rest of the network. Equipment operating in parallel to the DG equipment can be negatively impacted by these over voltages and therefore the maximum levels of the over voltages should be limited.

Two events typically occur when the DG equipment disconnects itself from the public supply.

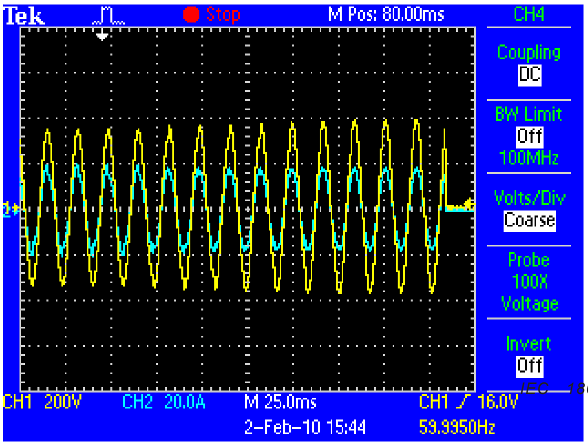
In particular it can happen that:

- DG equipment operates either supplying power to the public supply, or supplying only part of a heavier load. In this case the DG generally disconnects fast, as illustrated in Figure 2.
- DG output level is equal to the load level. In this case the disconnect process may take longer, often in the order of several hundred milliseconds, as shown in Figure 3.



IEC 1867/11

Figure 2 – Over voltages produced during DG quick disconnection



IEC 1868/11

Figure 3 – Over voltages produced during DG slow disconnection (greater than 10 ms)

In the IEC 61000-2-14 effects of over voltages on lamps and ITE equipment are considered. Concerning ITE, the so called CBEMA curve (Figure 4) is generally applied, which describes an AC input voltage envelope which typically can be tolerated (no interruption in function) by most Information Technology Equipment (ITE).

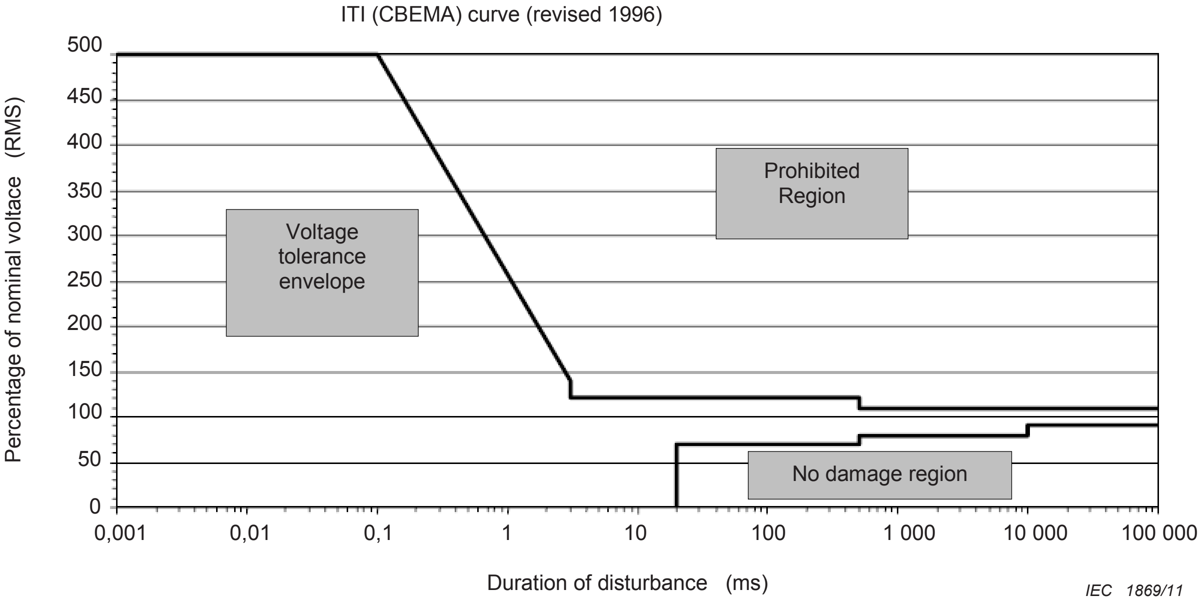


Figure 4 – CBEMA curve (IEC 61000-2-14)

Short duration over-voltages are defined as lasting less than 2 cycles of the fundamental (40 ms at 50Hz). Longer duration over-voltages are those lasting in excess of 2 cycles.

Most consumer electrical products can withstand short duration over voltages, such as a one or two cycle event, up to 20 % of the rated voltage. The public supply can have a steady state condition that is 10 % over nominal voltage under normal operating conditions.

To record the over voltages produced during DG disconnection, there are two maxima that should be measured. One is the r.m.s. value and the other one is a peak voltage measurement.

At present no over voltage limits are defined for DG when it disconnects from the public supply and the following procedures just cover how to record such over voltages.

A condition where the connected load is approximately identical to the DG output power capability should also be considered. In this case, the disconnect process will generally be slightly longer and may take several hundred milliseconds. As a result of the longer disconnection time, the over voltage may be present for a slightly longer duration as compared to the condition where the DG delivers power back to the public supply and disconnects very rapidly if the supply voltage exceeds tolerances.

7.6.2 Short duration over voltage test procedure

7.6.2.1 General

Connect the DG to the simulated public supply as in Figure 1 with a load as specified below, and follow the procedure for durations < 2 cycles and > 2 cycles.

7.6.2.2 Over voltage test for durations less than 2 cycles

Apply a load that is between 25 % – 50 % of the available DG output power. After the DG operates in a stable manner, disconnect the public supply, while recording the voltage waveform. This voltage recording can be done with an oscilloscope and appropriate voltage probes as shown in Figures 2 and 3, or may be accomplished with test equipment as in IEC 61000-4-30 provided that the sampling rate is at least 100 x the fundamental frequency of the public supply.

7.6.2.3 Over voltage test for durations exceeding 2 cycles

Apply a load that is 100 % ± 2 % of the available DG output power. After the DG operates in a stable manner, disconnect the public supply, while recording the voltage waveform. This voltage recording can be done with an oscilloscope and appropriate voltage probes as shown in Figures 2 and 3, or may be accomplished with test equipment per IEC 61000-4-30, provided that the sampling rate is at least 100 x the fundamental frequency of the public supply.

7.7 Switching frequencies

Problems have been found related to voltage distortion due to switching frequencies such as overheating affecting filters, power supplies, or auxiliary transformers. Failures of electronic control equipment or audible noise have also been found.

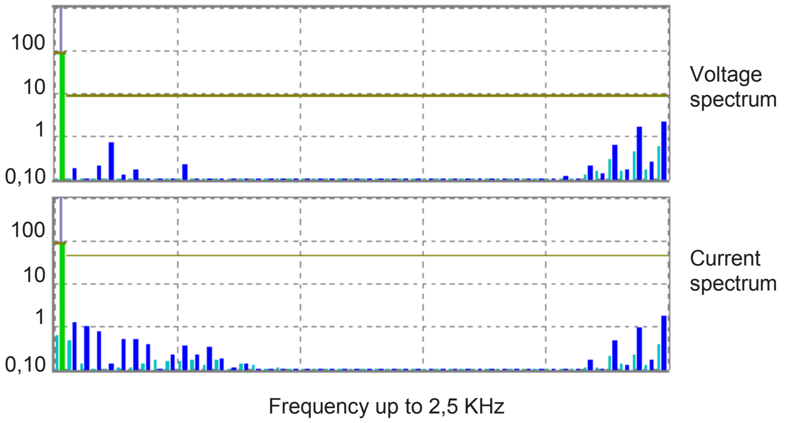
Higher frequency distortion created by inverters has been observed. As an example, Figure 5 shows the voltage in the low voltage system of a higher power photovoltaic plant whose power level appears to be outside the scope of this Technical Report. The current waveform indicates that the internal filter of the equipment is a single three-phase inductor. This kind of first order filter has 20 dB per decade attenuation. As reported in Annex A, higher order filters, such as LCL filters, provide higher attenuation and thus significantly lower distortion.

Generally, the distortion caused by the inverter switching frequency is unrelated to the fundamental frequency of the public supply and can be higher than 2 kHz, especially for premise type solar inverters ≤ 10 kW. Switching frequencies in the range up to 9 kHz and even higher have been observed for these smaller DG units.

As the switching frequencies are generally not an integer multiple of the fundamental frequency (i.e. not a multiple of 50 Hz or 60 Hz), they cannot be measured with traditional harmonic analyzers that only measure integer harmonics. Consequently, it may not appear with a traditional harmonic measurement, as can be seen in the spectrum of Figure 5. IEC 61000-4-7 provides measurement methods in the range from 2 kHz to 9 kHz where the spectral components having 5 Hz resolution are grouped in 200 Hz wide frequency bands (so called bins). Frequencies in excess of 9 kHz require assessment methods that differ from those specified in IEC 61000-4-7 and are not dealt with in this Technical Report.

Currently, IEC 61000-3-10 is under preparation[2], dealing with emission limits in the range from 2 kHz to 9 kHz, probably using the grouping methodology as defined in IEC 61000-4-7. IEC 61000-3-10 will eventually be applicable to emissions caused both by loads and DG equipment in the range from 2 kHz to 9 kHz, but at the present time, there are no emission limits defined in such a frequency range.

2 This document (Emission limits in the frequency range of 2 kHz to 9 kHz) is being prepared by Subcommittee 77A: Low frequency phenomena.



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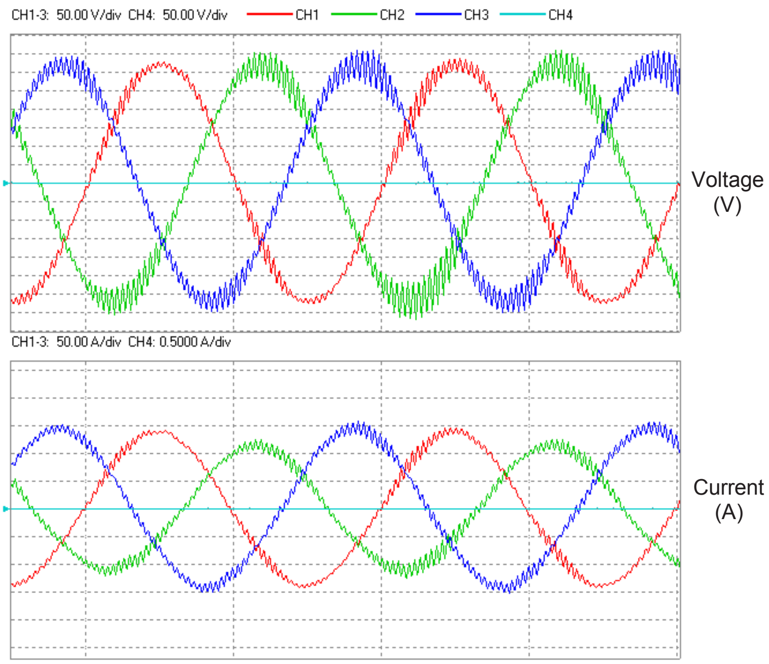

IEC 1871/11

Figure 5 – Distortion due to high power PV inverter

8 Immunity

8.1 General

Appropriate and applicable requirements concerning immunity as well as testing procedures are essential to guarantee reliable and compatible operations among pieces of equipment connected to networks with high penetration of distributed generators.

Minimum requirements should regard the behaviour of generators during network disturbances taking into account generation technology issues and the capacity of the installation. In this context, the low voltage ride through capability or the voltage support during disturbances become important issues.

Voltage dips and short interruptions are widely considered to be the most serious and frequent power quality disturbances due to their effect on consumer equipment and sensitive processes.

Note that the existing standards specifying the anti-islanding requirements may, in fact, inhibit the low voltage ride through capability of DG equipment. These anti-islanding requirements do not really cover the short duration dips/interrupts, lasting from just a few milliseconds to say 40 ms – 50 ms. The requirements in place in various states generally state that the inverter shall disconnect within times ranging from 200 ms to 2 s.

Hence, it is recommended that the anti-islanding specifications are better coordinated, so that very short voltage fluctuations lasting from 1 cycle to 5 cycles can be accommodated without the DG equipment disconnecting from the public supply. This would in fact improve power quality in those cases where dips/interrupts last less than 100 ms.

For the immunity tests covered by this Technical Report, the following general acceptance criteria are proposed:

- **A: generator continues to operate as intended in the specified operating range**
- **B: generator stops generating (disconnection) but recovers without external intervention**
- **C: generator stops generating (disconnection); an external intervention is necessary, if specified**
- **D: generator is damaged, loss of function, not recoverable**

8.2 Voltage dips and short interruptions

8.2.1 General

Existing standards for testing voltage dip immunity focus primarily on verifying minimum immunity requirements for equipment response to voltage dips.

IEC 61000-4-11 applies to equipment below 16 A and IEC 61000-4-34 is for equipment with current levels above 16 A per phase.

For semiconductor industry equipment, SEMI F47 [8] standard is applied. Preferred test levels are as illustrated in Figure 6 [9], and test characteristics are defined by standards.

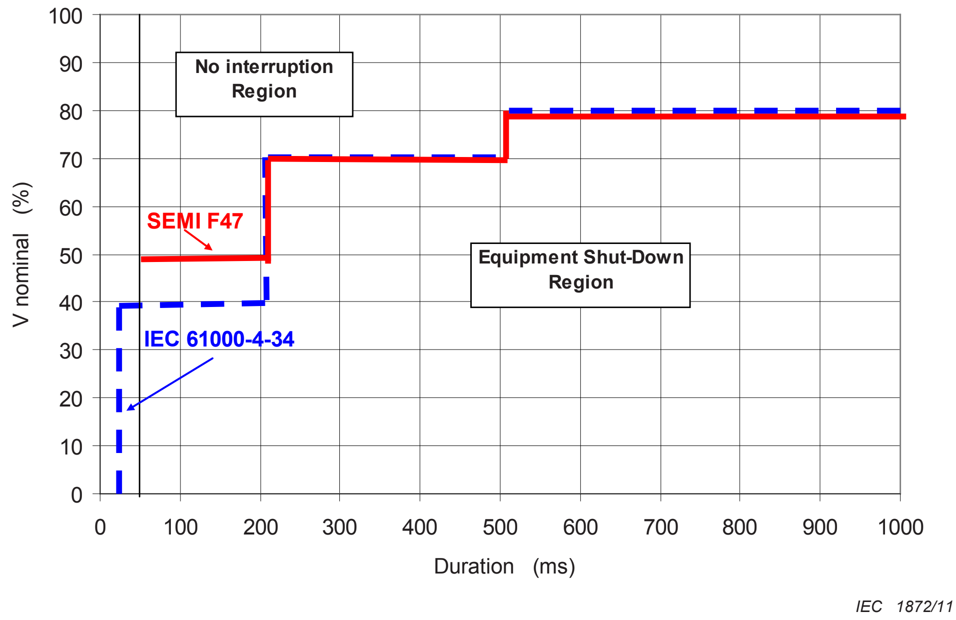

Figure 6 – Voltage dips and short interruption test levels from different standards

Figure 6 shows, as an example, the IEC 61000-4-34 preferred test levels (applicable to equipment with current greater than 16 A), related to Class 3 environment (industrial PCC of the unit under test) and based on IEC 61000-2-8. Similar trend are in IEC 61000-4-11 (for < 16 A). For equipment connected to the public network, Class level 2 applies and less severe test levels are requested, compared with those illustrated in Figure 6. The definition of environmental classes is given in IEC 61000-2-4.

For distributed generators, immunity requirements should be coordinated with protection requirements for the maximum tripping time with a given under-voltage. Protection requirements defined by DSO have to prevent islanding and to assure the correct operation of the short circuit protection. In Figure 7 [10] three types of voltage-tolerance curves for the immunity requirements are plotted together: protection requirement for grid interface requested by operators, immunity performance of the generator and immunity requirement requested by standards.

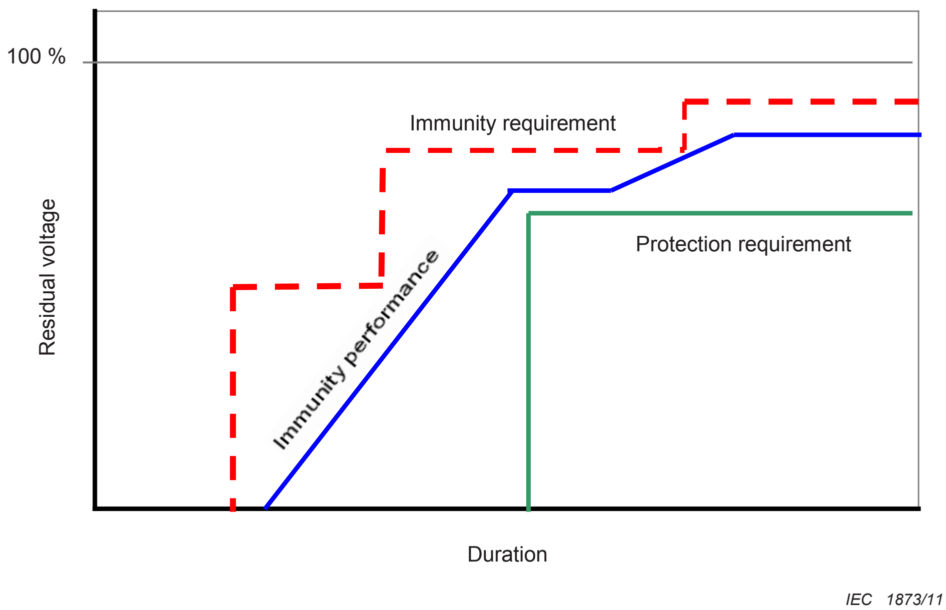

Figure 7 – Voltage tolerance curves for DG immunity requirements

Inverters are generally requested to disconnect in case of voltage disturbances. This is mandatory in LV grids for large systems with synchronous generators. The inverter disconnection time shall be shorter than the reclosure time of the grid after a fault.

Table 8 [11] illustrates the voltage window in which inverters are allowed to feed in the various countries. The last column shows the time within which disconnection is required.

Table 8 – Protection requirements for PV inverters under voltage disturbances

Country	Max AC Voltage	Min AC Voltage	Disconnection time
Austria	253 V	195 V	0,2 s
Belgium	253 V	< 195 V	0,2 s; up to 1,5 (< 10 kW)
Denmark	U > 265 V U > 253 V	U < 207 V	0,2 s 40 s 10 s
Finland	>244 V	207 V	30 s to 60 s > 244 V; 0,05 s at 253 V 2 s to 10 s at 207 V
France	264 V	195 V	0,1 s
Germany	253 V	195 V	0,2 s
Greece	264 V	184 V	0,5 s
Italy	276 V	184 V	0,1 s at 276 V; 0,2 s at 184 V
Korea (Rep. of)	264 V	194 V	0,16 s to 2 s
Mexico	126 V	108 V	0,16 s to 2 s
Netherlands	244 V	207 V	0,1
Norway	253 V	< 207 V	60 s > 253 V ; 0,2 s at 276 V 60 s < 207 V
Portugal	264 V	195 V	0,1 – 1 s
Slovenia	stage 1: 255 V stage 2: 265 V	stage 1: 196 V stage 2: 161 V	stage 1: 1,5 s stage 2: 0,2 s
Spain	253 V	195 V	0,5 s
Sweden	> 244 V	< 207 V	60 s > 244 V; 0,2 s at 276 V 60 s < 207 V; 0,2 s at 184 V
Switzerland	253 V	195 V	0,2 s
UK	stage 1: 253 V stage 2: 264 V	209 V 192 V	1 s at 253 V; 2,5 s at 209 V 0,5
Australia	270 V	200 V	2 s
Japan	120 V	80 V	0,5 s to 2 s
USA	> 164 V 164 > V > 132	< 60 V 60 < V < 105,6	33 ms / 0,1 s 2 s

Table 8 shows that protection requirements vary substantially from country to country.

For example, in Austria, Germany and Denmark, voltages at the equipment terminal lower than 85 % or greater than 110 % of the nominal voltage shall cause a switch off within 200 ms, while in Greece and Spain longer times are permitted. Some other countries require times as short as 100 ms. This means that the “forbidden domain” of the voltage tolerance characteristic strongly depends on the country in which the DG is operated.

Irrespective of the varying tolerances, once generators are disconnected, they should not be damaged by auto-reclosure. This means that DG units need to trip before the auto-reclosure takes place, and should then reconnect as soon as possible.

It is also observed, that there is an undefined state, of at least 100 ms (France, The Netherlands) where there is no specified behaviour that the DG should adhere to. In other words, some DG equipment may “ride-through” for a few cycles while other manufacturers may decide that the equipment shall shut down within one cycle or so, as illustrated in Figures 2 and 3.

Taking into account the limits required by protection requirements, DG immunity tests to voltage dips and short interruptions are proposed. To perform voltage dips and short interruption tests, a grid simulation, similar to the test setup illustrated in Figure 1, is suggested. The simulated public supply is then programmed to act as voltage dip generator. In addition, the immunity to grid impedance should also be tested, meaning that the inverter should be capable of operating without problems under different grid impedances. For that purpose, the dip/interrupt test can be conducted with the IEC 60725 Reference Impedance – or the Z_{test} for higher currents – in the bypass mode, followed by the impedance being in-line.

In addition to the dip/interrupt of the public supply (AC voltage) it will also be necessary to vary the DC voltage to the DG equipment where this applies. In the particular case of a photovoltaic inverter, a photovoltaic array simulator (or real solar panels) is recommended as power supply for the equipment under test. The dip generator has to produce voltage dips with defined magnitude, duration, point of wave of initiation and phase angle jump.

Tests should be carried out in different operation conditions of the equipment under test, at different power levels, such as simulating operation during a cloudy or sunny day for solar systems: accurate acquisition of the behaviour of the equipment under test should therefore include the DC voltages and currents, and any malfunction should be documented.

The tests should be repeated three times for each level. In between the dip levels by a given percentage, the unit is allowed to stabilize for 10 s (indicated by the “gap”) while the waiting time between successive steps in the test is indicated by the “delay”. This not only allows the unit to re-establish nominal operation, but also facilitates the easier identification of any step that causes the DG to disconnect from the public supply.

Two different tests are suggested:

- a short dip/interrupt, shorter than 100 ms: for this test several of the test patterns derived from IEC 61000-4-11 (see Figure 8) may be applied;
- a longer dip/interrupt: for this test the AC voltage should be slowly decreased (each step about 2 % of the nominal voltage) and tripping voltage/disconnection time should be recorded. As shown in Figure 9, a possible test pattern is proposed where the public supply is reduced to the remaining voltage level for 10 cycles (200 ms) and then returns to nominal for 5 s, followed by 2 more “dips” to the same level. Upon completion the DG is permitted to stabilize for some time (5 s in the example) and then the next step with a 2 % lower voltage is executed. While the test pattern is executed, the DG output is monitored, and the instant where the DG output current disappears (reduces to zero) is the disconnect point. By charting the above test results, a voltage dip tolerance curve is obtained.

The voltage dip tolerance curve may be used as a specification for a DG minimum ride-through capability.

Generally, mains monitoring for anti-islanding protection requires that DG equipment disconnects if the voltage falls below specified levels. For example, one specification states: “voltages at the equipment terminal lower than 80 % or greater that 115 % of the nominal voltage shall cause a switch off within 200 ms”. This can be understood by the inverter manufacturer as a requirement to either instantaneously disconnect the DG or implement a delayed trip (of 200 ms). Many inverters also have the capability to program delays and trip levels, and these can be selected to obtain optimum operational characteristics for the installation at hand.

	Remaining voltage (% U_{nom})	T_s (cycles)	Start phase	Repeat	Gap(s)	Delay(s)
1	70	1,00	0,00	3	10	5
2	70	2,00	0,00	3	10	5
3	70	5,00	0,00	3	10	5
4	40	1,00	0,00	3	10	5
5	40	2,00	0,00	3	10	5
6	40	5,00	0,00	3	10	5
7	0	1,00	0,00	3	10	5
8	0	2,00	0,00	3	10	5
9	0	5,00	0,00	3	10	5
10						5

IEC 1874/11

Figure 8 – DG immunity test for short dips/interruptions: an example

	Remaining voltage % U_{nom}	T_s (cycles)	Start phase	Repeat	Gap(s)	Delay(s)
1	100	10,0	0,00	2	5	5
2	98	10,0	0,00	2	5	5
3	96	10,0	0,00	2	5	5
4	94	10,0	0,00	2	5	5
5	92	10,0	0,00	2	5	5
6	90	10,0	0,00	2	5	5
7	88	10,0	0,00	2	5	5
8	86	10,0	0,00	2	5	5
9	84	10,0	0,00	2	5	5
10	82	10,0	0,00	2	5	5
11	80	10,0	0,00	2	5	5
12						

IEC 1875/11

Figure 9 – Test pattern for a DG voltage dip tolerance curve

8.2.2 Short duration voltage dips test procedure

Connect the DG to the simulated public supply as illustrated in Figure 1. Apply a load of 50 % ± 10 % of the available DG output power.

After the system is stable, execute the test as in Figure 8, and record the DG output current to the load and the DG output voltage (see 7.6).

Document the operating characteristics of the DG, identifying the "ride-through" capability, and the point at which the DG disconnects.

If the DG rides through the longest dips, lasting 5 cycles, increase the interrupt time in 1 cycle increments to identify at which point the DG does disconnect.

Test should be repeated at 50 % and 100 % DC power input level to solar inverters.

8.2.3 Longer duration voltage dips test procedure

Connect the DG to the simulated public supply as illustrated in Figure 1. Apply a load of 50 % ± 10 % of the available DG output power.

After the system is stable, execute the test as shown in Figure 9, and record the DG output current to the load.

Document the operating characteristics of the DG, identifying the voltage value at which the DG disconnects. It may be required to increase the "dip" period to 20 cycles for DG equipment that is programmed to have at least 200 ms delay before disconnecting.

Test should be repeated at 50 % and 100 % DC power input level to solar inverters.

8.3 Frequency variations

In public supply systems there is normally a power reserve in order to maintain the frequency within the declared tolerance band, which varies between various regions in the world, but is often set at ± 1 %.

However, in the event of major incidents in the transmission system, if frequency decreases, all generation shall be maintained as much as possible to avoid a network collapse. On the contrary, if frequency increases beyond 2 %, automatic disconnection of generation is necessary to balance load and generation.

For operation of PV systems under frequency disturbances, the varying requirements are illustrated in Table 9 [12].

Within the normal tolerances, the main effect of a change in power frequency is on the speed of rotation machines. Hence, mains electrical clocks will lose or gain time and motors will deliver more or less power, the change depending on the speed/torque relationship of the load.

Power frequency variation may have a de-tuning effect on harmonic filters.

Any electronic equipment using the power supply frequency as a time reference will also be affected.

Table 9 – Protection requirements for PV inverters under frequency disturbances

Country	Maximum frequency	Minimum frequency	Disconnection time
Australia	52 Hz	48 Hz	2 s
Austria	50,2 Hz	49,8 Hz	0,2 s
Denmark	53 Hz	47 Hz	0,2 s
Germany	50,2 Hz	49,8 Hz	0,2 s
Greece	50,5 Hz	49,5 Hz	0,5 s
Italy	50,3 Hz	49,7 Hz	0,1 s
Japan (60 Hz)	51,5 (61,8) Hz	48,5 (58,2) Hz	0,5 – 2 s
Korea (Rep. of)	60,3 Hz	59,7 Hz	0,5 s
Malaysia	52 Hz	47 Hz	Continuous operation 10 s (worst case)
Mexico	69.48 Hz	59,52 Hz	0,1 – 2 s
The Netherlands	52 Hz	48 Hz	2 s
Portugal	50,25 Hz	49,75 Hz	0,1 s
Slovenia	51 Hz	47 Hz	0,2 s
Switzerland	50,2 Hz	49,8 Hz	0,2 s
UK	stage 1: 51.5 stage 2: 52 Hz	47.5 47 Hz	90 s at 51,5 Hz; 20 s at 47,5Hz 0,5 s
USA	60,5 Hz	59,3 Hz	0,1 s power ≤ 30 kW (IEEE 1547)

To test the immunity against power frequency variations of DG equipment connected to 50 Hz or 60 Hz network with rated line current up to 75 A per phase, the standard IEC 61000-4-28 may be applied.

Although the scope of IEC 61000-4-28 includes equipment up to 16 A per phase, the test principles can be used for higher power DG equipment up to 75 A per phase as well.

The test should be performed at nominal mains voltage in representative operational modes of the equipment under test. For each test, any degradation of the performance should be recorded.

Figure 10 illustrates a test pattern where the frequency is stepped in 0,1 Hz increments starting at 50,3 Hz. Generally, DG equipment shall be able to handle a variation of at least ± 0,5 Hz, so starting at 50,3 Hz includes normal operation.

The test should be conducted in steps of 0,2 % of nominal frequency (or 0,1 Hz absolute), in a range that varies from country to country, but could be as wide as ± 6 %. Tripping frequencies and the disconnection time delay should be recorded.

To identify the status of the inverter during immunity tests, the general acceptance criteria proposed in 8.1 are applicable.

	Frequency steps in 0,1 Hz steps starting at 50,3 Hz					
	Type	**Time (s)**	**Voltage**	**Frequency**	**Repeat**	**Waveform**
1	Freq. step	0,200		50,30	0	Sinewave
2	Freq. step	0,200		50,40	0	Sinewave
3	Freq. step	0,200		50,50	0	Sinewave
4	Freq. step	0,200		50,60	0	Sinewave
5	Freq. step	0,200		50,70	0	Sinewave
6	Freq. step	0,200		50,80	0	Sinewave
7	Freq. step	0,200		50,90	0	Sinewave
8	Freq. step	0,200		51,00	0	Sinewave

IEC 1876/11

Figure 10 – DG frequency variation (increment) immunity test: an example

8.4 Harmonics and interharmonics

The increasing presence of harmonics and interharmonics superimposed on the grid voltage should be taken into account in order to guarantee that generators and DG equipment can continue to work properly.

In case of photovoltaic based inverters, they can be particularly sensitive to harmonic and interharmonic disturbances that may affect the current control and output power conversion. The (inter) harmonic frequencies may also affect internal protection and monitoring circuits.

Common disturbances are identified in more detail in IEC 61000-4-13, but they include mains signaling signals used for tariff and distribution equipment switching (by the utilities) as well as harmonics and inter-harmonics caused by controlled rectifiers and various user equipment.

Distributed generators should be able to withstand these common disturbances without false trips of the grid interface protection, over-current protection, or loss of output power and/or other problems.

In order to test the immunity for harmonics and interharmonics on equipment connected to 50 Hz or 60 Hz network with rated line current up to 75 A per phase, the standard IEC 61000-4-13 may be applied.

Although the scope of IEC 61000-4-13 covers equipment up to 16 A per phase, the same principles apply for higher power DG equipment, as the equipment is subjected to the same distortion of the public supply.

In general, the test set-up is similar to the one illustrated in Figure 1. The network simulator (AC power source) is programmed to generate the harmonic and interharmonic voltage disturbances as specified in IEC 61000-4-13 and the following tests can be performed.

- Combined harmonic waveforms (flat-curve and over-swing curve): see 8.2.1 of IEC 61000-4-13.
- Individual harmonics/interharmonics with predefined sequence of test levels: see 5.1 and 5.2, and 8.2.3 of IEC 61000-4-13.
- Sweep in frequencies: see 8.2.2 of IEC 61000-4-13.
- Meister curve test: see 8.2.4 of IEC 61000-4-13.

Table 10 illustrates the test levels for non-triplen and triplen odd harmonics (h).

The standard IEC 61000-4-13 has similar tables for even harmonic and for interharmonics frequencies. In addition, the standard specifies typical “flat-top” and “over-swing” curves, as they occur on the public supply on a daily basis.

Table 10 – Harmonic voltage disturbance levels for odd harmonics (IEC 61000-4-13)

h	Class 1	Class 2	Class 3	Class X
	Test levels % U_1	Test levels % U_1	Test levels % U_1	Test levels % U_1
5	4,5	9	12	Open
7	4,5	7,5	10	Open
11	4,5	5	7	Open
13	4	4,5	7	Open
17	3	3	6	Open
19	2	2	6	Open
23	2	2	6	Open
25	2	2	6	Open
29	1,5	1,5	5	Open
31	1,5	1,5	3	Open
35	1,5	1,5	3	Open
37	1,5	1,5	3	Open

NOTE 1 Classes 1, 2, and 3 are defined in annex C.

NOTE 2 The levels given for class X are open. These levels shall be defined by the product committees. However, for equipment supplied by low voltage public supply systems, the values shall not be lower than those of class 2.

h	Class 1	Class 2	Class 3	Class X
	Test levels % U_1	Test levels % U_1	Test levels % U_1	Test levels % U_1
3	4,5	8	9	Open
9	2	2,5	4	Open
15	No test	No test	3	Open
21	No test	No test	2	Open
27	No test	No test	2	Open
33	No test	No test	2	Open
39	No test	No test	2	Open

NOTE 1 Classes 1, 2, and 3 are defined in annex C.

NOTE 2 The levels given for class X are open. These levels shall be defined by the product committees. However, for equipment supplied by low voltage public supply systems the values shall not be lower than those of class 2.

IEC 61000-4-13 Class 2 represents the most applicable test levels for DG equipment < 16 A per phase.

In certain application areas and higher DG power levels, Class 3 levels may have to be considered for DG inverters that operate in industrial environments.

In principle, the test procedures and test configuration per IEC 61000-4-13 for Class-2 equipment applies, unless the tested DG equipment has a power level > 16 A per phase, in which case the Class 3 test levels may need to be considered.

The acceptance criteria as proposed in 8.1 are applicable.

Annex A
(informative)

Examples of harmonic measurements and analysis on DG equipment connected to low voltage networks

A.1 Overview

This Annex provides some examples of harmonic measurements and analysis made on DG equipment, included active infeed converters (AIC). Some of the measurements were actually performed in the process of validating several of the proposed tests in this Technical Report.

A.2 Typical behaviour of a DG connected to the network

In DG equipment where the control system takes its current reference waveform from the measured network voltage, the harmonic components in the voltage produce harmonic currents that tend to increase the voltage distortion.

This behaviour is illustrated in Figure A.1, where the simulated network distortion is increased from 3 % to 9 % in 1 % steps. The set up adopted for these measurements is the same as in Figure 1 of this Technical Report. The horizontal scale represents 200 ms measurement windows in accordance with IEC 61000-4-7.

The current distortion in the mains supply is roughly double the programmed voltage distortion value.

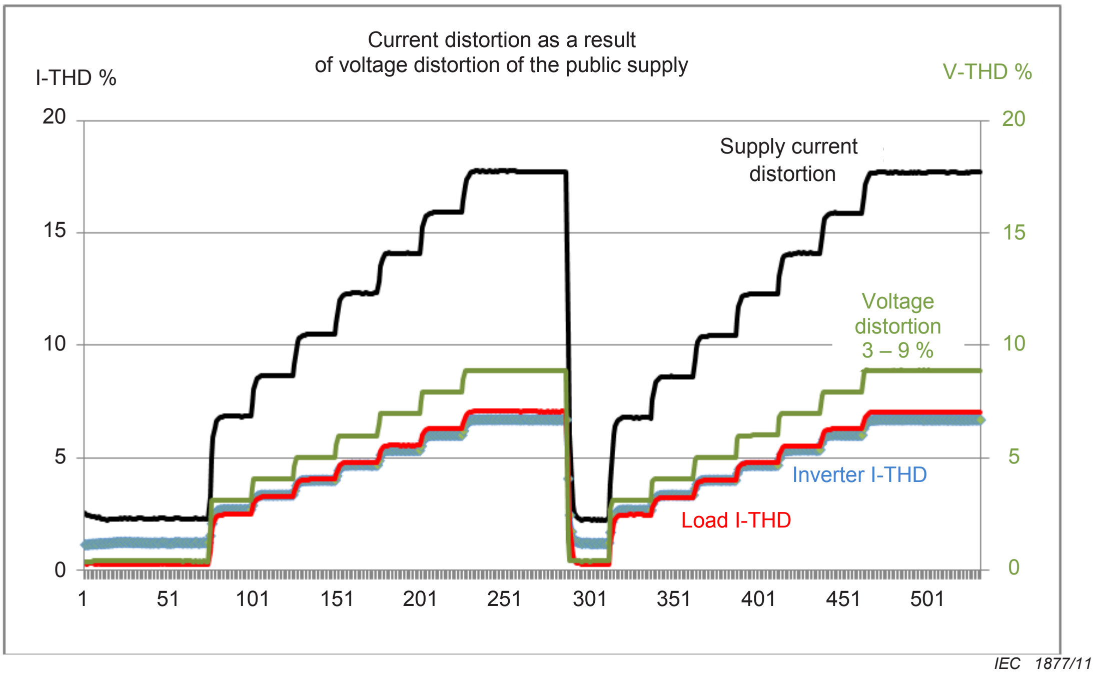

Figure A.1 – Total current distortion due the network and the connected inverter

In the proposed harmonic current tests reported in 7.2.2 and 7.2.3, several load levels are defined as harmonic currents could differ considerably under different generating condition.

As an example, distortions at high and low input power inverter operations were measured for a 5 kW inverter. The results, reported in Figure A.2, show the relative distortion in percent of the fundamental current for harmonics up to order 20 at different inverter operating conditions.

As shown in Figure A.2, the distortion at 30 % (1 500 Watt inverter operating power) is about double than the distortion at 60 % power (3 000 Watt inverter operating power).

This is not uncommon for control loops that are optimized for full power operation.

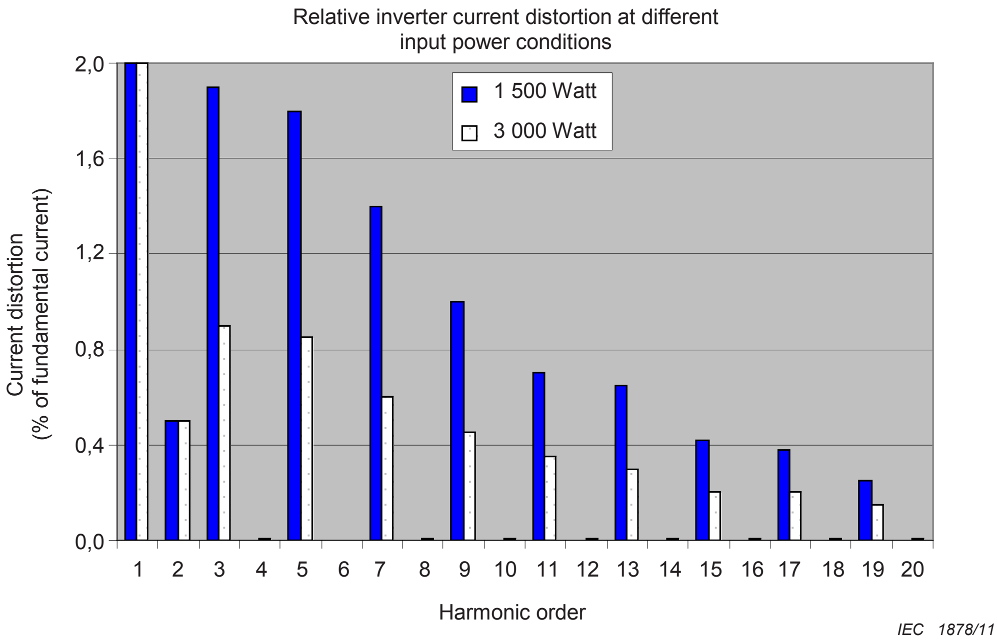

Figure A.2 – Harmonic distortions at different input power of a 5 kW inverter

A.3 Behaviour of increasing number of active infeed converters (AIC) with LCL filters connected to the network

Some measurement campaigns have been recently performed in Finland to investigate how the voltage distortion changes when the number of parallel operating active infeed converters (AIC) with LCL filters is increased [13]. The measurements were made at lower than the converter's 93 A rated current in order to better show the harmonics in the current.

Figure A.3 shows an active infeed converter with LCL filter.

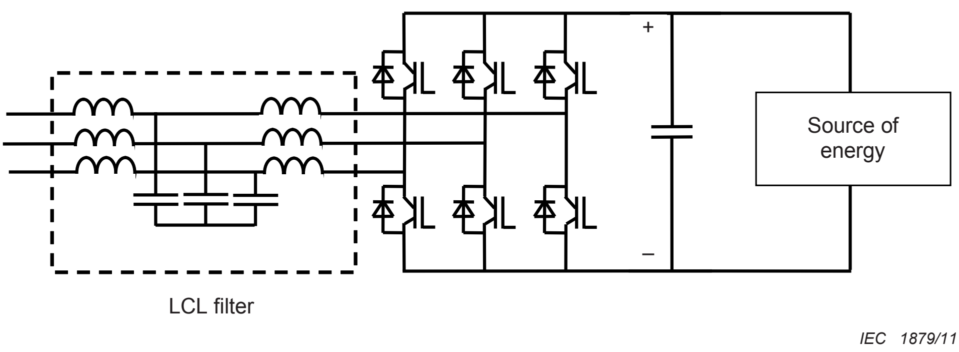

Figure A.3 – DG equipment with LCL filter

To introduce such active converters with LCL filter, Figure A.4 shows the result of a simulation study where the impedance of a DG equipment was defined and compared with a model that replaced the IGBT inverter and the filter inductor at its terminals by ideal current source and a resistor. The fast current control of the inverter makes it resemble a current source. However, the inverter has to stabilize the LCL filter resonance. This is usually done by the inverter control.

This artificial damping is the reason why the phase angle of the impedance is not very far away from zero in the filter's resonance range. As can be seen, at least with the device studied, the damping can be quite accurately modeled by a parallel resistor.

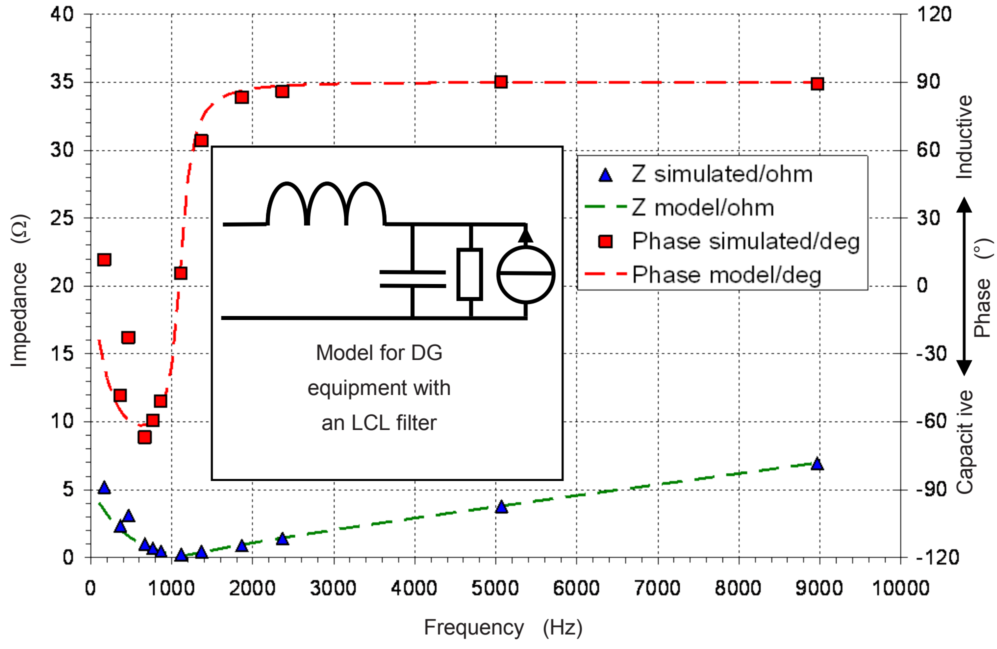

Figure A.4 – Impedance model for DG equipment with LCL filter

During measurement campaigns performed in Finland, background phase-to-phase voltage harmonics (harmonic groups) were recorded and a value of THD, measured up to 2 kHz, equal to 2,4 % was obtained.

Values of THD obtained connecting first of all one inverter and, successively, two and four units are reported in Table A.1. The THD data of different AICs with LCL filters (each of 10 A) connected to the network are related to the background phase to phase voltage harmonics.

Table A.1 – THD of increasing numbers of AICs with LCL filters connected to the network

Configuration	THD (%)
Background phase-to-phase voltage harmonics (harmonic groups)	2,4
Single AIC	1,8
Two AICs	2,2
Four AICs	2,0

As an example, the voltage spectrum and current harmonics for four AIC inverters at 10 A r.m.s. are reported in Figures A.5 and A.6.

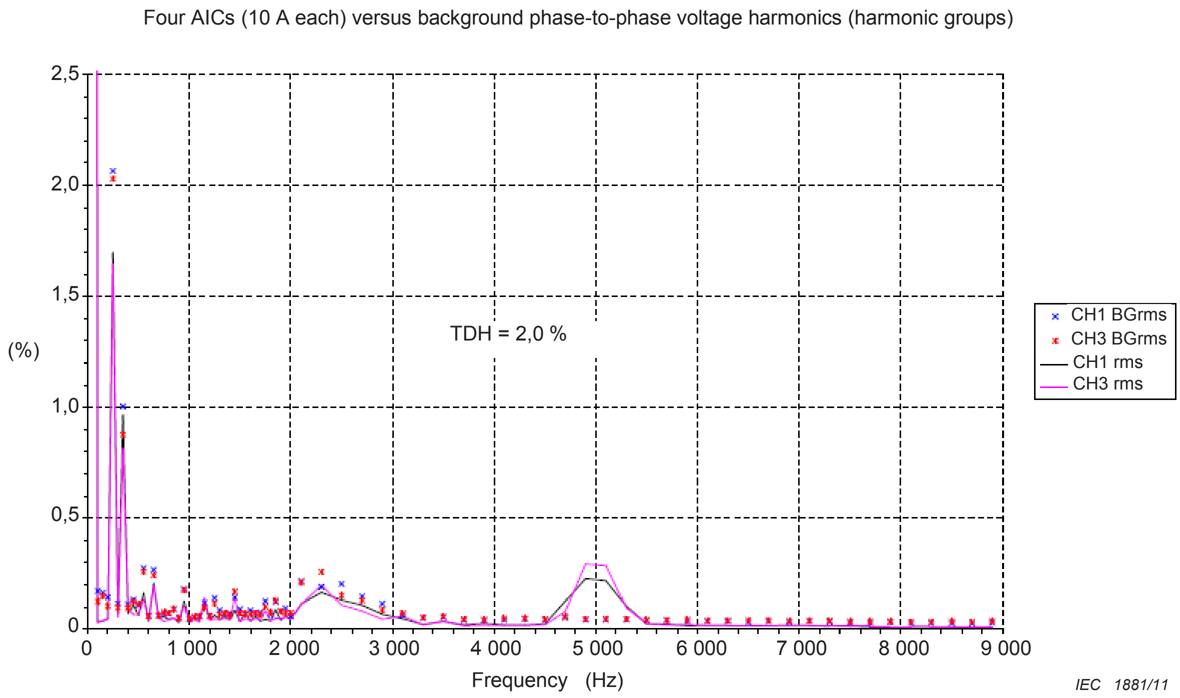

Figure A.5 – Voltage spectrum: four AICs connected

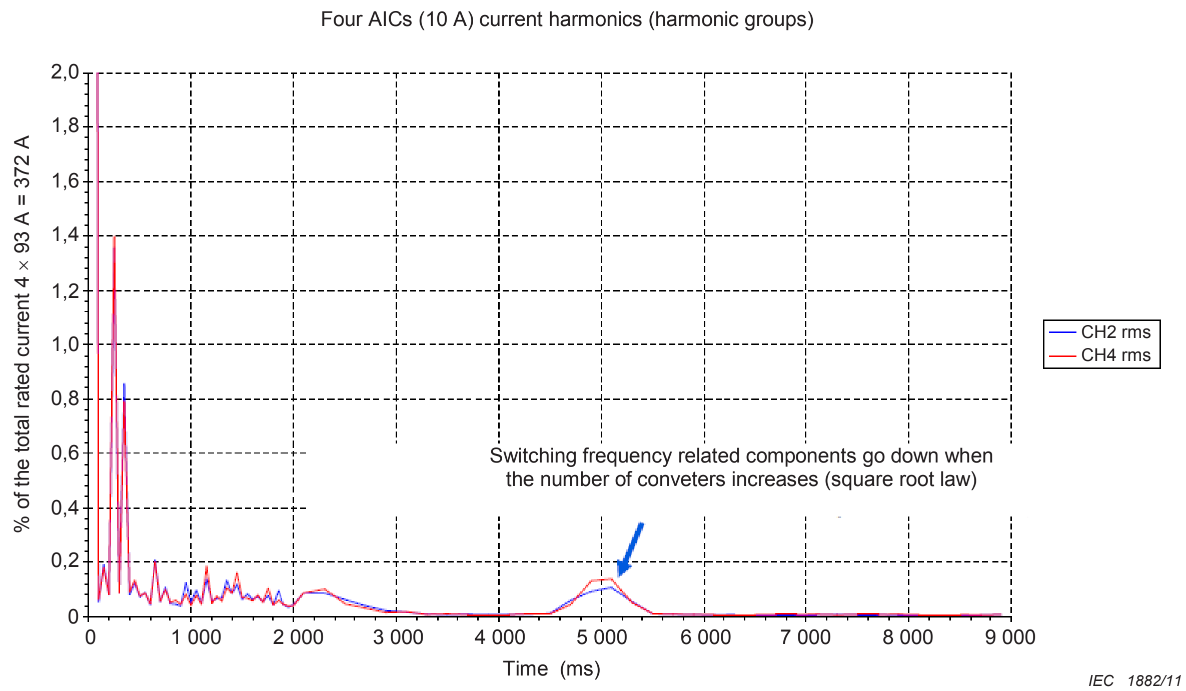

Figure A.6 – Current harmonics: four AICs at 10 A r.m.s. (0,11 I_N)

A.4 Some conclusions

- Active infeed converters with LCL filters do not increase voltage distortion, but tend to decrease it.

- Due to the filtering effect, erroneous results are likely when compliance with harmonic current limits is verified in a distorted grid.
- The harmonics related to switching frequency are proportional to the square root of the number of the parallel connected AICs even when the converters are close to each other and operate at the same operation point.
- If limits for harmonics above 2 kHz are set the influence of the wider 200 Hz grouping band to the harmonic values has to be taken in the account.

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IEC/TR 61000-3-7, *Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems*

3 Third edition under consideration.

IEC 61000-3-8, *Electromagnetic compatibility (EMC) – Part 3-8: Limits – Signalling on low-voltage electrical installations – Emission levels, frequency bands and electromagnetic disturbance levels*

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

IEC/TR 61000-3-10, *Electromagnetic compatibility (EMC) – Part 3-10: Limits – Emission limits in the frequency range 2 kHz to 9 kHz*[4]

IEC 61000-3-11:2000, *Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subject to conditional connection*

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

IEC 61000-3-14, *Electromagnetic compatibility (EMC) – Part 3-14: Limits – Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems*[5]

IEC 61000-4-7, *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 61000-4-11, *Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests*

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

IEC 61000-4-15, *Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Flickermeter – Functional and design specifications*

IEC 61000-4-28, *Electromagnetic compatibility (EMC) – Part 4-28: Testing and measurement techniques – Variation of power frequency, immunity test*

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

IEC 61000-4-34, *Electromagnetic compatibility (EMC) – Part 4-34: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with mains current more than 16 A per phase*

IEC 61727, *Photovoltaic (PV) systems – Characteristics of the utility interface*

IEC/TS 62578, – *Power electronics systems and equipment – Operation conditions and characteristics of active infeed converter applications*[6]

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4 Under consideration.

5 To be published.

6 Second edition under consideration.

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