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Executive Summary

This report determines the electromagnetic compatibility requirements established by regulations emission and immunity requirements, collects the reference standards where these requirements are set, and describes the test procedure which shall be performed in order to certificate the conformity of equipment under test. Furthermore, this document approaches several electromagnetic disturbance mitigation methods which may be applied in case the equipment is not in accordance with the former electromagnetic requirements.

Electromagnetic compatibility European directive and specific standards, technical reports and datasheets concerning every device of interest (wind turbines, electrical rotating machines and power converters) are analysed aiming to set their electromagnetic compatibility requirements and regulations. A diagram with the electromagnetic compatibility regulations of each device is shown in Figure 1.

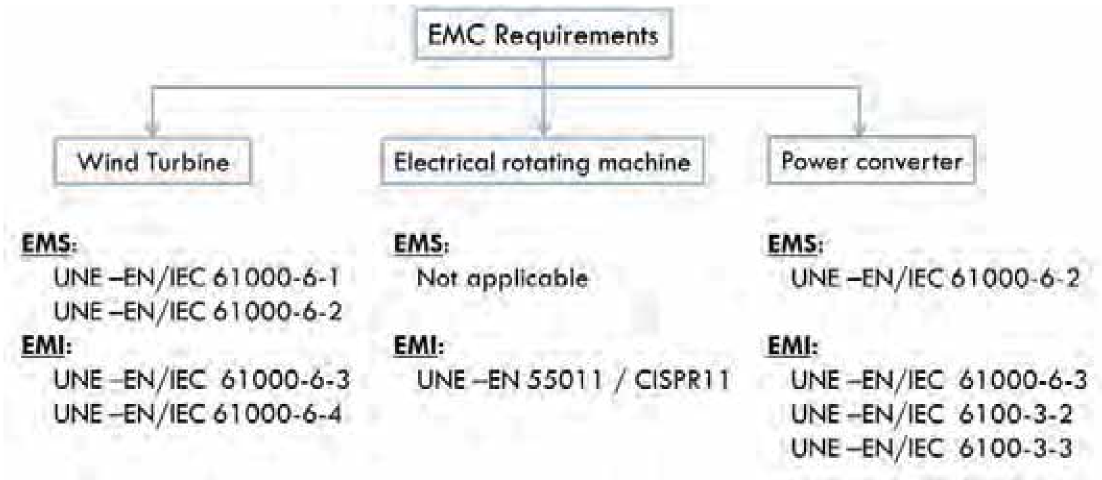

Figure 1. Diagram with EMC regulations.

The apparatus to certificate shall be put under test to verify if meets the requirements established by the correspondent regulations. A description of every test which shall be performed is included, detailing the test procedure, as well as the necessary equipment to carry out the test description, including its more relevant features.

Finally, several electromagnetic mitigation methods are presented. These methods shall be applied as corrective measures when the electromagnetic compatibility requirements stablished by the regulations are not met by the tested equipment.

Abbreviation list

	Description
AMN	Artificial main network
AN	Artificial networks
AE	Auxiliary equipment
CDN	Coupling/decoupling network
DFT	Discrete Fourier transform
EMC	Electromagnetic compatibility
EMI	Electromagnetic interferences
ESD	Electrostatic discharges
EUT	Equipment under test
HPF	High-pass filter
HCP	Horizontal coupling plane
ISN	Impedance stabilization network
LCL	Longitudinal conversion loss
P_{lt}	Long-term flicker indicator
LPF	Low-pass filter
d_{max}	Maximum voltage change characteristic
OATS	Open-area test site
PWHD	Partial weighted harmonic distortion
PE	Protective earth
RF	Radio-frequency
Z_{ref}	Reference impedance
d (t)	Relative voltage change
SAC	Semi-anechoic chamber
R_{sce}	Short-circuit ratio
P_{st}	Short-term flicker indicator
d_c	Steady-state voltage change
SPD	Surge-protective device
THC	Total harmonic current
THD	Total harmonic distortion
VCP	Vertical coupling plane
WT	Wind turbine

1 Introduction

This task covers the electromagnetic compatibility (EMC) requirements for wind turbines (WTs), and proposes suitable methods to reduce electromagnetic interferences (EMI) both emitted and captured by any sensitive equipment of the wind turbine.

First of all, it is necessary to establish the meaning of EMC, which is defined as the ability of an equipment or system to work satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to other equipment in that environment. This definition includes two basic concepts: in order to confirm that a device is electromagnetically compatible, it must not produce EMI, and at the same time has to be immune to the electromagnetic disturbances in its environment. Both conditions have to be fulfilled to satisfy the EMC regulation requirements; if the device only complies with one of them, the equipment is considered invalid.

EMC requirements detailed in this report are established by regulations as, for instance, EMC Directive 2004/108/EC of the European Parliament and of the Council [1]. Once the directive has been analyzed, the study continues covering the specific standards appointed by the directive. WT requirements are set by WT standards IEC 61400-1 [2] and IEC 61400-2 [3], and by technical report CLC/TR 50373 [4]. For electrical machines, its correspondent rotating electrical machines standard IEC 60034-1 [5] is consulted; this regulation indicates that electrical machine EMC requirements are contained in standard CISPR 11 [6]. Power converter EMC requirements are established on IEC 61000-6-2 [7] regarding immunity, and IEC 61000-6-3 [8], IEC 61000-3-2 [9] and IEC 61000-3-3 [10] regarding emission.

2 Scope

The EMC requirements explained in this report are applicable to WTs, rotating electrical machines and power converters. These requirements refer to electromagnetic immunity and both radiated and conducted emissions.

If the tested devices not fulfill the requirements established by the standards, it is possible to implement some corrective actions; those actions are described at clause 8 of this report.

3 Wind turbine EMC requirements

EMC Directive 2004/108/EC [1], WTs standards IEC 61400-1 [2] and IEC 61400-2 [3], and technical report CLC/TR 50373 [4] are analyzed and studied. All these regulations indicate that the EMC requirements for WTs are detailed in IEC 61000-6 family of standards.

Regulations specify that WT manufacturers have to point out the environment where the WT will be working. Depending on the environment established by the manufacturer, the WT must meet different standards and requirements. The environment must be detailed in the WT data sheet.

Two kinds of environments are considered by the regulation, industrial environments and residential, commercial and light-industrial environments.

Industrial environments are applied to apparatus intended to be connected in a power network with a high or medium-voltage transformer. These devices supply installations that feed manufacturing plants or similar, and are intended to operate in or in proximity of industrial locations. Industrial environments are applied also to battery-operated apparatus intended to be used in industrial locations.

Residential, commercial and light-industrial environments are applied to apparatus intended to be directly connected to low-voltage public main networks or connected to a dedicated DC source, which operates as interface between the apparatus and the low-voltage public main networks. Residential, commercial and light-industrial environments are applied also to apparatus which are powered by batteries or by a non-public, but non-industrial, low-voltage power distribution system; this apparatus are intended to be used in locations like residential properties, retail outlets, business premises, areas of public entertainment, outdoor locations or light-industrial locations.

EMC immunity requirements are set by the standard IEC 61000-6-1 [11] for residential, commercial and light-industrial environments; and by the standard IEC 61000-6-2 [7] for industrial environments.

Regarding EMC emission requirements, both environments are considered in the technical report CLC/TR 50373 [4], which makes reference to standards IEC 61000-6-3 [8] and IEC 61000-6-4 [12], although the specific standard for WTs IEC 61400-1 [2] only considers the obligation with standard IEC 61000-6-4 [12].

A third environment with the most stringent requirements is considered in the technical report UNE-CLC/TR 50373 [4]. This third environment is a combination of the previous two environments merging the most restrictive requirements: EMC immunity requirements for industrial environments (IEC 61000-6-2 [7]) and EMC emission requirements for residential, commercial and light-industrial environments (IEC 61000-6-3 [8]).

Finally, the regulation establishes that the EMC requirements fulfillment of the components which form the WT exclusively concerns to the WT and component manufacturer.

3.1 Emission

The emission requirements are established by the standards IEC 61000-6-3 [8] and IEC 61000-6-4 [12]. If all electric and electronic devices that constitute the WT fulfill all two clauses attached below, the emission requirements are complied.

- The devices are either in compliance with EMC regulations (specific product or generic standards) for corresponding electromagnetic environment, or they are exempt or excluded from the EMC directive
- The devices are installed in agreement with instructions and they are used according to the limitations specified by the manufacturer

Emission requirements established by standards IEC 61000-6-3 [8] and IEC 61000-6-4 [12] are shown in Table 1 and Table 2.

Table 1. Emission requirements for residential, commercial and light-industrial environments.

Table clause	Port	Frequency range	Limits	Basic standard	Applicability note	Remarks
1.1	Enclosure Test facility: OATS or SAC	30 MHz to 230 MHz	30 dB(µV/m) quasi-peak at 10 m	The measurement instrumentation shall be as defined in 4 of CISPR 16-1-1 [17]. The measuring antennas shall be as defined in 4.4 of CISPR 16-1-4 [25]. The measuring site shall be as described in Clause 5 of CISPR 16-1-4 [25]. The measurement method shall be as specified in 7.2 of CISPR 16-2-3 [16].	See [a, b and e]	May be measured at 3 m distance using the limits increased by 10 dB. As stated in CISPR 16-2-3 [16] the antenna height shall be varied between 1 m to 4 m. Additional guidance on the test method can be found in CISPR 16-2-3 [16] clause 7.3 and clause 8.
		230 MHz to 1000 MHz	37 dB(µV/m) quasi-peak at 10 m			
1.2	Enclosure Test facility: FAR	30 MHz to 230 MHz	42 to 35 dB(µV/m) quasi-peak at 3 m Limit reducing linearly with the logarithm of the frequency	The measurement instrumentation shall be as defined in 4 of CISPR 16-1-1 [17]. The measuring antennas shall be as defined in 4.4 of CISPR 16-1-4 [25]. The measuring site shall be as described in Clause 5.8 of CISPR 16-1-4 [25]. The measurement method shall be as specified in 7.2.9.2 of CISPR 16-2-3 [16].	See [a, b and e] Only applicable to table top equipment	May be measured at greater distances with the limits decreased by 20 dB/decade (relative to distance). The limitations on EUT size in CISPR 16-1-4 [25] apply.
		230 MHz to 1000 MHz	42 dB(µV/m) quasi-peak at 3 m			

Table clause	Port	Frequency range	Limits	Basic standard	Applicability note	Remarks
1.3	Enclosure Test facility: TEM Waveguide	30 MHz to 230 MHz	30 dB(µV/m) quasi-peak	IEC 61000-4-20 [33]	Only applicable to battery powered equipment not intended to have external cables attached. Restricted to equipment complying with the definition 6.2 in IEC 61000-4-20 [33]. See [a, b and e]	
		230 MHz to 1000 MHz	37 dB(µV/m) quasi-peak			
			The small-EUT correction factor given in A.4.3 of IEC 61000-4-20 [33] shall be used. The limit relates to the OATS measurement distance of 10 m			
1.4	Enclosure Test facility: OATS, SAC or FAR	1 GHz to 3 GHz	70 dB(µV/m) peak at 3 m	The measurement instrumentation shall be as defined in 5 and 6 of CISPR 16-1-1 [17]. The measuring antennas shall be as defined in 4.5 of CISPR 16-1-4 [25]. The measuring site shall be as described in Clause 8 of CISPR 16-1-4 [25]. The measurement method shall be as specified in 7.3 of CISPR 16-2-3 [16].	See [a,c,d and e]	May be measured at greater distances with the limits decreased by 20 dB/decade (relative to distance). For SAC and OATS facilities absorber may be required to achieve free space conditions as defined in CISPR 16-1-4 [25].
			50 dB(µV/m) average at 3 m			
		3 GHz to 6 GHz	74 dB(µV/m) peak at 3 m			
			54 dB(µV/m) average at 3 m			

[a] For apparatus containing devices operating at frequencies less than 9 kHz measurements only need to be performed up to 230 MHz.

[b] The apparatus is deemed to comply with the enclosure port requirement below 1 GHz if it meets the requirements defined in one or more of the table clauses 1.1, 1.2 or 1.3 of IEC 61000-6-3 [8].

[c] If the highest internal frequency of the EUT is less than 108 MHz, the measurement shall only be made up to 1 GHz.
If the highest internal frequency of the EUT is between 108 MHz and 500 MHz, the measurement shall only be made up to 2 GHz.
If the highest internal frequency of the EUT is between 500 MHz and 1 GHz, the measurement shall only be made up to 5 GHz.
If the highest internal frequency of the EUT is above 1 GHz, the measurement shall be made up to 6 GHz.
Where the highest internal frequency is not known, tests shall be performed up to 6 GHz.

[d] The peak detector limits shall not be applied to disturbances produced by arcs or sparks that are high voltage breakdown events. Such disturbances arise when devices contain or control mechanical switches that control current in inductors, or when devices contain or control subsystems that create static electricity (such as paper handling devices). The average limits apply to disturbances from arcs or sparks, and both peak and average limits apply to other disturbances from such devices.

[e] At transitional frequencies the lower limits applies.

Table clause	Port	Frequency range	Limits	Basic standard	Applicability note	Remarks
2.1	Low voltage AC mains	0 kHz to 2 kHz	Limits are presented in the basic standards. See basic standards column.	IEC 61000-3-2 [9] IEC 61000-3-3 [10] IEC 61000-3-11 [20] IEC 61000-3-12 [21]	See [a] and [b]	
		0.15 MHz to 0.5 MHz	66 dB(µV) to 56 dB(µV) quasi-peak	The measurement instrumentation shall be as defined in 4 and 6 of CISPR 16-1-1 [17]. The measuring networks shall be as defined in 4 of CISPR 16-1-2 [15]. The measurement set up and method shall be as described in Clause 7 of CISPR 16-2-1 [19].	See [c]	
			56 dB(µV) to 46 dB(µV) average			
			Limits decrease linearly with the logarithm of the frequency			
		0.5 MHz to 5 MHz	56 dB(µV) quasi-peak			
			46 dB(µV) average			
		5 MHz to 30 MHz	60 dB(µV) quasi-peak			
			50 dB(µV) average			
		0.15 MHz to 30 MHz	Discontinuous interference limits defined in 4.2 of CISPR 14-1 [18]	CISPR 14-1 [18]		

[a] Applicable to apparatus covered within the scope of IEC 61000-3-2 [9], IEC 61000-3-3 [10], IEC 61000-3-11 [20] and IEC 61000-3-12 [21].

[b] Equipment which meets the requirements of IEC 61000-3-3 [10], is excluded from IEC 61000-3-11 [20].

[c] At transitional frequencies the lower limit applies.

Table clause	Port	Frequency range	Limits	Basic standard	Applicability note	Remarks
3.1	DC power	0.15 MHz to 0.5 MHz	79 dB(µV) quasi-peak	The measurement instrumentation shall be as defined in 4 and 6 of CISPR 16-1-1 [17]. The measuring networks shall be as defined in 4 of CISPR 16-1-2 [15]. The measurement set up and method shall be as described in Clause 7 of CISPR 16-2-1 [19].	Applicable only to ports intended for connection to - a local DC power network, or - a local battery by a connecting cable exceeding a length of 30 m See [a]	
			66 dB(µV) average			
		0.5 MHz to 30 MHz	73 dB(µV) quasi-peak			
			60 dB(µV) average			

[a] At transitional frequencies the lower limit applies.

Table clause	Port	Frequency range	Limits	Basic standard	Applicability note	Remarks
4.1	Telecommunications/ network	0.15 MHz to 0.5 MHz	84 dB(μV) to 74 dB(μV) quasi-peak	CISPR 22 [13]	See [a] and [b]	
			74 dB(μV) to 64 dB(μV) average			
			40 dB(μA) to 30 dB(μA) quasi-peak			
			30 dB(μA) to 20 dB(μA) average			
			Limits decrease linearly with the logarithm of the frequency			
		0.5 MHz to 30 MHz	74 dB(μV) quasi-peak			
			64 dB(μV) average			
			30 dB(μA) quasi-peak			
			20 dB(μA) average			

[a] The current and voltage disturbance limits are derived for use with an impedance stabilization network (ISN) which presents a common mode (asymmetric mode) impedance of 150 Ω to the telecommunication port under test (conversion factor is 20 $\log_{10}$ 150/I=44 dB).

[b] When performing measurement using an ISN, the EUT shall meet the voltage limits of this table. All elements within CISPR 22 [13] shall be followed, including but not limited to selection of test method, test configuration, cable characteristics.

Table 2. Emission requirements for industrial environments.

Port	Frequency range	Units	Basic standards	Applicability note	Remarks
1) Enclosure port- Open area test site or semi-anechoic method	30 MHz - 230 MHz	40 dB (µV/m) Quasi-peak at 10 m	CISPR 16-2-3 [16]	See Note 1.	May be measured at 30 m distance using the limits decreased by 10 dB.
	230 MHz - 1000 MHz	47 dB (µV/m) Quasi-peak at 10 m			
2) Low voltage AC mains port	0.15 MHz-0.5 MHz	79 dB (µV) Quasi-peak	CISPR 16-2-1 [19], 7.4.1 CISPR 16-1-2 [15], 4.3	See Note 2.	
		66 dB (µV) average			
	0.5 MHz-30 MHz	73 dB (µV) Quasi-peak			
		60 dB (µV) average			
3) Telecommunications/network port	0.15 MHz-0.5 MHz	97 dB (µV) – 87 dB (µV) Quasi-peak	CISPR 22 [13]	See Notes 3, 4 and 5.	
		84 dB (µV) – 74 dB (µV) average			
		53 dB (µA) – 43 dB (µA) Quasi-peak			
		40 dB (µA) – 30 dB (µA) average			
	0.5 MHz-30 MHz	87 dB (µV) Quasi-peak		See Notes 3 and 5.	
		74 dB (µV) average			
		43 dB (µA) Quasi-peak			
		30 dB (µA) average			

NOTE 1. If the internal emission source(s) is operating at a frequency below 9 kHz then measurements need only to be performed up to 230 MHz.

NOTE 2. Impulse noise (clicks) which occur less than five times per minute is not considered. For clicks appearing more often than 30 times per minute the limits apply. For clicks appearing between 5 and 30 times per minute, a relaxation of the limits is allowed of 20 log 30/N dB (where N is the number of clicks per minute). Criteria for separated clicks may be found in CISPR 14-1 [18].

NOTE 3. At transitional frequencies the lower limit applies.

NOTE 4. The limits decrease linearly with the logarithm of the frequency in the range 0.15 MHz to 0.5 MHz.

NOTE 5. The current and voltage disturbance limits are derived for use with an impedance stabilization network (ISN) which presents a common mode (asymmetric mode) impedance of 150 Ω to the telecommunication port under test (conversion factor is 20 $\log_{10}150/I=44$ dB).

3.2 Immunity

The immunity requirements are established by the standards IEC 61000-6-1 [11] and IEC 61000-6-2 [7]. If all electric and electronic devices that form WT fulfill the two clauses below, the immunity requirements are satisfied.

- The devices are either in compliance with EMC regulations (specific product or generic standards) for corresponding electromagnetic environment, or they are exempt or excluded from the EMC directive
- The devices are installed in agreement with instructions and they are used according to the limitations specified by the manufacturer

Immunity requirements established by standards IEC 61000-6-1 [11] and IEC 61000-6-2 [7] are shown from Table 3 to Table 6 for residential, commercial and light-industrial environments, and from Table 7 to Table 10 for industrial environments.

Table 3. Immunity requirements for residential, commercial and light-industrial environments.

	Environmental phenomena		Test specifications	Units	Basic standards	Remarks	Performance criterion
1.1	Power-frequency magnetic field		50, 60	Hz	IEC 61000-4-8 [31]	The test shall be carried out at the frequencies appropriate to the power supply frequency. Equipment intended for use in areas supplied only at one of these frequencies need only be tested at that frequency. [a]	A[b]
			3	A/m			
1.2	Radio-frequency electromagnetic field. Amplitude modulated		80 to 1000	MHz	IEC 61000-4-3[c] [27]	The test level specified is the r.m.s. value of the unmodulated carrier.	A
			3	V/m			
			80	% AM (1 kHz)			
1.3	Radio-frequency electromagnetic field. Amplitude modulated		1.4 to 2.0	GHz	IEC 61000-4-3[c] [27]	The test level specified is the r.m.s. value of the unmodulated carrier. [d]	A
			3	V/m			
			80	% AM (1 kHz)			
1.4	Radio-frequency electromagnetic field. Amplitude modulated		2.0 to 2.7	GHz	IEC 61000-4-3[c] [27]	The test level specified is the r.m.s. value of the unmodulated carrier. [d]	A
			1	V/m			
			80	% AM (1 kHz)			
1.5	Electrostatic discharge	Contact discharge	±4 (charge voltage)	kV	IEC 61000-4-2 [26]	See basic standard for applicability of contact and/or air discharge test	B
		Air discharge	±8 (charge voltage)	kV			B

[a] Applicable only to apparatus containing devices susceptible to magnetic fields.

[b] For CRTs, the acceptable jitter depends upon the character size and is calculated for a test level of 1 A/m as follows:

$$J \leq \frac{(3C + 1)}{40}$$

where jitter J and character size C is in millimetres.

As jitter is linearly proportional to the magnetic field strength, tests can be carried out at other test levels extrapolating the maximum jitter level appropriately.

[c] IEC 61000-4-20 [33] may be used for small EUTs as defined in IEC 61000-4-20 [33] subclause 6.1.

[d] The frequency range has been selected to cover the frequencies with the highest potential risk of a disturbance.

Table 4. Immunity requirements for residential, commercial and light-industrial environments. Access through signal ports.

	Environmental phenomena	Test specifications	Units	Basic standards	Remarks	Performance criterion
2.1	Radio-frequency common mode	0.15 to 80	MHz	IEC 61000-4-6 [30]	The test level specified is the r.m.s. value of the unmodulated carrier. [a,b]	A
		3	V			
		80	% AM (1 kHz)			
2.2	Fast transients	±0.5	kV (open circuit test voltage)	IEC 61000-4-4 [28]	Capacitive clamp used [b]	B
		5/50	Tr/Th ns			
		5	Repetition frequency kHz			

[a] The test level can also be defined as the equivalent current into a 150 Ω load.

[b] Applicable only to ports interfacing with cables whose total length according to the manufacturer's functional specification may exceed 3 m.

Table 5. Immunity requirements for residential, commercial and light-industrial environments. Access through input and output power interface ports in DC.

	Environmental phenomena	Test specifications	Units	Basic standards	Remarks	Performance criterion
3.1	Radio-frequency common mode	0.15 to 80	MHz	IEC 61000-4-6 [30]	The test level specified is the r.m.s. value of the unmodulated carrier [a,b]	A
		3	V			
		80	% AM (1 kHz)			
3.2	Surges line-to-earth line-to-line	1.2/50 (8/20)	Tr/Th µs	IEC 61000-4-5 [29]	For application to input ports [c]	B
		±0.5	kV (open circuit test voltage)			
		±0.5	kV (open circuit test voltage)			
3.3	Fast transients	±0.5	kV (open circuit test voltage)	IEC 61000-4-4 [28]	For application to input ports [d]	B
		5/50	Tr/Th ns			
		5	Repetition frequency kHz			

[a] The test level can also be defined as the equivalent current into a 150 Ω load.

[b] Applicable only to ports interfacing with cables whose total length according to the manufacturers functional specification may exceed 3 m.

[c] Not applicable to input ports intended for connection to a battery or a rechargeable battery which must be removed or disconnected from the apparatus for recharging. Apparatus with a DC power input port intended for use with an AC-DC power adaptor shall be tested on the AC power input of the AC-DC power adaptor specified by the manufacturer or, where none is so specified, using a typical AC-DC power adaptor. DC ports which are not intended to be connected to a DC distribution network are treated as signal ports.

[d] Not applicable to input ports intended for connection to a battery or a rechargeable battery which must be removed or disconnected from the apparatus for recharging. Apparatus with a DC power input port intended for use with an AC-DC power adaptor shall be tested on the AC power input of the AC-DC power adaptor specified by the manufacturer or, where none is so specified, using a typical AC-DC power adaptor. The test is applicable to DC power input ports intended to be connected permanently to cables longer than 3 m.

Table 6. Immunity requirements for residential, commercial and light-industrial environments. Access through input and output power interface ports in AC.

	Environmental phenomena	Test specifications	Units	Basic standards	Remarks	Performance criterion
4.1	Radio-frequency common mode	0.15 to 80	MHz	IEC 61000-4-6 [30]	The test level specified is the r.m.s. value of the unmodulated carrier [a]	A
		3	V			
		80	% AM (1 kHz)			
4.2	Voltage dips	0	% residual voltage	IEC 61000-4-11 [32]	Voltage shift at zero crossing[b]	B
		0.5	cycle			
		0	% residual voltage			B
		1	cycle			
		70	% residual voltage			C
		25/30 at 50/60 Hz	cycle			
4.3	Voltage interruptions	0	% residual voltage	IEC 61000-4-11 [32]	Voltage shift at zero crossing[b]	C
		250/300 at 50/60 Hz	cycle			
4.4	Surges line-to-earth line-to-line	1.2/50 (8/20)	Tr/Th µs	IEC 61000-4-5 [29]		B
		±2	kV (open circuit test voltage)			
		±1	kV (open circuit test voltage)			
4.5	Fast transients	±1	kV (open circuit test voltage)	IEC 61000-4-4 [28]		B
		5/50	Tr/Th ns			
		5	Repetition frequency kHz			

[a] The test level can also be defined as the equivalent current into a 150 Ω load.
[b] Applicable only to input ports.

Table 7. Immunity requirements for industrial environments. Access through the housing.

	Environmental phenomena		Test specifications	Units	Basic standards	Remarks	Performance criterion
1.1	Power-frequency magnetic field		50, 60	Hz	IEC 61000-4-8 [31]	[a] The test shall be carried out at the frequencies appropriate to the power supply frequency. Equipment intended for use in areas supplied only at one of these frequencies need only be tested at that frequency	A[b]
			30	A/m			
1.2	Radio-frequency electromagnetic field. Amplitude modulated		80 to 1000	MHz	IEC 61000-4-3[d] [27]	[c] The test level specified is the r.m.s. value of the unmodulated carrier	A
			10	V/m			
			80	% AM (1 kHz)			
1.3	Radio-frequency electromagnetic field. Amplitude modulated		1.4 to 2.0	GHz	IEC 61000-4-3[d] [27]	[e] The test level specified is the r.m.s. value of the unmodulated carrier	A
			3	V/m			
			80	% AM (1 kHz)			
1.4	Radio-frequency electromagnetic field. Amplitude modulated		2.0 to 2.7	GHz	IEC 61000-4-3[d] [27]	[e] The test level specified is the r.m.s. value of the unmodulated carrier	A
			1	V/m			
			80	% AM (1 kHz)			
1.5	Electrostatic discharge	Contact discharge	±4 (charge voltage)	kV	IEC 61000-4-2 [26]	See basic standard for applicability of contact and/or air discharge tests	B
		Air discharge	±8 (charge voltage)	kV			B

[a] Applicable only to apparatus containing devices susceptible to magnetic fields.

[b] For CRTs, the acceptable jitter depends upon the character size and is calculated for a test level of 1 A/m as follows:

$$J \leq \frac{(3C + 1)}{40}$$

where jitter J and character size C is in millimetres.

As jitter is linearly proportional to the magnetic field strength, tests can be carried out at other test levels extrapolating the maximum jitter level appropriately.

[c] Except for the ITU broadcast frequency bands 87 MHz to 108 MHz, 174 MHz to 230 MHz, and 470 MHz to 790 MHz, where the level shall be 3 V/m.

[d] IEC 61000-4-20 [33] may be used for small EUTs as defined in IEC 61000-4-20 [33] subclause 6.1.

[e] The frequency range has been selected to cover the frequencies with the highest potential risk of a disturbance.

Table 8. Immunity requirements for industrial environments. Access through signal ports.

	Environmental phenomena	Test specifications	Units	Basic standards	Remarks	Performance criterion
2.1	Radio-frequency common mode	0.15 to 80	MHz	IEC 61000-4-6 [30]	[a,b,c] The test level specified is the r.m.s. value of the unmodulated carrier	A
		10	V			
		80	% AM (1 kHz)			
2.2	Fast transients	± 1	kV (open circuit test voltage)	IEC 61000-4-4 [28]	[c] Capacitive clamp used	B
		5/50	Tr/Th ns			
		5	Repetition frequency kHz			
2.3	Surges line-to-earth	1.2/50 (8/20)	Tr/Th μs	IEC 61000-4-5 [29]	[d,e]	B
		± 1	kV (open circuit test voltage)			

[a] The test level can also be defined as the equivalent current into a 150 Ω load.

[b] Except for the ITU broadcast frequency band 47 MHz to 68 MHz, where the level shall be 3V.

[c] Applicable only to ports interfacing with cables whose total length according to the manufacturer's functional specification may exceed 3 m.

[d] Applicable only to ports interfacing with cables whose total length according to the manufacturer's functional specification may exceed 30 m.

[e] Where normal functioning cannot be achieved because of the impact of the CDN on the EUT, this test is not required.

Table 9. Immunity requirements for industrial environments. Access through input and output power interface ports in DC.

	Environmental phenomena	Test specifications	Units	Basic standards	Remarks	Performance criterion
3.1	Radio-frequency common mode	0.15 to 80	MHz	IEC 61000-4-6 [30]	[a, b] The test level specified is the r.m.s. value of the unmodulated carrier	A
		10	V			
		80	% AM (1 kHz)			
3.2	Surges line-to-earth line-to-line	1.2/50 (8/20)	Tr/Th µs	IEC 61000-4-5 [29]	[c]	B
		± 0.5	kV (open circuit test voltage)			
		± 0.5	kV (open circuit test voltage)			
3.3	Fast transients	± 2	kV (open circuit test voltage)	IEC 61000-4-4 [28]	[d]	B
		5/50	Tr/Th ns			
		5	Repetition frequency kHz			

[a] The test level can also be defined as the equivalent current into a 150 Ω load.

[b] Except for the ITU broadcast frequency band 47 MHz to 68 MHz, where the level shall be 3V.

[c] Not applicable to input ports intended for connection to a battery or a rechargeable battery which must be removed or disconnected from the apparatus for recharging. Apparatus with a DC power input port intended for use with an AC-DC power adaptor shall be tested on the AC power input of the AC-DC power adaptor specified by the manufacturer or, where none is so specified, using a typical AC-DC power adaptor. DC ports, which are not intended to be connected to a DC distribution network are treated as signal ports.

[d] Not applicable to input ports intended for connection to a battery or a rechargeable battery which must be removed or disconnected from the apparatus for recharging. Apparatus with a DC power input port intended for use with an AC-DC power adaptor shall be tested on the AC power input of the AC-DC power adaptor specified by the manufacturer or, where none is so specified, using a typical AC-DC power adaptor. The test is applicable to DC power input ports intended to be connected permanently to cables longer than 3 m.

Table 10. Immunity requirements for industrial environments. Access through input and output power interface ports in AC.

	Environmental phenomena	Test specifications		Units	Basic standards	Remarks	Performance criterion
4.1	Radio-frequency common mode	0.15 to 80		MHz	IEC 61000-4-6 [30]	[a,b] The test level specified is the r.m.s. value of the unmodulated carrier	A
		10		V			
		80		% AM (1 kHz)			
4.2	Voltage dips	0		% residual voltage	IEC 61000-4-11 [32]	[c] Voltage shift at zero crossing	B [d]
		1		Cycle			
		40	70	% residual voltage			C [d]
		10/12 at 50/60 Hz	25/30 at 50/60 Hz	Cycle			
4.3	Voltage interruptions	0		% residual voltage	IEC 61000-4-11 [32]	[c] Voltage shift at zero crossing	C [d]
		250/300 at 50/60 Hz		Cycle			
4.4	Surges line-to-earth line-to-line	1.2/50 (8/20)		Tr/Th µs	IEC 61000-4-5 [29]	See clause 5, paragraph 3	B
		± 2		kV (open circuit test voltage)			
		± 1		kV (open circuit test voltage)			
4.5	Fast transients	± 2		kV (open circuit test voltage)	IEC 61000-4-4 [28]		B
		5/50		Tr/Th ns			
		5		Repetition frequency kHz			

[a] The test level can also be defined as the equivalent current into a 150 Ω load.

[b] Except for the ITU broadcast frequency band 47 MHz to 68 MHz, where the level shall be 3 V.

[c] Applicable only to input ports.

[d] For electronic power converters, the operation of protective devices is allowed.

4 Electrical machine EMC requirements

EMC Directive 2004/108/EC of the European Parliament and of the Council [1] and standard IEC 60034-1 [5] have been consulted in order to collect the EMC requirements and tests for electrical machines. EMC requirements for both emission and immunity are explained on the next sections.

4.1 Immunity

Electrical machines without electronic components under normal use conditions are not sensitive to electromagnetic disturbance emissions. Therefore, no requirements and no tests for EMC immunity are established for them. Electronic components used in electrical machines are usually passive components, so no requirements and no tests for EMC immunity are established for electrical machines with electronic components neither.

4.2 Emission

EMC emission requirements for brushless rotating electrical machines are defined by the EMC Directive 2004/108/EC [1] and the standard IEC 60034-1 [5] as the requirements detailed for devices belong to Group1 and Class B in the standard CISPR 11 [6]. Table 11 shows electromagnetic emission limits for brushless rotating electrical machines.

Table 11. Brushless rotating electrical machine electromagnetic emission limits.

	Frequency range	Limits
Radiated emission	30 MHz to 230 MHz	30 dB(µV/m) quasi peak, measured at 10 m distance (Note 1)
	230 MHz to 1000 MHz	37 dB(µV/m) quasi peak, measured at 10 m distance (Note 1)
Conducted emission on AC supply terminals	0.15 MHz to 0.50 MHz Limits decrease linearly with logarithm frequency	66 dB(µV) to 56 dB(µV) quasi peak
		56 dB(µV) to 46 dB(µV) average
	0.50 MHz to 5 MHz	56 dB(µV) quasi peak
		46 dB(µV) average
	5 MHz to 30 MHz	60 dB(µV) quasi peak
		50 dB(µV) average

NOTE 1. May be measured at 3 m distance using the limits increased by 10 dB.
NOTE 2. Emission limits are from CISPR 11, Class B, Group 1.

5 Power converter EMC requirements

Power converter EMC requirements are established by the standards IEC 61000-6-2 [7], IEC 61000-6-3 [8], IEC 61000-3-2 [9] and IEC 61000-3-3 [10] which are in accordance with the EMC Directive 2004/108 /EC of the European Parliament and of the Council [1].

5.1 Immunity

Power converter EMC requirements are collected in the standard IEC 61000-6-2 [7]. This regulation is the same that establishes the WT EMC immunity requirements for industrial environments. The power converter EMC requirements are shown from Table 7 to Table 10.

5.2 Emission

Power converter EMC emission requirements are established by the standard IEC 61000-6-3 [8]. This standard is the same that determines the WT EMC emission requirements for residential, commercial and light-industrial environments. In addition to the requirements collected in standard IEC 61000-6-3 [8], power converter has to meet with the limits for harmonic current emissions, voltage changes, voltage fluctuations and flicker determined in the standards IEC 61000-3-2 [9] and IEC 61000-3-3 [10] respectively. The requirements determined by both standards are detailed below.

The limits established by the standard IEC 61000-3-3 [10] are the following:

- Short-term flicker indicator (P_{st}) ≤ 1
- Long-term flicker indicator (P_{lt}) ≤ 0.65
- Maximum time ($d(t)$ ≥ 3.3%) ≤ 500 ms[1]
- The relative steady-state voltage change (d_c) ≤ 3.3%
- The maximum relative voltage change (d_{max}) ≤ 4%

Power converter is classified in the standard IEC 61000-3-2 [9] as Class A equipment. Power converter shall meet the limits collected in the Table 12.

Table 12. Limits for class A equipment.

Harmonic order n	Maximum permissible harmonic current A
Odd harmonics	
3	2.30
5	1.14
7	0.77
9	0.40
11	0.33
13	0.21
15 ≤ n ≤ 39	$0.15\ \frac{15}{n}$
Even harmonics	
2	1.08
4	0.43
6	0.3
8 ≤ n ≤ 40	$0.23\ \frac{8}{n}$

[1] The value of $d(t)$ during a voltage change shall not exceed 3.3% for more than 500 ms. Where $d(t)$ is the voltage change characteristic.

All tests must be performed by an accredited laboratory, or a certifying body shall verify that the entity which performs tests is in accordance with standards ISO/IEC 17020 or ISO/IEC 17025 criteria.

6 Emission tests

Emission tests are performed in order to assure that the equipment under test (EUT) is in accordance with specifications of CISPR regulations. The electromagnetic disturbances generated by the EUT are measured during the test and they are compared with the limits established in CISPR standards.

"A CISPR limit is a limit which is recommended to national authorities for incorporation in national publications, relevant legal regulations and official specifications. It is also recommended that international organizations use this limits"[2].

A statistical assessment procedure is used to certificate the conformity of EUT. The test is performed on a sample of not less than five and not more than twelve pieces of the equipment manufactured. The assessment of conformity in accordance with the specifications of CISPR is achieved if the relationship below is obeyed:

$$\overline{x} + kS_n \leq L \tag{6.1}$$

where:

- $\overline{x}$ is the arithmetic mean value of the disturbance level of n equipment in the sample
- S_n is the standard deviation of the sample

$$S_n{}^2 = \frac{1}{n-1}\sum(x_n - \overline{x})^2 \tag{6.2}$$

where:

x_n is the disturbance level of an individual equipment

n is the sample size

- L is the permitted limit
- k is the factor derived from tables of the non-central t statistical distribution which ensures that 80 % or more of the production is below the limit with 80 % confidence. Values of k are given in Table 13 as a function of n

x_n, $\overline{x}$, S_n and L are expressed logarithmically: dB (μV), dB (μV/m) or dB (pW)

[2] CISPR 22.

Table 13. The non-central t statistical distribution factor k as a function of the sample size n.

	Non-central t statistical distribution factor k as a function of the sample size n									
n	3	4	5	6	7	8	9	10	11	12
k	2.04	1.69	1.52	1.42	1.35	1.30	1.27	1.24	1.21	1.20

Randomly chosen single sample equipment shall be tested in case of small-scale production. The statistical assessment described above has to be made when the single sample does not comply with the established CISPR limits. Finally, a third type of manufacture process when the equipment is not produced in series is covered; in this case each equipment unit has to comply with the limits.

6.1 Emission test – Telecommunications and network port

The test described in this chapter is performed in order to measure common-mode conduced disturbances emitted at the telecommunications and network port of the EUT under the specifications collected in standard CISPR 22 [13].

6.1.1 Test equipment

The following devices are needed to carry out the tests.

6.1.1.1 Measuring receivers

Quasi-peak detectors and average detectors shall be used to perform the measurement test. A peak detector receiver may be used replacing the quasi-peak detector receiver or average detector receiver in order to reduce measurement time. The detectors used to measure shall be in accordance with standard CISPR 16-1-1.

6.1.1.2 Impedance stabilization network

The impedance stabilization network (ISN) is connected with a cable to the telecommunication port to assess the response of the EUT against common-mode (asymmetric mode) current or voltage disturbances at telecommunication port. Therefore the common-mode termination impedance seen by the telecommunication port during the disturbance measurements is defined by the ISN.

The properties that ISN shall meet are given below:

- The ISN shall attenuate common-mode current or voltage disturbances originated from the auxiliary equipment (AE) at least, 10 dB below the relevant disturbance limit.
  The preferred isolation level is:
  - 150 kHz to 1.5 MHz > 35 dB to 55 dB, increasing linearly with the logarithm of the frequency
  - 1.5 MHz to 30 MHz > 55 dB

- The common-mode termination impedance in the frequency range 0.15 MHz to 30 MHz shall be 150 ± 20 Ω, phase angle 0 ± 20º
- The ISN longitudinal conversion loss (LCL) shall be in accordance with the proper value which depends on the port designed for every kind of cable where the measuring is performed

The ISN shall be interposed in the signal cable between the EUT and any AE or load required to use the EUT in order to not affect the normal operation of the EUT.

If the ISN is provided with a voltage measuring port, the voltage division factor[3] of the ISN shall be added to the receiver voltage measured directly at the voltage measuring port. The result has to be compared with the voltage limits determined in the standard CISPR 22 [13]. The accuracy of the voltage division factor shall be ± 1 dB.

If a current probe is used, it shall be mounted on the cable to measure within 0.1 m distance of the ISN. The insertion impedance of the current probe must be, as maximum, 1 Ω. The operating currents in the primary winding cannot cause saturation effects in the current probe which must have a uniform frequency response without resonances.

6.1.2 Test procedure

6.1.2.1 General measurement conditions

The noise level in test site shall be at least 6 dB below the specified limits in order to permit distinguishing disturbances from the EUT from those belonging to ambient noise. If ambient noise and source disturbance combined do not exceed the specified limit it is not necessary that the ambient noise level would be 6 dB below the specified limit.

6.1.2.2 Measurement of disturbances

Measurement is carried out at telecommunication ports using ISNs with proper LCL; the LCL selection depends on the port, which is designed for every specific type of cable. When the ISN impedance is not determined, measuring is performed using current probe or voltage probe in accordance with the clause 6.1.2.2.3 of this document.

LAN utilization higher than 10 % conditions during at least 250 ms shall be created in order to make reliable emission measurements.

The measurement method depends on the cable connection type for which the port has been designed. Therefore, measurement methods in ports intended for connection to unscreened balanced pairs can be based on ISN or coupling/decoupling network (CDN)[4]. To measure in ports intended for connection to screened cables or to coaxial cables, not only the previous method can

[3] Standard CISPR 22 [13], clause 9.6.2-E.

[4] Described in IEC 61000-4-6 [14] as CDN/ISNs.

be implemented, but also the method based on a 150 Ω load to the outside surface of the shield. Finally, the measurement method in ports intended for connection to cables containing more than four balanced pairs or to unbalanced cables is based on a combination of current probes and capacitive voltage probes. All these methods are explained below.

6.1.2.2.1 Measurement method using impedance stabilization network or coupling/decoupling network

CDN/ISN shall be used for unscreened single and double balanced pairs. CDNs also can be used for other types of cables (screened and unscreened) if the EUT can operate normally with the CDN inserted into the cable connected to the EUT.

The measurement method consists of connecting CDN/ISN directly to the reference ground plane and measuring the disturbances. If voltage measurement is used in the CDN/ISN, after correcting the reading by adding the correspondent CDN/ISN voltage division factor, measured voltage must be compared with the voltage limit. If the current measurement is used, measured current ouput from the current probe must be compared with the current limit.

The best measurement results with the smallest possible measurement uncertainty are obtained using this method. A scheme of this method is shown in Figure 2.

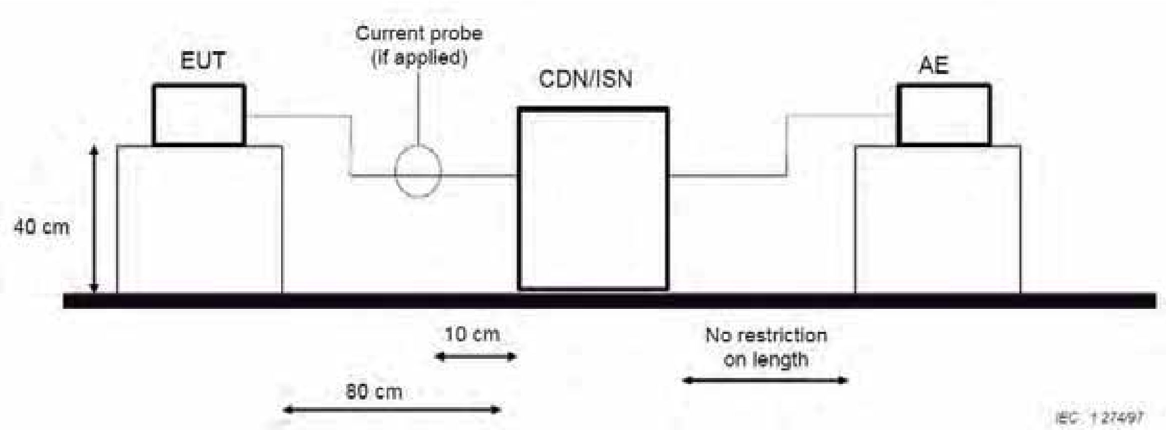

Figure 2. Using CDN/ISNs.

6.1.2.2.2 Measurement method using a 150 Ω load to the outside surface of the shield

This method could be used for all types of coaxial cables or shielded multi-pair cables. For measuring the disturbances it is necessary to open the external insulation of the cable in order to reach the outside metallic surface of the shield. Once the insulation is broken, it is connected to a 150 Ω resistor from the outside surface of the shield to ground, and a ferrite tube or clamp is placed between the resistor connection and the AE. Afterwards, the current is measured with the current probe is compared to the adequate current limit.

The common-mode impedance towards the right of the 150 Ω resistor shall be sufficiently large as not to affect the measurement.

The 150 Ω resistor may be replaced by a 50 Ω to 150 Ω adaptor if the appropriate correction factor is applied. On the other hand, high impedance installed in parallel with the 150 Ω resistor may be also used for voltage measurement. A scheme of this method is shown in Figure 3.

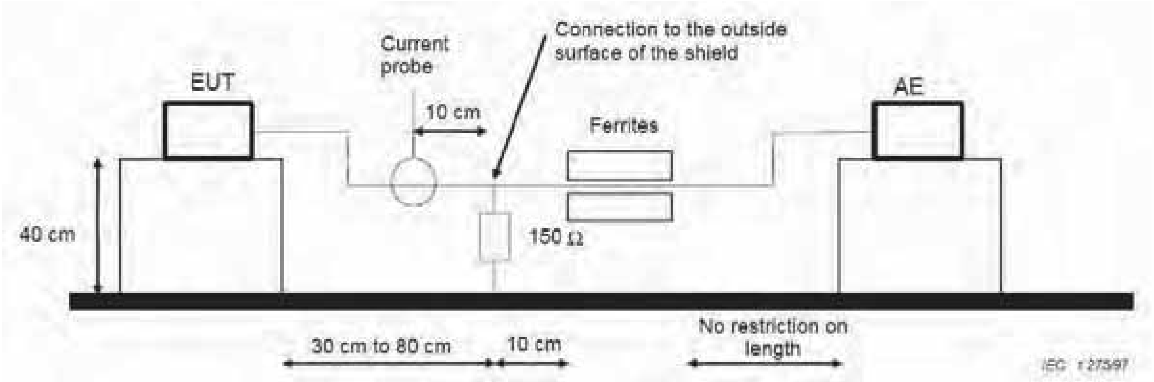

Figure 3. Using a 150 Ω load to the outside surface of the shield.

6.1.2.2.3 Measurement method using a combination of current probe and capacitive voltage probe

It is possible to use this method for cables containing more than four balanced pairs or to unbalanced cables. This method is based on capturing the current value with a current probe and comparing with the current limit; afterwards, voltage is measured with a capacitive voltage (5.2.2 of CISPR 16-1-2 [15]), and finally the measured voltage is adjusted and compared with the voltage limit. The applicable current and voltage limits shall not be exceeded by the measured current and the adjusted voltage.

Unless EUT is battery operated, an artificial main network (AMN) shall supply the EUT (see chapter 6.3.1.1.2). The AMN shall be placed on the reference ground plane at least 10 cm from the nearest edge of the ground plane. A scheme of this method is shown in the Figure 4.

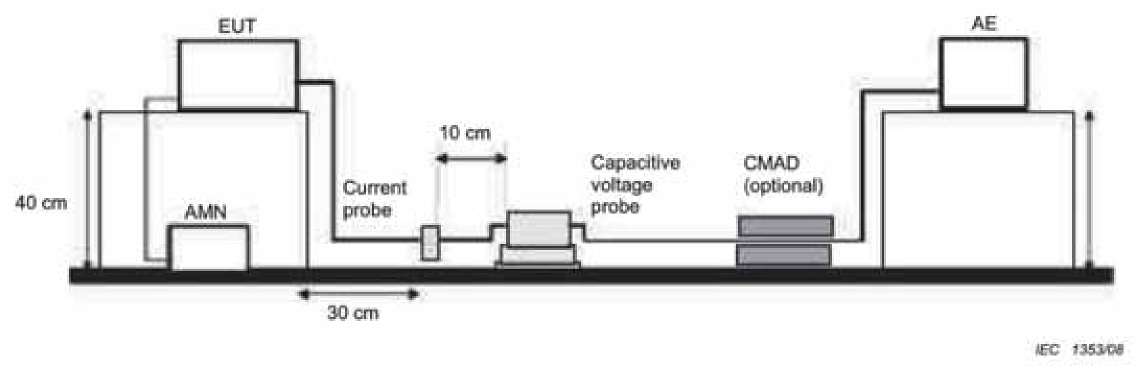

Figure 4. Using a combination of current probe and capacitive voltage probe.

6.2 Emission test – Enclosure port

This test is performed with the aim of measuring radiated disturbance phenomena in the frequency range from 9 kHz to 18 GHz. The test is made on an open-area test site (OATS) or semi-anechoic chamber (SAC). Specifications of this test are collected in standard CISPR 16-2-3 [16].

6.2.1 Test equipment

The test measurement shall be performed using quasi-peak detector for the weighted measurement of broadband disturbance. This kind of detector is also used for narrowband disturbances. The detector shall be in accordance to standard CISPR 16-1-1 [17].

6.2.2 Test procedure

Electric field strength measurements made on OATS or SAC showing the direct and reflected rays arriving at the receiving antenna is shown in Figure 5.

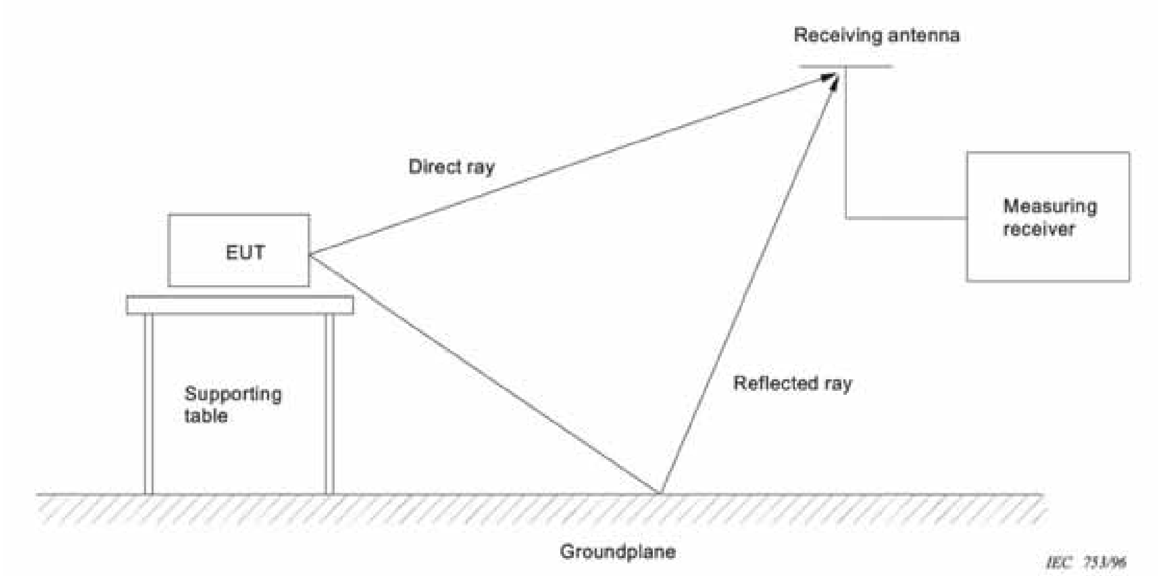

Figure 5. Concept of electric field strength measurements made on an OATS or SAC showing the direct and reflected rays arriving at the receiving antenna.

The maximum electric field strength emitted by the EUT is the parameter to be measured in this test. The measurement is performed as a function of horizontal and vertical polarization. The electric field strength shall be measured from a specific position, in a horizontal projection between the boundary of the EUT and the antenna of 10 m, while the height of the antenna must be in the range between 1 m and 4 m. The measurement shall be done over all the angles in the azimuth plane, and the height of the antenna is varied to allow the direct and reflected rays approach or meet in phase addition. The distance values quoted above are considered as a “rule of thumb”, although the use of alternative measurement distances, such as 3 m or 30 m, instead of 10 m, shall be considered as alternative measurement methods if the height is modified. The measuring process may need to be repeated in order to find the maximum disturbance.

6.3 Emission test – Mains port

The test described in this clause is intended to measure conduction and radiation of radio-frequency (RF) disturbances emitted at the mains port of the EUT under the specifications collected in the standards CISPR 14-1 [18], CISPR16-1-2 [15] and CISPR16-2-1 [19], IEC 61000-3-2 [9], IEC 61000-3-3 [10], IEC 61000-3-11 [20] and IEC 61000-3-12 [21]. The standard which applies varies depending of test frequency range and the environment where the EUT will be installed as is presented in Table 1 and Table 2.

6.3.1 CISPR 14-1

The requirements from standard CISPR 14-1 [18] are explained below.

6.3.1.1 Test equipment

The equipment necessary to carry out the tests consist of measurement receivers, AMN, voltage probe and disturbance analyser for discontinuous disturbance.

6.3.1.1.1 Measurement receivers

Quasi-peak detectors and average detectors shall be used to perform the test. Both detectors shall be in accordance with standard CISPR 16-1-1 [17].

6.3.1.1.2 Artificial mains networks

An AMN isolates the circuit under test from the ambient noise on the power lines, and also provides at the terminals of the EUT a defined impedance for high frequencies across the power feed. The AMN used in the test shall have a nominal impedance 50 Ω/50 µH and shall be in accordance with clause 4.3 of CISPR 16-1-2 [15]. This clause of CISPR regulation determines that the AMN shall have the impedance (magnitude and phase) versus frequency characteristic shown in the Figure 6 and Table 14 in the relevant frequency range. Tolerances of ± 20 % for the magnitude and ± 11.5º for the phase are permitted.

Table 14. Magnitudes and phase angles of the AMN.

Frequency MHz	Impedance magnitude Ω	Phase angle Degree
0.15	34.29	46.70
0.17	36.50	43.11
0.20	39.12	38.51
0.25	42.18	32.48
0.30	44.17	27.95
0.35	45.52	24.45
0.40	46.46	21.70
0.50	47.65	17.66
0.60	48.33	14.86
0.70	48.76	12.81
0.80	49.04	11.25
0.90	49.24	10.03

Frequency MHz	Impedance magnitude Ω	Phase angle Degree
1.00	49.38	9.04
1.20	49.57	7.56
1.50	49.72	6.06
2.00	49.84	4.55
2.50	49.90	3.64
3.00	49.93	3.04
4.00	49.96	2.28
5.00	49.98	1.82
7.00	49.99	1.30
10.00	49.99	0.91
15.00	50.00	0.61
20.00	50.00	0.46
30.00	50.00	0.30

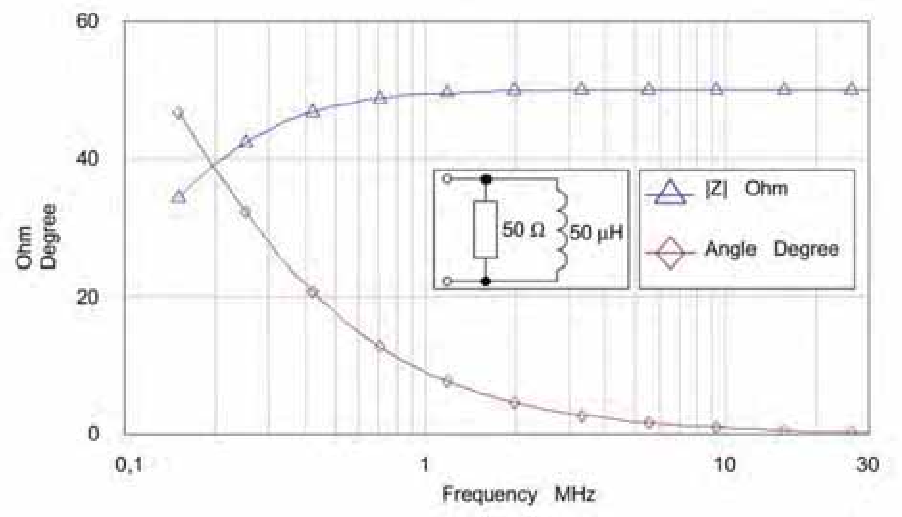

Figure 6. Impedance of the AMN.

The AMN shall be connected to the measuring receiver by means of a coaxial cable with a characteristic impedance of 50 Ω.

Suitable RF impedance shall be inserted between the AMN and the supply mains in order to reduce the unwanted signals affections occurring on the supply mains. The impedance of the mains does not materially affect the impedance of the AMN at the frequency of measurement.

6.3.1.1.3 Voltage probe

If the use of the AMN influences unduly the EUT or the test equipment, the measuring at main terminal shall be performed with a voltage probe. The voltage probe shall also be used while measuring on terminals other than mains terminals, as load and control terminals.

When the voltage probe is used to measure, the obtained values shall be corrected in accordance with the voltage division between the measuring set and the voltage probe, taking into account only the resistive parts of the impedances. The voltage probe impedance consists of a resistance of at least 1500 Ω in series with a capacitor with an impedance value negligible compared to the resistance. This voltage probe impedance shall be increased as needed in case its value is too low and hence affects the function of the EUT.

6.3.1.1.4 Disturbance analyser for discontinuous disturbance

For measuring discontinuous disturbance shall be used analysers according to clause 10 of CISPR 16-1-1 [17]. An oscilloscope may be used as alternative method if its degree of accuracy is sufficient.

6.3.1.2 Test procedure

The disturbance voltage measurements are made in the cable between the AMN and the EUT at the plug end of the lead; the AMN must be placed at a distance of 0.8 m from the EUT. The earthing conductor of the main lead of the EUT, if existent, shall be connected to the reference ground of the measuring.

Where EUT has AE connected at the end of a lead apart from its mains lead, the disturbance measurement shall be performed on the terminals of the EUT and on the terminals of the AE. The disturbances are also measured at all other incoming and outgoing leads by a probe in series with the input of the measuring receiver, as described in 6.3.1.1.3.

6.3.2 CISPR16-1-2 and CISPR16-2-1

The requirements of standards CISPR 16-1-2 [15] and CISPR 16-2-1 [19] are explained below.

6.3.2.1 Test equipment

The equipment necessary to carry out the tests is based on artificial network (AN) and current probes.

6.3.2.1.1 Artificial networks

AN, ISN and AMN shall be in accordance with CISPR 16-1-2 [15] standard which requirement are described in the clause 6.3.1.1.2 of this document.

6.3.2.1.2 Current probes

Current probes are used for measuring the common-mode current clipping the probe around the lead. The current probe operation characteristics allow measure a common-mode current with a small amplitude in presence of differential mode (operating) currents with large amplitude.

6.3.2.2 Test procedure

The disturbance voltage is measured connecting the EUT to the power supply mains and any other extended network via one or more AN(s), as described in the next clauses.

To perform the measuring in a EUT intended to be used on a table, the distance from a referenced ground plane to either the bottom or the rear of the EUT shall be 40 cm, and all other conductive surfaces of the EUT shall be more than 40 cm away from the reference ground plane.

The same provisions are applicable for floor-standing EUTs with the exception that they shall be placed on the floor. For floor-standing EUTs, it shall be used a ground-connected floor of metal which shall make contact with the intentional ground conductors of the EUT, but not with the floor supports of the EUT. This metal floor may be used as the reference ground plane. Examples of test configurations are shown in Figure 7, Figure 8, Figure 9 and Figure 10 .

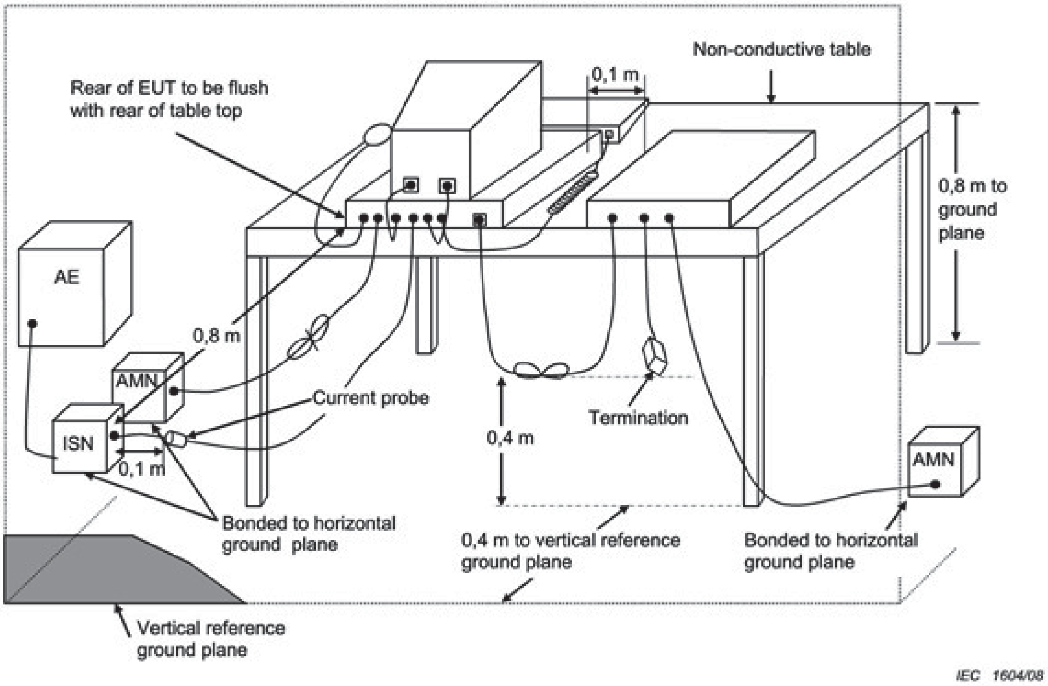

Figure 7. Table-top equipment for conducted disturbance measurements on power mains test configuration.

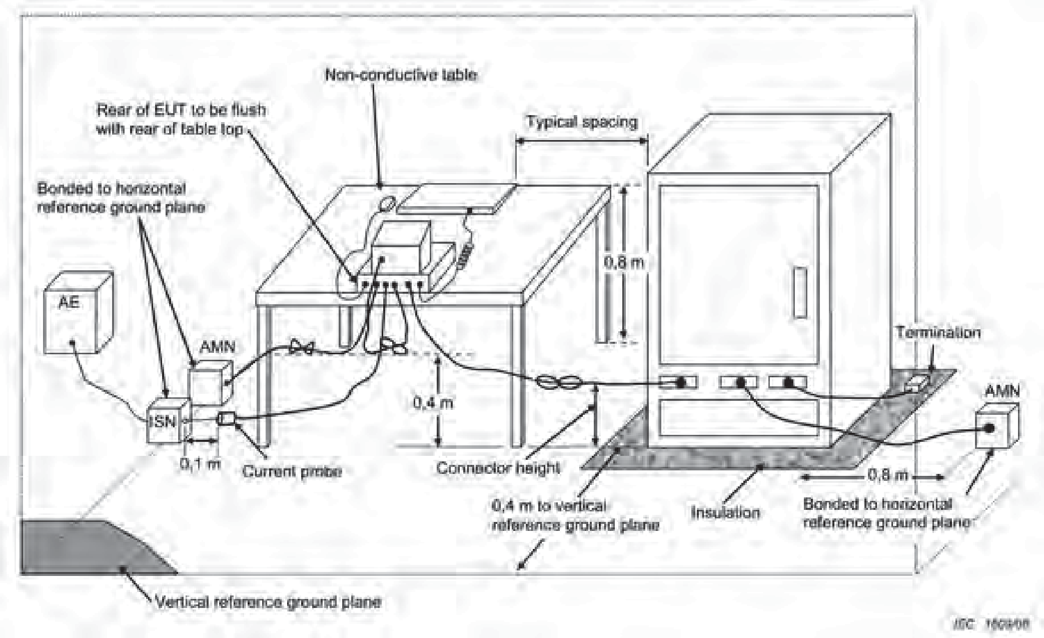

Figure 8. Floor-standing equipment and table-top equipment test configuration.

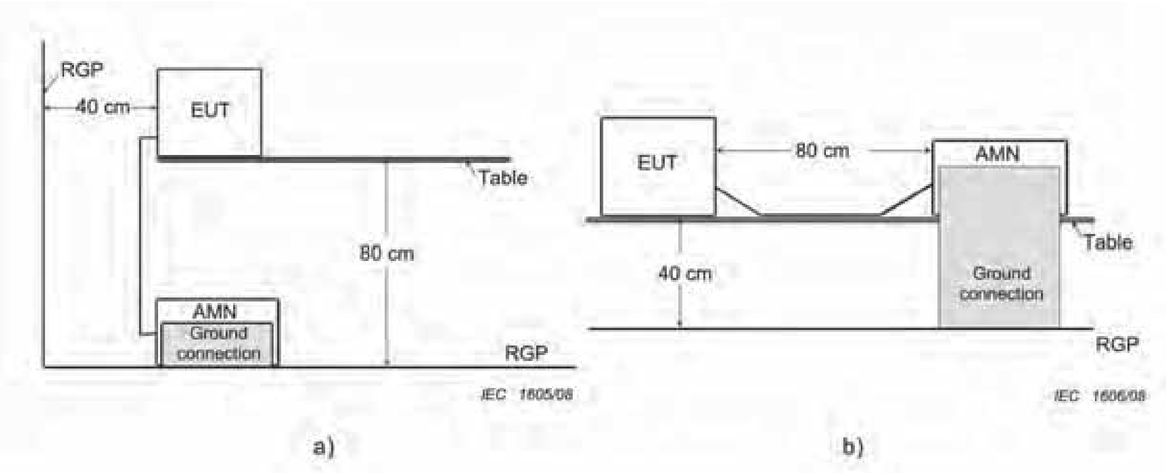

Figure 9. Arrengement of the EUT and AMN at 40 cm distance with a) vertical RPG and b) horizontal RPG.

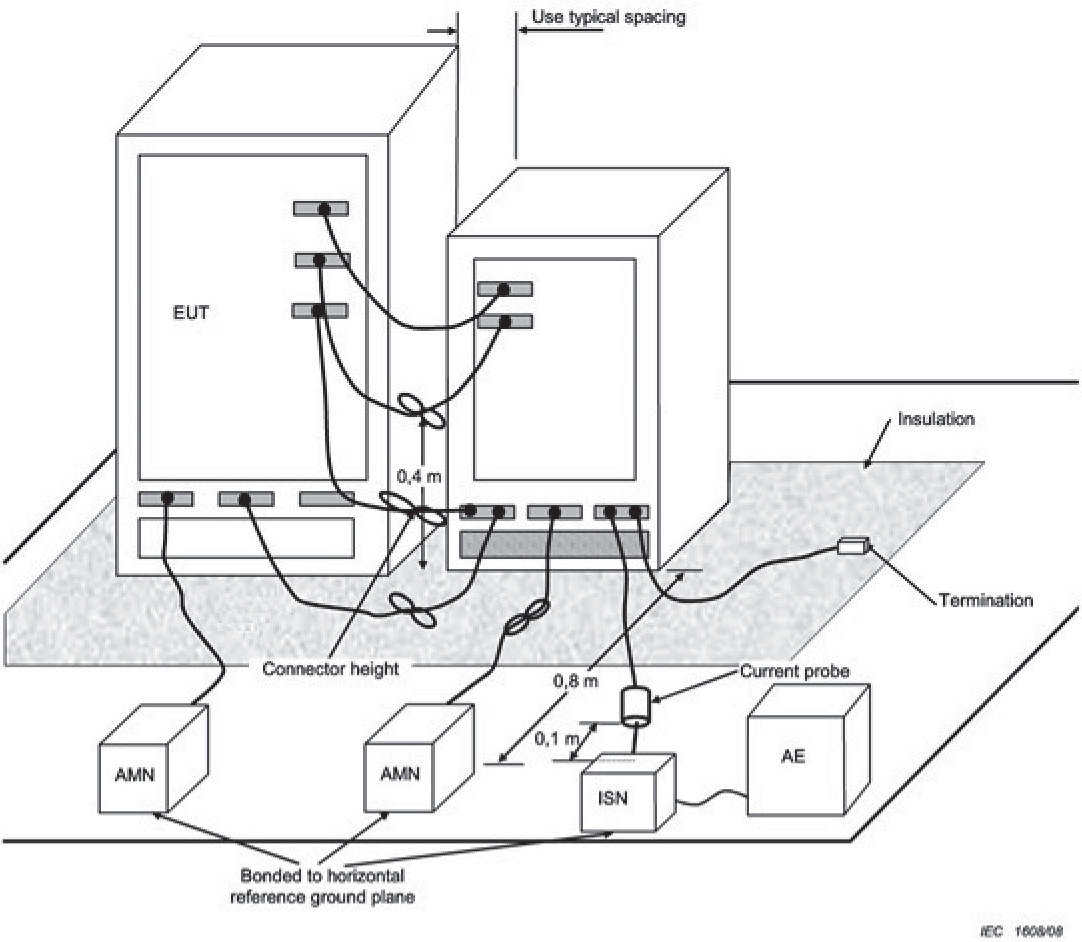

Figure 10. Floor-standing equipment test configuration.

6.3.3 IEC 61000-3-2

This regulation specifies limits of harmonic components from the current, which may be produced by electrical and electronic equipment intended to be connected to a public low-voltage distribution system and having a rated current up to 16 A (included) per phase.

6.3.3.1 Measuring equipment

Measuring equipment requirements are established by standard IEC 61000-4-7 [22].

6.3.3.1.1 Test circuit

Figure 11 and Figure 12 show the circuits that shall be used to measure the harmonic currents of single-phase equipment and three-phase equipment respectively.

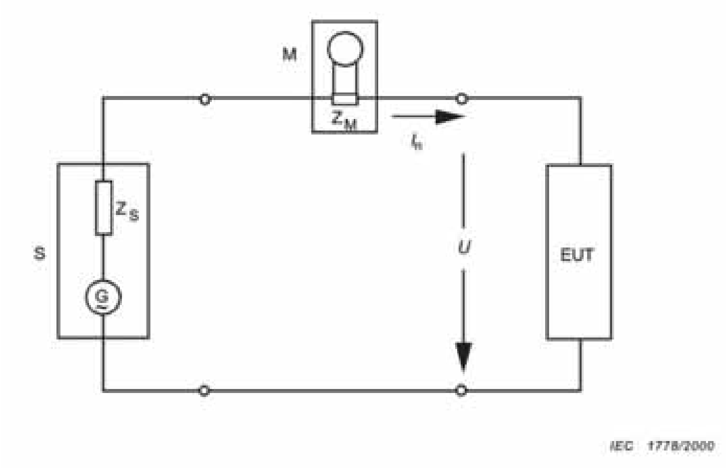

Figure 11. Measurament circuit for single-phase equipment.

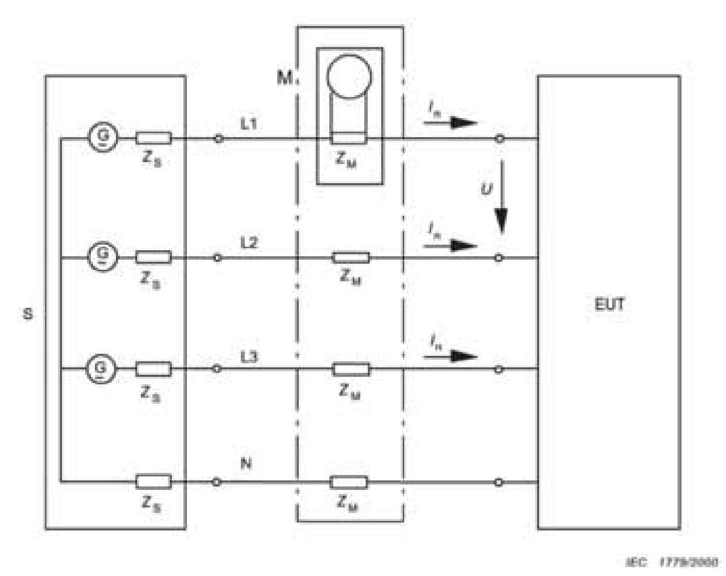

Figure 12. Measurament circuit for three-phase equipment.

where:

- S, power supply source
- M, measurement equipment
- U, test voltage
- Z_M, input impedance of measurement equipment
- Z_S, internal impedance of the supply source

  Z_S y Z_M must be sufficiently low for meeting the test requirements
- I_n, harmonic component of order n of the line current
- G, open loop voltage of the supply source

6.3.3.1.2 Supply source

The test voltage shall be the same as the EUT rated voltage ± 2 %, with a maximum frequency variation of ± 0.5 % of the rated value. If the supply source is a three-phase source, the angle

between the fundamental voltage on each pair of phase shall be 120 ± 1.5º. The maximum values allowed for the harmonic ratios, with the EUT connected in normal operation, are the following:

- 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 harmonic of order 2 to 10
- 0.1 % for harmonic of order 11 to 40

6.3.3.2 Test procedure

Requirements and method to perform the measurement are described below.

6.3.3.2.1 Test requirements

The measurement is carried out under the following requirements.

- Test observation period

Observation period is described in Table 15. Harmonic current and power shall not be measured during the first 10 s following a switching event either if the EUT is brought into operation or is taken out of operation. The EUT only may be in stand-by mode up to 10 % of observation period.

- Repeatability

The repeatability of the average value for the individual harmonic currents over the entire test observation period shall be better than ± 5 % of the applicable limit. The EUT and the test system shall be the same and the test and climatic conditions shall be identical to achieve this repeatability value.

Table 15. Test observation period.

Type of equipment behaviour	Observation period
Quasi-stationary	T_{obs} of sufficient duration to meet the requirements for repeatability in chapter 6.2.3.1 of the standard
Short cyclic ($T_{cycle} \leq 2.5$ min)	$T_{obs} \geq 10$ cycles (reference method) or T_{obs} of sufficient duration or synchronisation to meet the requirements for repeatability in chapter 6.2.3.1 of the standard[5]
Random	T_{obs} of sufficient duration to meet the requirements for repeatability in chapter 6.2.3.1 of the standard
Long cyclic ($T_{cycle} > 2.5$ min)	Full equipment program cycle (reference method) or a representative 2.5 min period considered by the manufacturer as the operating period with the highest THC

[5] By 'synchronization' is meant that the total observation period is sufficiently close to including an exact integral number of equipment cycles such that the requirements for repeatability in chapter 6.2.3.1 of the standard are met.

- Reproducibility

The reproducibility of measurements of average value of the current on the same EUT during the entire test observation period with different test systems shall be better than ± (1 % + 10 mA). This value is an estimated value not a calculated value. Because of this, if test results obtained at different locations or on different occasions meet all the relevant limits, it shall be accepted that the test is in accordance with the regulation even if the results do not meet the repeatability and reproducibility values given previously.

- Harmonic current measurement

The test is carried out with the EUT set to the mode expected to produce, under normal operating conditions, the maximum total harmonic current (THC).

Measurement shall be performed at the connexion point between the EUT and the supply source.

As a general rule, the measurement is performed in the line conductors, not in the neutral conductor. Only in case of single-phase equipment, it is allowed to measure the harmonic currents in the neutral conductor instead of in the line conductors.

The harmonic current measurement procedure consists of measuring the instantaneous harmonic current; after this step the discrete Fourier transform (DFT) is calculated in the time window specified by the standard and smoothing will be applied with a 1.5 s time constant low-pass filter (LPF). Subsequently, it is calculated the arithmetic average of the obtained values over the entire observation period. This procedure shall be performed for each harmonic order.

6.3.4 IEC 61000-3-3

The IEC 61000-3-3 regulation deals with voltage fluctuations and flicker for low voltage public networks. The standard limits the voltage change that the equipment with a rated current up to 16 A per phase can generate in the low-voltage, specifically on grids between 220 and 250 V. This standard only applies to equipment not subjected to conditional connection.

6.3.4.1 Measuring equipment

Figure 13 shows the test circuit needed to verify if the EUT accomplish the limitations imposed by the standard. The test circuit consists of:

- Test supply voltage
- Reference impedance
- EUT
- A flickermeter in accordance with standard IEC 61000-4-15 [23]

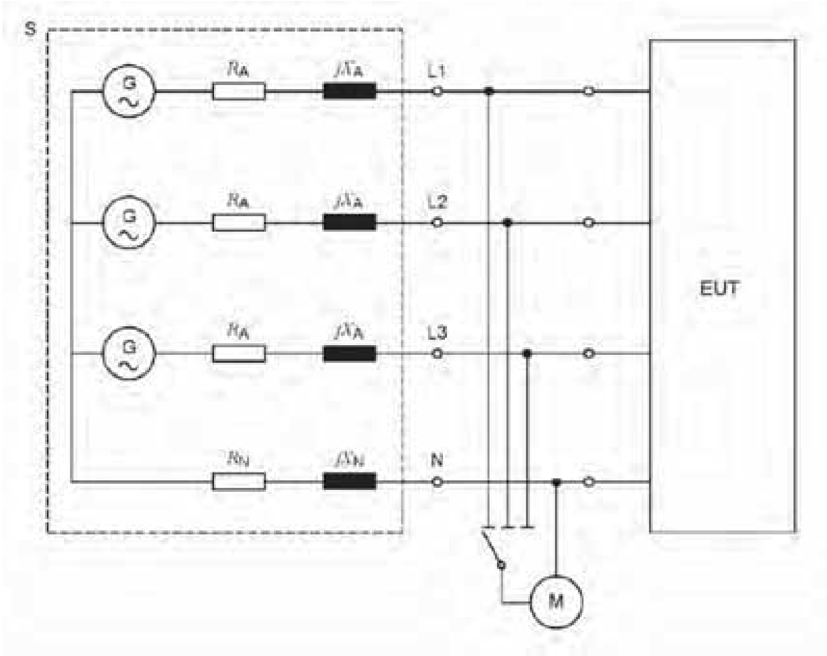

Figure 13. Reference network for single-phase and three-phase supplies derived from a three-phase, four wire supply.

where:

- G is the voltage source
- M is the measuring equipment
- S is the supply source consisting of the supply voltage generator G and reference impedance Z with the elements:
  - For each phase, $R_A = 0.24\ \Omega$ $jX_A = 0.15\ \Omega$ at 50 Hz
  - For neutral, $R_N = 0.16\ \Omega$ $jX_N = 0.10\ \Omega$ at 50 Hz

Test voltage shall be the rated voltage of the equipment. The test voltage shall be maintained within ± 2 % of nominal value. The frequency shall be 50 Hz ± 0.5 %. Total harmonic distortion (THD) of the supply voltage shall be less than 3 %.

6.3.4.2 Test procedure.

The following four magnitudes shall be measured:

- d_c is the steady-state voltage change
- d_{max} is the maximum voltage change characteristic
- P_{st} is the short-term flicker indicator
- P_{lt} is the long-term flicker indicator

In some cases, for instance when the source impedance is subjected to unpredictable variations, an impedance with the same values of the reference impedance must be connected between the power supply and the EUT terminals.

Voltage can be measured on both sides of the reference impedance; the maximum relative voltage change d_{max}, measured at the supply terminal shall be less than 20 % of the d_{max} measured at the equipment terminals.

The relative voltage change, d(t), shall be determined with a total accuracy lower than ± 8 % with reference to the maximum value d_{max}. The total impedance of the circuit must be equal to the reference impedance. The accuracy should be maintained during the whole process.

From the r.m.s. current the relative voltage change, d(t), can be obtained.

The relative voltage change, d(t), may be measured directly or derived from the r.m.s. current. P_{st} value of the EUT can be measured using a flicker meter, although other methods described in IEC 61000-3-3 [10] may be used.

The magnitude of the current shall be measured with an accuracy of at least 1 %.

6.3.5 IEC 61000-3-11

This regulation deals with the limitation of voltage fluctuations and flicker impressed on the public low voltage grid. It specifies limits for voltage changes which may be produced by electrical and electronic equipment having a rated input current from 16 A up to 75 A (included) per phase, which are intended to be connected to a public low-voltage distribution system of between 220 V and 250 V line to neutral at 50 Hz, and which are subjected to conditional connection.

The equipment and the procedure to perform the test are specified by IEC 61000-3-3 [10], explained in chapter 6.3.4 of this report.

Equipment which does not meet the limits of IEC 61000-3-3 [10] when tested or evaluated with reference impedance Z_{ref}, are subjected to conditional connection and the manufacturer shall choose between the two options explained below.

6.3.5.1 Evaluation and declaration by the manufacturer of the permissible system impedance

The maximum permissible system impedance Z_{max} at the interface point on the user supply side is determined and is declared in the equipment instruction manual. The user is instructed to determine in consultation with the supply authority, if necessary, that the equipment cannot be connected to a supply with higher impedance.

6.3.5.2 Evaluation and declaration by the manufacturer of the minimum permissible service current capacity

The equipment is tested setting the test impedance Z_{test} in complex terms at a 0.15 + j 0.15 Ω for each line, 0.1+ j 0.1 Ω for three phase equipment, and 0.25 + j 0.25 Ω for single phase equipment. It is declared in the equipment instruction manual that the equipment is intended for use only in premises having a service current capacity ≥ 100 A per phase, supplied from a 400/230 V distribution network. The user is instructed to determine in consultation with the supply authority, if necessary, that the service current capacity at the interface point is sufficient for the

equipment. The equipment shall be clearly marked as being a suitable for use only grid connection points with a current capacity of at least 100 A per phase.

6.3.6 IEC 61000-3-12

This regulation specifies limits of harmonic components of the current which may be produced by electrical and electronic equipment intended to be connected to a public low-voltage distribution system and having a rated current exceeding 16 A and up to 75 A (included) per phase. The test equipment and the used method to perform the test are similar to which are determined by IEC 61000-3-2 [9] explained in chapter 6.3.3 of this report with the particularities explained below.

6.3.6.1 Supply source

The supply source output voltage shall be the same that the EUT rated voltage ± 2 % and with a maximum frequency variation of ± 0.5 % of the nominal value. In the case of a voltage range the output voltage shall be in accordance IEC 60038. If the supply source is three-phase source, the maximum voltage unbalance permitted is 50 % of the voltage unbalance compatibility level given in IEC 61000-2-2 [24].

The maximum values allowed for the harmonic ratios, with the EUT connected in normal operation, are indicated below:

- 1.5 % for harmonic of order 5
- 1.25 % for harmonic of order 3 and 7
- 0.7 % for harmonic of order 11
- 0.6 % for harmonic of order 9 and 13
- 0.4 % for even harmonic of order 2 to 10
- 0.3 % for harmonic of order 12 and 14 to 40

6.3.6.2 Emission limits

Limit values are established as a short-circuit ratio, R_{sce}, function. Depending on the R_{sce} value the THD, the partial weighted harmonic distortion (PWHD) and the harmonic current limits are set. The harmonic current limit is given as the quotient between the reference fundamental current and the harmonic current component. The limits are established in clause 5.2 of IEC 61000-3-12 [21]. The methods to be used to obtain the value of these parameters are given below.

R_{sce} value is calculated as follows:

- For single-phase equipment:

$$R_{sce} = S_{cc}/(3S_{equ}) \quad (6.3)$$

where:

S_{cc} is the short circuit power of the system

S_{equ} is the rated apparent power of the equipment

- For interphase equipment:

$$R_{sce} = S_{cc}/(2S_{equ}) \tag{6.4}$$

- For three-phase equipment:

$$R_{sce} = S_{cc}/S_{equ} \tag{6.5}$$

I_1 shall be either measured or calculated. The I_1 measurement shall be performed by the same procedure used to obtain the harmonic current given in 6.3.3.2. The I_1 value is calculated with the equation (6.6).

$$I_1 = \frac{I_{equ}}{\sqrt{1 + THD^2}} \tag{6.6}$$

where:

- I_{equ} is the rated line current
- THD is the limit of total harmonic distortion given by the regulation[6]

THD and PWHD shall be calculated and the obtained values shall meet the limits established by the standard. Equations (6.7) and (6.8) give the expression to calculate THD and PWHD respectively.

$$THD = \sqrt{\sum_{n=2}^{40} \left(\frac{I_n}{I_1}\right)^2} \tag{6.7}$$

where:

- I_n is the harmonic current component

$$PWHD = \sqrt{\sum_{n=14}^{40} n \left(\frac{I_n}{I_1}\right)^2} \tag{6.8}$$

6.4 Emission test – Radio-frequency disturbances

This CISPR publication contains RF disturbance emission limits and covers conformity assessment requirements for equipment tested on a standardized test site[7]. Specifications for this test are collected in standard CISPR 11 [6].

[6] IEC 61000-3-12 [21], clause 5.2.

6.4.1 Measuring equipment

To carry out the measurement, the equipment required are measurement receivers, AMN, voltage probes and an antenna.

6.4.1.1 Measurement receivers

Quasi-peak detectors and average detectors shall be used to perform the measurement test, and they shall be in accordance with standard CISPR 16-1-1 [17].

6.4.1.2 Artificial main network

AMN shall be in accordance with CISPR 16-1-2 [15] standard; its specifications are described in the chapter 6.3.1.1.2 of this report.

6.4.1.3 Voltage probe

The voltage probe shown in Figure 14 shall be installed when the AMN cannot be used; it is installed to measure phase to ground voltage. Internally, voltage probes are based on a capacitor and a resistor; the impedance between the phase and ground should be higher than 1500 Ω.

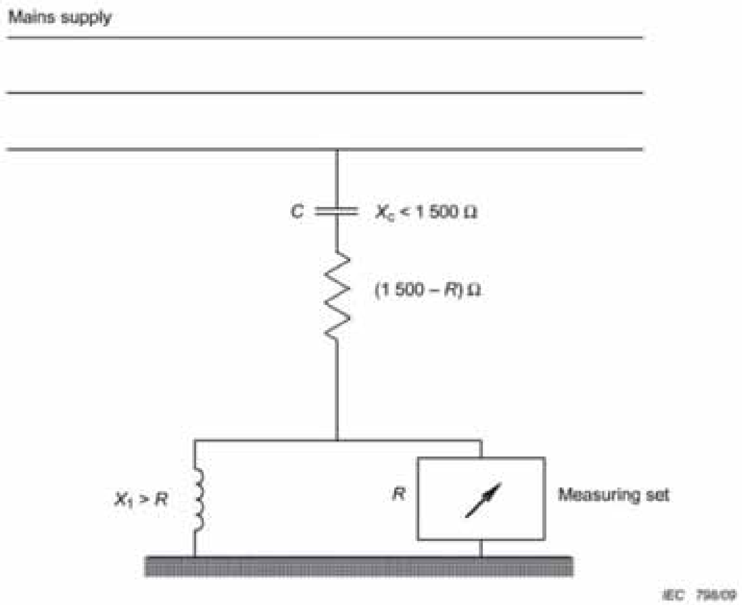

Figure 14. Circuit for disturbance voltage measurements on mains supply.

6.4.1.4 Antenna

The antenna used to perform this test shall be a loop type antenna and shall be in accordance with in CISPR 16-1-4 [25]. In the frequency range below 30 MHz, antennas shall be supported in the vertical plane and be rotatable about a vertical axis. They must be installed higher than 1 m above ground level.

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[7] Class B equipment shall be measured on a standardized test site. CISPR 16-1-1 [17], clause 6.1 (see chapter 4 of this report).

Measurements between 30 MHz and 1 GHz can be made with antennas with both types of polarization, horizontal and vertical. In this case the distance between the ground and the lower component of the antenna should be longer than 0.2 m.

6.4.2 Test procedure

6.4.2.1 Radiation measurement

In some cases, the noise coming from the EUT and the one that being radiated from the environment may be distinguished. Ambient noise can be measured with the EUT disconnected; its value must be 6 dB under the specified limits but this must be only verified if the sum of the noise generated by the EUT and by the ambient is above the limit.

Emplacement to perform the test shall be in accordance with an ellipse with the following dimensions:

- Major axis shall be equal to twice the distance between the foci
- Minor axis shall be equal to the square root of three times of the distance between the foci

The EUT shall be placed at one focus and the measurement equipment shall be placed at the other focus. The path length of any ray reflected from an object on the perimeter of the ellipse will be equal to twice the length between the foci. A scheme of the test site is given in Figure 15.

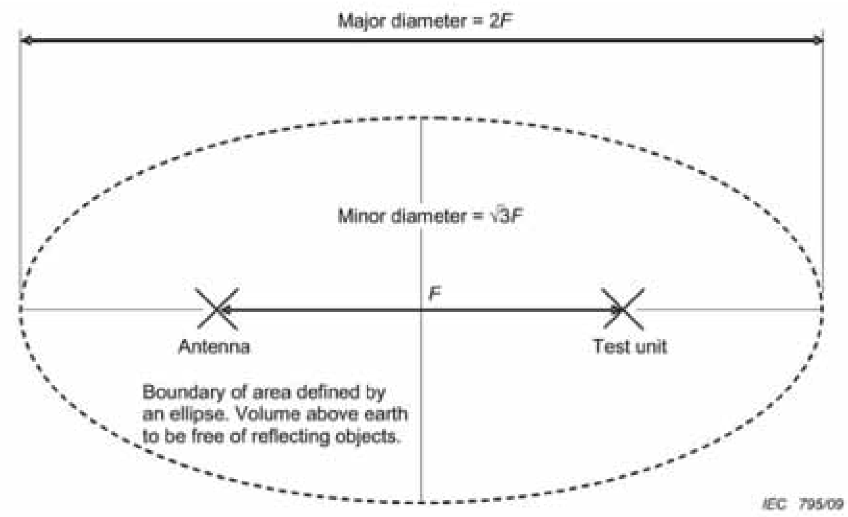

Figure 15. Test site.

F may vary depending on conditions (see Table 11) but never can be less than 3 m.

The natural ground plane shall have such dimensions that the distances between the boundary of the EUT and the end of the ground plane and from the measurement antenna to the end of the ground plane will be at least 1 m. Figure 16 shows the minimum dimensions that metal ground plane shall meet.

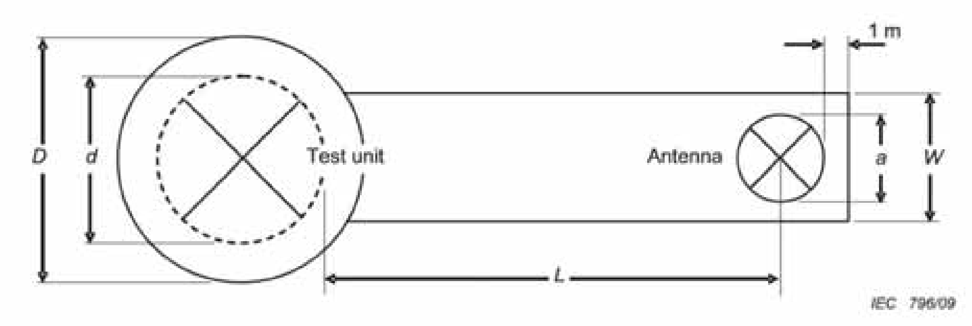

Figure 16. Minimum size of metal ground plane.

where:

- $D = (d + 2)$, where *d* is the EUT maximum test unit dimension in meters
- $W = (a + 1)$, where *a* is the antenna maximum test unit dimension in meters
- L is the length between the EUT and the antenna in meters

Radiation measurement with the EUT located on a turn table is preferred when it is possible.

If the EUT is placed on a turn table, the turn table shall be fully rotated and the measurement antenna shall be positioned for horizontal and vertical polarization. The highest registered value of the electromagnetic radiation disturbance at each frequency shall be noted.

If the equipment cannot be placed on a turn table, the measurement antenna shall be situated at several points in the azimuth plane for horizontal and vertical polarization. The measurement shall be performed in the maximum electromagnetic radiation orientation and the highest registered value for each frequency shall be noted.

6.4.2.2 Measurement of mains terminal disturbance voltage

There are three options to measure the mains terminal disturbance voltage:

- On the radiation test site, maintaining the EUT on configuration mode used during the radiation measurement
- Above a metal ground plane which must exceed the edges of the EUT at least 0.5 m. Its minimum size is 2 m x 2 m
- In a screened room in which the floor and the walls will act as ground plane

In the first option the test site has a metal ground plane, while in the other two options the position of the test unit depends on the type of test unit to be used during the test. If the device to be tested is a non-floor-standing unit, it must be placed 0.4 m over the ground plane; if it is a floor-standing type it must be placed on the ground plane, with its contact points between device and ground properly isolated. In any case the distance between the test unit and any other metal surface should be longer than 0.8 m.

The reference terminal of the AMN shall be connected to the ground plane with the shortest cable possible. To avoid interferences between the power and signal cables, they must be placed in a similar way as they are oriented in relation to the ground plane in the normal use.

7 Immunity test

EMC tests are performed in order to assess the device capabilities to operate on EMC perturbed environments. Equipment performance under these conditions shall be described and noted by the manufacturer in a test report, containing a description of every test carried out over the apparatus. The response of the apparatus against every EMC tests is classified according to IEC 61000-6-1 [11] and IEC 61000-6-2 [7] criteria, as follows:

- **Performance criterion A:** Apparatus with A performance will be fully operational with no performance loss during and after the tests
- **Performance criterion B:** The apparatus may suffer some performance degradation, specified by the manufacturer, during the test. Once the test is finished, the device must work properly without any damage. No change of stored data or operating state is allowed
- **Performance criterion C:** Temporary loss of function is allowed but the function must be self-recoverable or restorable by the operation of the controls

If as a result of or during any test defined on the regulations the apparatus becomes unsafe or dangerous, it will be considered that the apparatus has failed the test.

7.1 Immunity test – Electrostatic discharge

The aim of this test is to evaluate the performance of the apparatus against electrostatic discharges (ESD), under the test specifications collected in the standard IEC 61000-4-2 [26]. Two different methods are available to carry out the ESD tests, but if possible contact discharge method should be performed, otherwise air discharge method can be executed. Since there are two different methods referencing different voltage test levels, test severities and results are not equivalent for both methods.

7.1.1 Test generator

The ESD test generator consists of:

- Charging resistor, R_c
- Energy-storage capacitor, C_s
- Distributed capacitance, C_d
- Discharge resistor, R_d
- Voltage indicator
- Discharge switch
- Charge switch

- Interchangeable tips of the discharge electrode
- Discharge return cable
- Power supply unit

A simplified diagram of the ESD generator is shown in Figure 17.

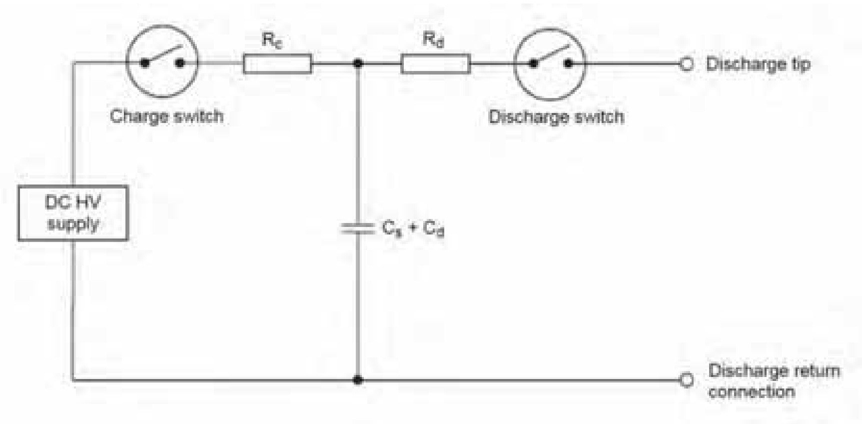

Figure 17. Simplified diagram of the ESD generator.

In the diagram shown in Figure 17 the next components can be found:

- C_d is a distributed capacitance between the generator and its surroundings
- C_d + C_S has a typical value of 150 pF
- R_d has a typical value of 330 Ω

Table 16 and Table 17 show the specifications of the test generator. Figure 18 shows an ideal current waveform and the measurement points referred to in Table 16 and Table 17.

Table 16. General specifications.

Parameter values	General specifications
Output voltage, contact discharge mode (see NOTE 1)	At least 1 kV to 8 kV, nominal
Output voltage, air discharge mode (see NOTE 1)	At least 2 kV to 15 kV, nominal (see NOTE 2)
Tolerance of output voltage	±5 %
Polarity of output voltage	Positive and negative
Holding time	≥5 s
Discharge mode of operation	Single discharge (see NOTE 3)

NOTE 1 Open circuit voltage measured at the discharge electrode of the ESD generator.

NOTE 2 It is not necessary to use a generator with 15 kV air discharge capability if the maximum test voltage to be used is lower.

NOTE 3 The generator should be able to generate at a repetition rate of at least 20 discharges per second for exploratory purposes.

Table 17. Contact discharge current waveform parameters.

Level	Indicated voltage kV	First peak current of discharge ± 15 % A	Rise time t_r (± 25 %) ns	Current (± 30 %) at 30 ns A	Current (± 30 %) at 60 ns A
1	2	7.5	0.8	4	2
2	4	15	0.8	8	4
3	6	22.5	0.8	12	6
4	8	30	0.8	16	8
The reference point for measuring the time for the current at 30 ns and 60 ns is the instant when the current first reaches 10 % of the 1st peak of the discharge current. NOTE The rise time, t_r, is the time interval between 10 % and 90 % value of 1st peak current.					

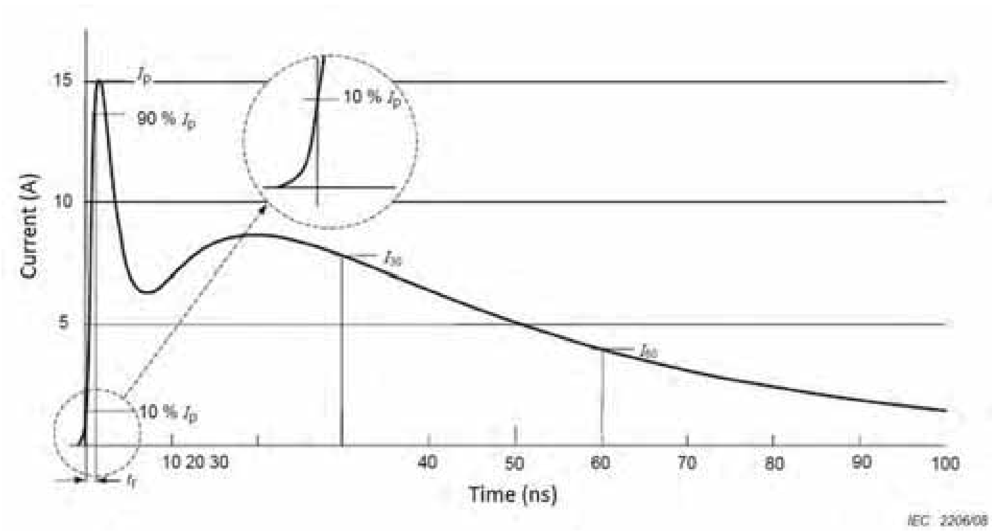

Figure 18. Ideal contact discharge current waveform at 4 kV.

7.1.2 Test procedure

There are two different types of tests:

- Type (conformance) tests performed in laboratory
- Post installation tests performed on equipment in its final installed conditions

Laboratory testing is preferred, but under agreement between manufacturer and customer post installation tests may be performed in-situ. The test is carried out for all normal modes of operation of the EUT. If monitoring equipment is required during the test, it should be decoupled from the EUT with the aim to prevent false indications.

The test has to be performed under specific conditions in order to minimize the impact of environmental parameters on test results, regardless of the test type. Electromagnetic conditions shall guarantee correct operation of the EUT, so that test results are not to be affected. Climatic

conditions shall ensure correct operation of both EUT and test equipment, and must fulfil the limits set by their respective manufacturers, unless the responsible committee for the generic or product standard differs.

7.1.2.1 Test performance

A time interval between tests of 1 second is advised, but longer times could necessary so as to assess system failure cases. During the tests, ESDs shall be directly (contact discharge or air discharge) and/or indirectly applied to the EUT, according to a test plan. This plan should include:

- Representative operating conditions of the EUT
- Whether the EUT should be tested as table-top or floor-standing
- The points at which discharges are to be applied
- At each point, whether contact or air discharges are to be applied
- The test level to be applied, it must be according to the product specifications
- 10 single discharges must be applied (in the most sensitive polarity) at each point for conformance testing
- Whether post-installation tests are also to be applied

7.1.2.1.1 Direct discharge application

Unless stated otherwise in the related standard, direct discharges shall be applied only on the points and surfaces accessible during normal use, including the following exclusions:

- Points and surfaces only accessible under maintenance
- Points and surfaces only accessible under service by the user
- Points and surfaces not accessible after EUT fixed installation
- Contacts of coaxial and multi-pin connectors provided with metallic connector shell
- Contacts of connectors and other parts sensitive to ESD because of functional reasons, which are provided with ESD warning label

For contact discharge tests, contact between the electrode and the EUT has to be effective before the discharge is started. Provided that a conductive surface of the EUT is painted, the paint layer has to be penetrated by the electrode tip in order to ensure contact with the substrate if the paint has not been declared as insulating coating. On the contrary, if it has been declared as insulating coating the surface will only be submitted to the air discharge tests.

In the case of air discharges, the ESD generator shall move forward towards the EUT as fast as possible, ensuring that it does not cause any mechanical damage. After each discharge, the discharge electrode shall be removed from the EUT. These steps shall be repeated until the desired number of discharges is reached.

7.1.2.1.2 Indirect discharge application

In addition to the direct application of the discharge test, indirect application of the discharge test shall be performed. In this test procedure, the discharges of the ESD generator are applied to a coupling plane and from this plane to the EUT. The coupling plane could be either a horizontal coupling plane (HCP) or vertical coupling plane (VCP).

In both cases at least 10 single discharges should be applied (in the most sensitive polarity). HCP shall be installed 0.1 m away from the front side of the EUT, applying the discharge at the front edge. The VCP should be placed 0.1 m away from the EUT, and discharges shall be applied in different positions to ensure that the four faces of the EUT have been affected. Illustrative examples are provided in Figure 19 for table-top equipment, while in Figure 20 for floor-standing equipment is described.

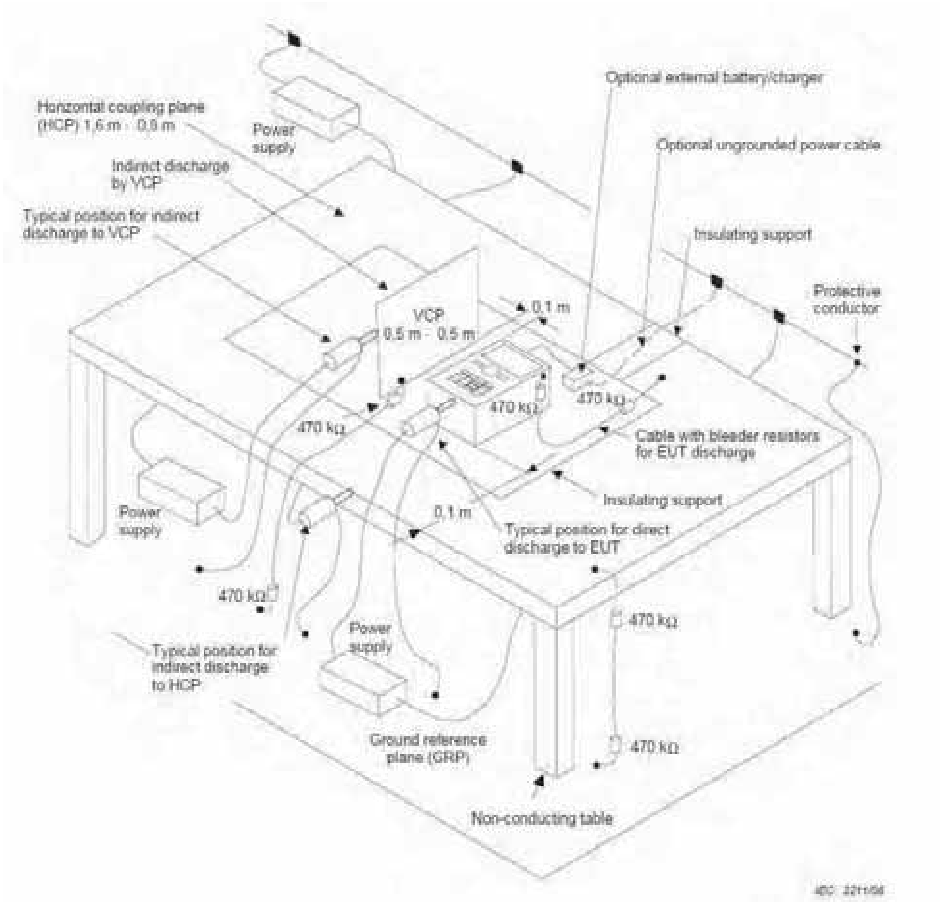

Figure 19 . Example of a test setup for ungrounded table-top equipment.

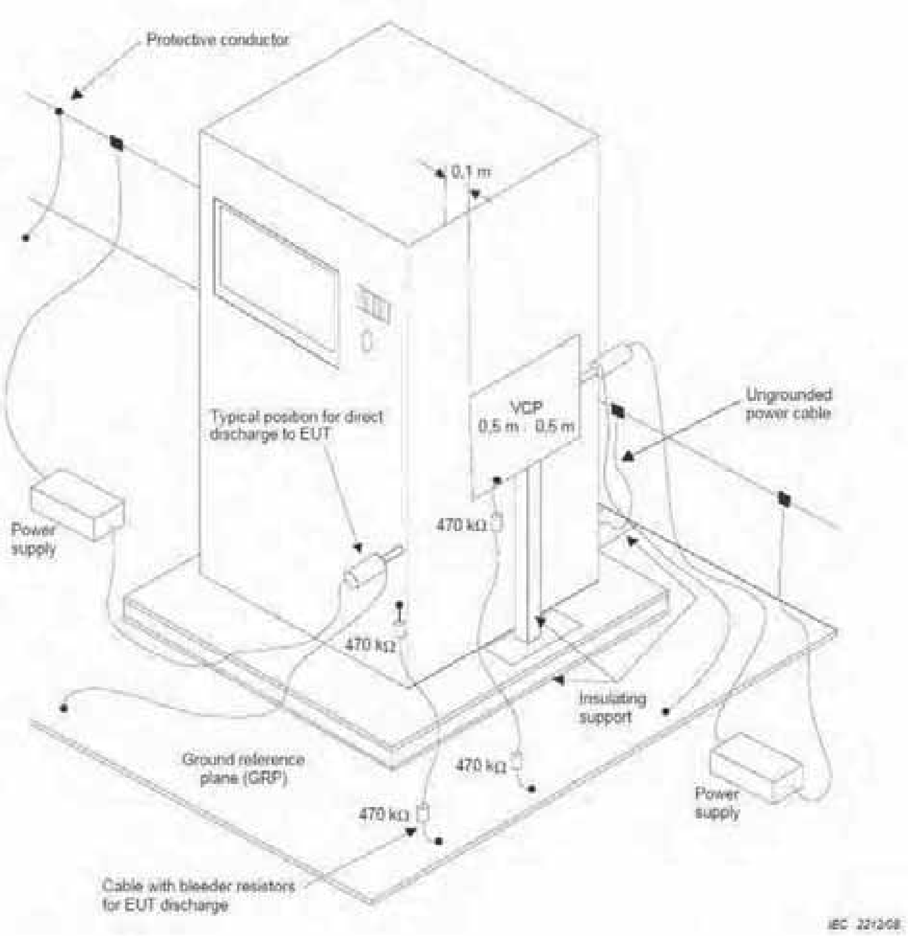

Figure 20 . Example of a test setup for ungrounded floor-standing equipment.

7.2 Immunity test - Radiated and radio-frequency electromagnetic field

This test is performed with the aim to evaluate the performance of the apparatus when subjected to radiated, RF electromagnetic fields. The test specifications are collected in the standard IEC 61000-4-3 [27], and normally cover (without exception) the magnetic strength wave frequencies between 80 MHz and 1000 MHz. The magnetic strength wave to be used within these tests is composed by a high frequency non-modulated carrier signal, whose amplitude is modulated with a 1 kHz sine wave at 80 % of the reference value, in order to simulate real threats. The shape of the non-modulated carrier signal and the final modulated wave are illustrated on Figure 21.

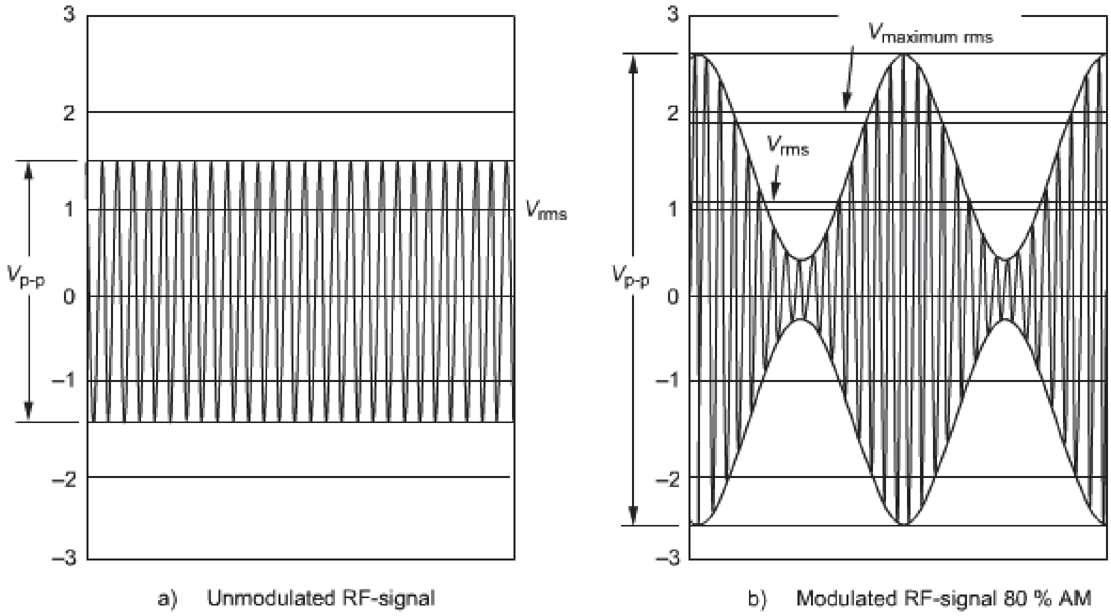

Figure 21 . Unmodulated (left side) and modulated (right) signals to use within RF inmunity tests.

7.2.1 Test equipment

The following equipment is recommended to carry out the necessary test procedures:

- Anechoic chamber. Insulates the EUT from exterior sources of disturbances, with compatible dimensions for the EUT, and it must be capable to maintain a uniform field
- EMI filters. Any additional resonance effects due to filter installation must be avoided
- RF signal generator(s). It must be able to generate signals in the frequency band and amplitude range specified in the standard, including the modulation features of the magnetic wave. The control of the generated signal should be performed either manually or by programming. The generator should not be affected by harmonics, so filters might be needed
- Power amplifiers. Their function consists of amplifying the low power signals created by the generator, and provide antenna drive to the necessary field level
- Field generating antennas. They have to be capable of satisfying the frequency requirements. There are different types of antennas (log periodic, horn, or any linearly polarized antenna) suitable for this application
- An isotropic field sensor with adequate immunity of any head amplifier and opto-electronics to the field strength to be measured, and a fibre optic link to the indicator outside the chamber
- Associated equipment to control the generation of the needed field strength level for testing, as well as to record the required power levels

7.2.2 Test procedure

The test has to be performed under specific conditions in order to minimize the impact of environmental parameters on test results. Electromagnetic conditions shall guarantee correct operation of the EUT, so that test results are not to be affected. Climatic conditions shall ensure correct operation of both EUT and test equipment, and must fulfil the limits set by their respective manufacturers, unless the responsible committee for the generic or product standard states differs.

National and internationals regulations prohibit interference to radio communications, so the test shall be performed on a suitable shielded enclosure. Besides, data collecting equipment is generally sensitive to electromagnetic fields, so it must be protected against the disturbances generated during the immunity test. Figure 22 shows an example of the chamber required to accommodate the EUT, isolate the environment from the magnetic fields generated during the testing, and carry out the tests within the required conditions.

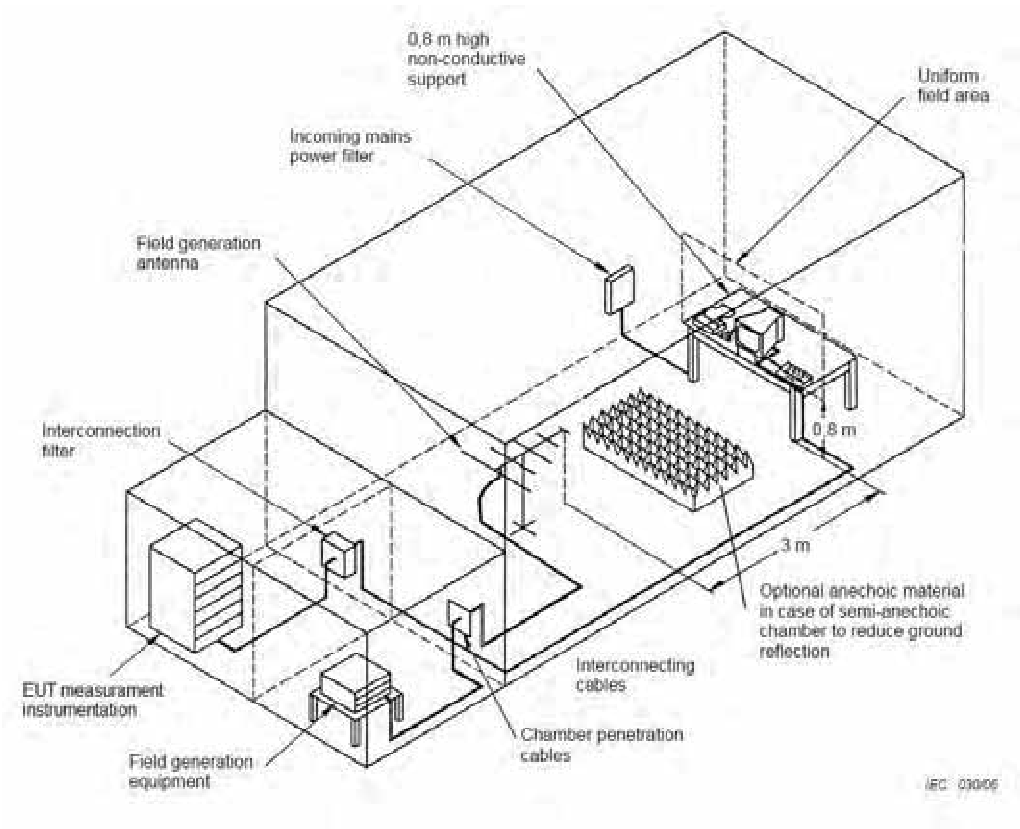

Figure 22. Example of suitable test facility.

The test can be done continuously increasing the frequency of the generated wave, pausing if necessary, to sweep the frequency band to cover. In any case, the increase in the frequency step cannot be bigger than 1 % of the previous step and the dwell time for each step should be enough so as to register the response of the EUT (always longer than 0.5 s).

Every side of the EUT should be faced by the antenna during the test and, if it is technically justified, fewer sides' exposure to the antenna might be allowed.

7.3 Immunity test - Electrical fast transient/burst immunity test

This test is carried out with the aim to evaluate the performance of the apparatus when subjected to electrical fast transient/bursts (EFT/B) on supply, signal, control and earth ports and to demonstrate the immunity of the apparatus when they are subjected to transient disturbances typologies such as those originated from switching transients. Test specifications are collected in the standard IEC 61000-4-4 [28].

7.3.1 Test equipment

Test equipment is composed by the following components:

- Burst generator
- CDN for A.C./D.C. power port
- Capacitive coupling clamp

The main characteristics of each component are explained below.

7.3.1.1 Burst generator

The burst generator simplified circuit is given in Figure 23.

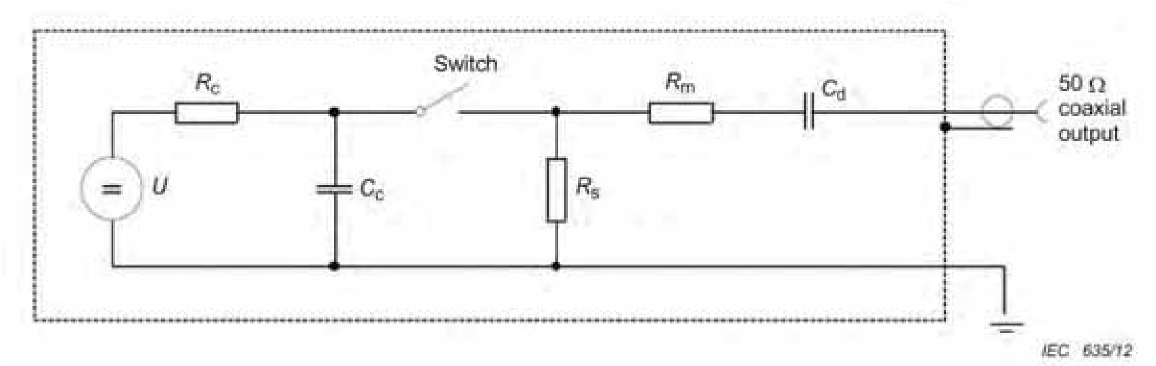

Figure 23. Simplified circuit diagram showing major elements of a fast transient/burst generator.

The components of the simplified circuit diagram are:

- U, high-voltage source
- R_c, charging resistor
- C_c, energy storage capacitor
- R_s, impulse duration shaping resistor
- R_m, impedance matching resistor
- C_d, D.C. blocking capacitor
- Switch, high-voltage switch

The values for C_c, R_s, R_m, and C_d of the circuit components have to be properly dimensioned to generate a fast transient under open circuit conditions and with a 50 Ω resistive load.

The output voltage range of the generator depends on the connected load:

- For 1000 Ω load, output voltage shall be at least from 0.24 kV to 3.8 kV
- For 50 Ω load, output voltage shall be at least from 0.125 kV to 2 kV

Short-circuit operation shall be withstood by the generator with no damage. The characteristics and waveform of an electrical fast transient/burst to generate during the test is shown in Table 18 and Figure 24.

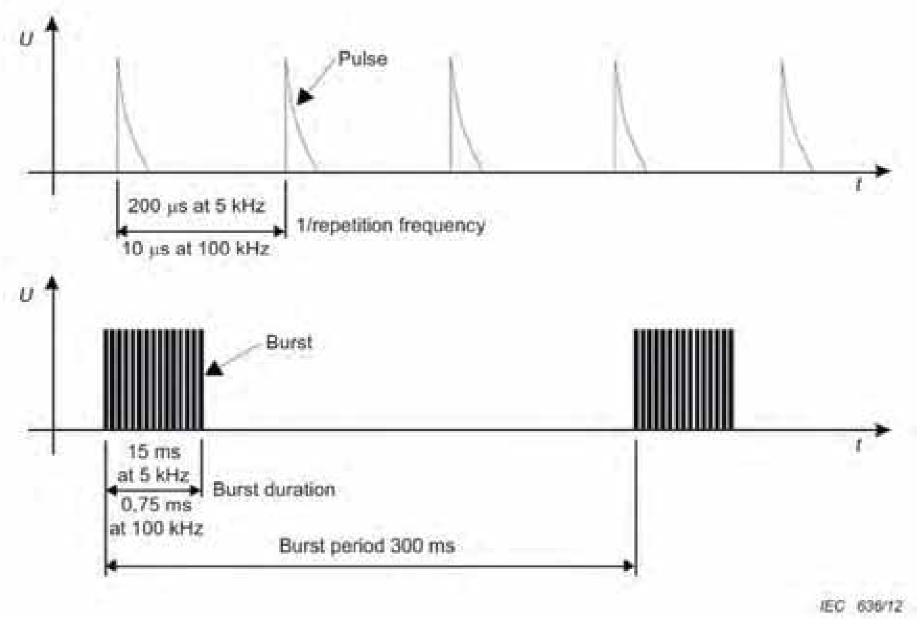

Figure 24. Representation of an electrical fast transient/burst.

Table 18. Pulse and surge characteristic definition.

Pulse Rise time (t_r) ns	Pulse width (t_w) ns	Pulse repetition frequency kHz	Burst duration ms	Burst period ms
5 ± 1.5 into 50 Ω load	50 ± 30 % into 50 Ω load	5	15 ± 3 at 5 kHz	300 ± 60
5 ± 30 % into 1000 Ω load	50, tolerance -15 +100, into 1000 Ω load	100	0.75 ± 0.15 at 100 kHz	300 ± 60

On the other hand, the ideal waveform of a single pulse injected into a 50 Ω load with nominal parameters rise time t_r = 5 ns, and pulse width t_w = 50 ns, is shown in Figure 25.

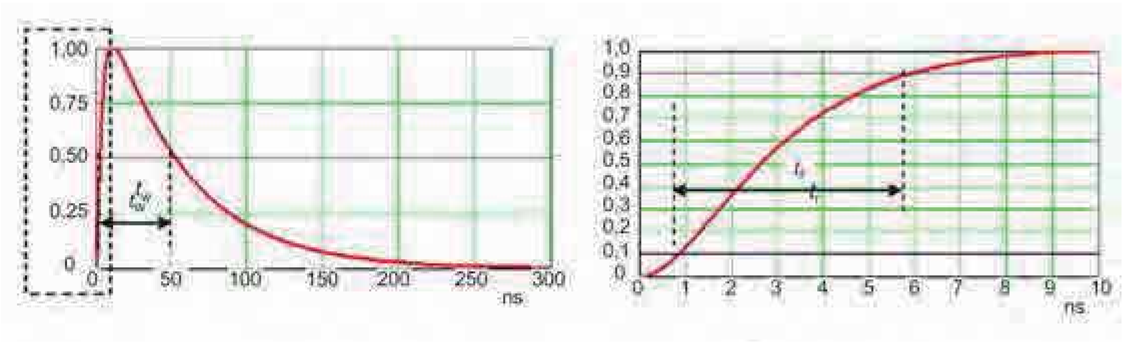

Figure 25. Ideal waveform of a single pulse into a 50Ω load with nominal parameters rise time t_r=5 ns and pulse width t_w=50ns.

7.3.1.2 Coupling/decoupling network for AC/DC power supply port

To carry out the test is necessary to decouple the EUT from the power grid (AC or DC network) and to couple it with the signal generator. This is achieved connecting high-back impedances capable of isolating the EUT from the power grid, while high voltage capacitors sized to allow the full waveform durations to be sent to the EUT provide coupling with the test generator. This procedure is illustrated on Figure 26, for the particular case of a three-phase EUT. Typical characteristics of the CDN are the following:

- Decoupling inductor with ferrite: > 100 µH
- Coupling capacitors: 33 nF

The waveform of the generator shall be verified at the output of the coupling network.

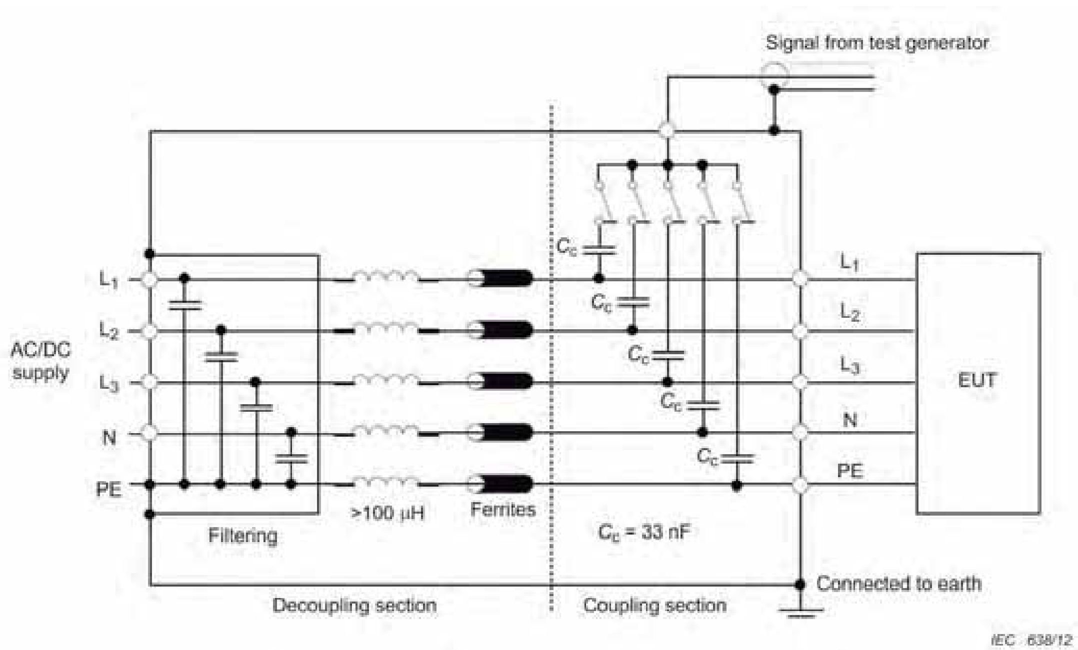

Figure 26. Coupling/decoupling network for AC/DC power mains supply ports/terminals.

7.3.1.3 Capacitive coupling clamp

The clamp is capable of coupling the fast transients/bursts to the EUT port to be tested, providing galvanic isolation from any part of the EUT. This method usage is intended for lines connected to signal and control ports, and only should be applied to power ports when the coupling/decoupling method explained in 7.3.1.2 cannot be implemented.

A capacitive coupling clamp device is based on a metallic structure connected to the ground reference plane (it shall be extended beyond the clamp), which surrounds and houses the cables of the EUT. In order to provide maximum coupling capacitance between the cable and the clamp, the clamp shall be as much closed as possible, and the EUT shall be connected to the generator through a high-voltage connector, choosing the nearest connector between the two present at both ends of the clamp.

The dimensions which shall be used to construct the clamp are provided below:

- Lower coupling plate height: (100 ± 5) mm
- Lower coupling plate width: (140 ± 7) mm
- Lower coupling plate length: (1 000 ± 50) mm

An example of a capacitive coupling clamp is shown in Figure 27.

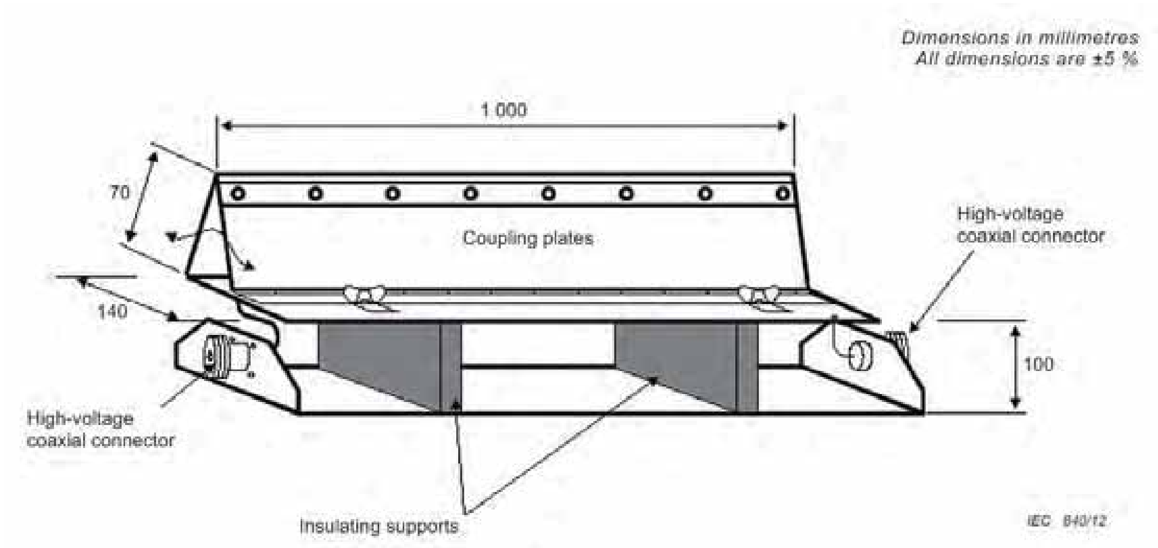

Figure 27. Example of a capacitive coupling clamp.

7.3.2 Test procedure

The procedure is based on the coupling of a number burst involving fast transients with every power, control, signal and earth port of the EUT. The main characteristics of the test are high repetition frequency, short rise time, high amplitude, and low energy of the transient.

The test has to be performed under conditions which minimize the impact of environmental parameters on test results, regardless of the test type. Electromagnetic conditions shall guarantee correct operation of the EUT, so that test results are not to be affected. Climatic conditions shall

ensure correct operation of both EUT and test equipment, and must fulfil the limits set by their respective manufacturers, unless the responsible committee for the generic or product standard states otherwise.

During the test, the EUT should operate under normal conditions. A test plan shall be elaborated, establishing the test basis, including the verification of the EUT performance as defined in the technical specification, and specifying the next concepts:

- Type of test (laboratory or in situ)
- Duration of the test per port
- Test level
- Coupling mode (common-mode, and unsymmetric mode)
- Polarity of the test voltage (both polarities are mandatory)
- EUT ports to be tested
- Representative operating conditions of the EUT
- Repetition frequency
- Sequence of application of the test voltage to the ports of the EUT
- AE

Figure 28 shows the scheme of the equipment required to carry out the transient/burst test.

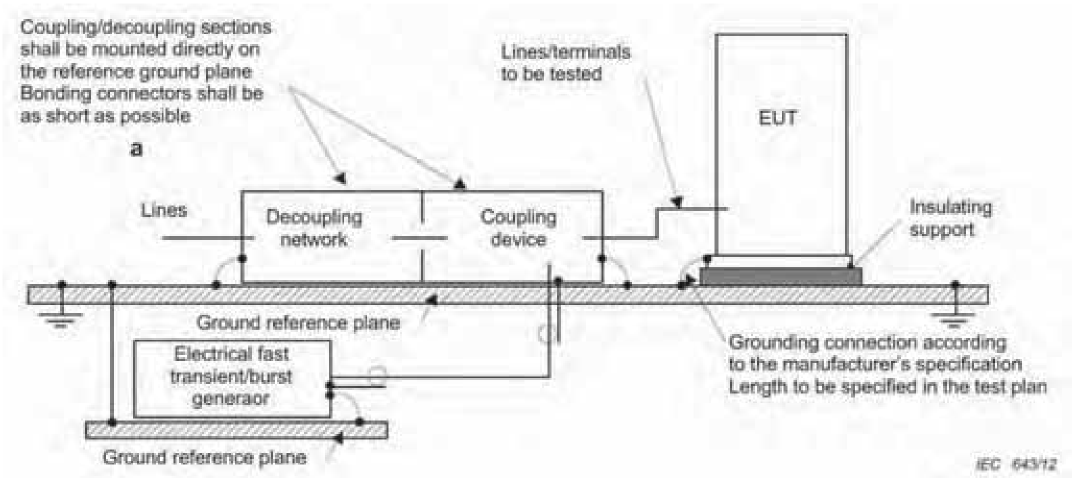

Figure 28. Block diagram for electrical fast transient/burst immunity test.

There are two different types of tests:

- Type (conformance) tests performed in laboratories
- Post installation tests performed on equipment in its final installed conditions

Laboratory performed testing is preferred. When agreement between manufacturer and customer is achieved post installation tests, which are performed in situ, may be applied. Both test types are described in the following sections.

7.3.2.1 Tests performed in laboratories

One of the coupling/decoupling methods previously explained must be used, either coupling network or capacitive clamp. The injected voltage signals test should be coupled and applied to all the ports of the EUT, in the conditions stated on previous sections.

7.3.2.1.1 Power port

Direct coupling of the EFT/B disturbance voltage via a CDN is the preferred method of coupling to power ports.

7.3.2.1.2 Signal and control ports

Capacitive coupling clamp is the preferred method of coupling for application of the disturbance test voltage to signal and control ports. The cable shall be placed in the centre of the coupling clamp. Non-tested or AE connected may be appropriately decoupled.

7.3.2.1.3 Earth terminal

In case a CDN cannot be used, the test voltage shall be applied to the protective earth (PE) connection through a (33 ± 6.6) nF coupling capacitor. The terminal of the PE conductor shall be the test point for the metallic enclosure having a power port.

7.3.2.2 In situ tests

This tests should be avoided and, if necessary, carried out under manufacturer and customer agreement because they can have destructive nature for the EUT and any equipment connected in the surroundings of the EUT can be damaged or inadmissibly affected.

The EUT shall be tested in the final installed conditions and the test will be performed without CDNs in order to simulate the actual electromagnetic environment as closely as possible. Only if the EUT are overly affected during the test, a decoupling network can be used under agreement between customer and manufacturer.

7.3.2.2.1 Power port

The test voltage shall be applied simultaneously between a ground reference plane and the power supply terminals, AC or DC, and the protective or functional earth port on the EUT cabinet.

The EFT/B generator shall be connected to the coupling capacitor(s) by a coaxial cable as short as possible and with its shielding unconnected to the capacitor end. Coupling capacitors shall have a value of (33 ± 6.6) nF.

7.3.2.2.2 Signal and control ports

The capacitive coupling clamp is the preferred method for coupling the test voltage into signal and control ports. The cable shall be placed in the centre of the coupling clamp.

7.4 Immunity test - Surge

This test is performed with the aim to evaluate the performance of the apparatus when they are subjected to unidirectional surges caused from switching and lighting transients, and shall be

noted that in any case the aim is to evaluate the capability of the insulation in order to withstand high-voltage stress. The test specifications are collected in the standard IEC 61000-4-5 [29].

7.4.1 Test equipment

Test equipment is based on the following components:

- Test generator
- CDN

The main characteristics of the components are explained below.

7.4.1.1 Test generator

The 1.2/50 µs combination wave generator is used to generate the disturbance signals for this test. Figure 29 shows a simplified circuit diagram of the 1.2/50 µs combination wave generator.

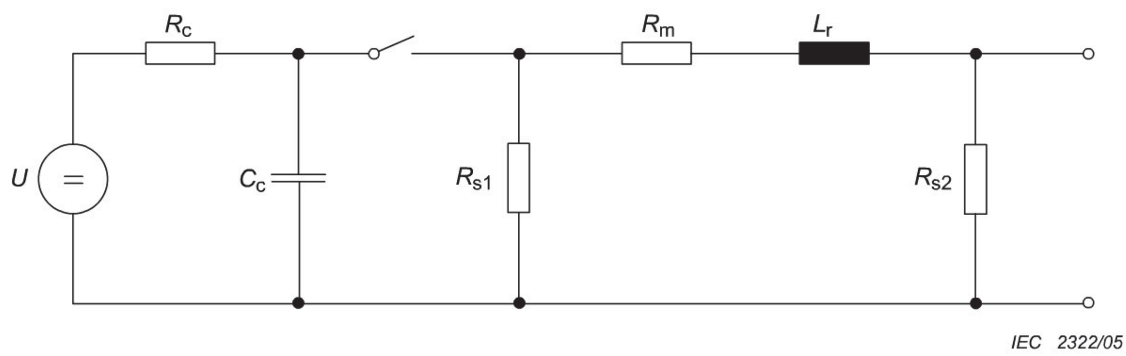

Figure 29. Simplified circuit diagram of the 1.2/50 µ combination wave generator.

The components of the simplified circuit diagram are:

- U, high-voltage source
- R_c, charging resistor
- C_c, energy storage capacitor
- R_s, impulse duration shaping resistor
- R_m, impedance matching resistor
- L_r, rise time shaping inductor

The values R_{s1}, R_{s2}, R_m, L_r and C_c for the different components are selected so that the generator is capable of delivering a 1.2/50 µs voltage surge at open-circuit conditions and a 8/20 µs current surge into a short circuit.

This generator is expected to generate a surge having:

- An open-circuit voltage front time of 1.2 µs
- An open-circuit voltage time to half value of 50 µs
- A shot-circuit current front time of 8 µs
- A shot-circuit current time to half value of 20 µs

The open-circuit voltage surge is shown in Figure 30, whereas the waveform of shot-circuit current to generate is shown in the Figure 31. Both waveform parameters are defined in Table 19.

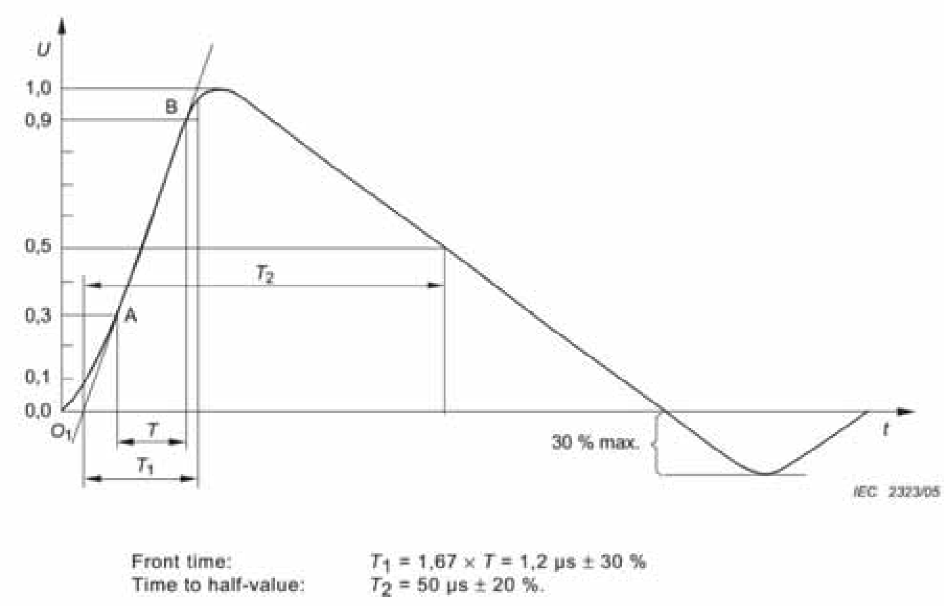

Figure 30. Waveform of open-circuit voltage (1.2/50µs).

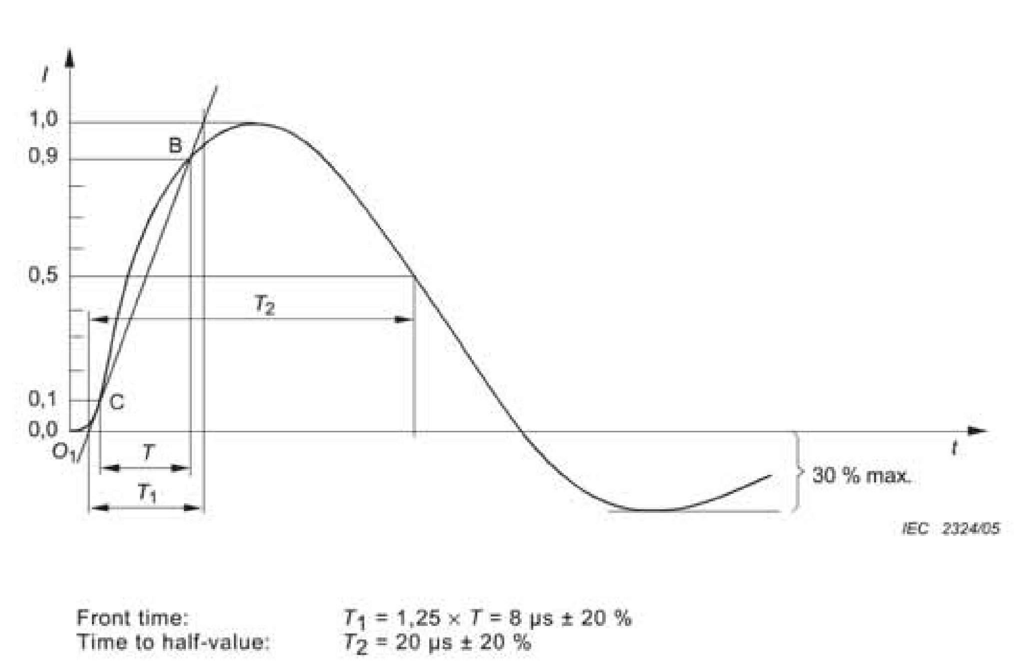

Figure 31. Waveform of shot-circuit current (8/20µs).

Table 19. Definitions of the waveform 1.2/50 µs parameters.

Definitions	In accordance with IEC 60060-1		In accordance with IEC 60469-1	
	Front time µs	Time to half value µs	Rise time (10 % - 90 %) µs	Duration time (50 % - 50 %) µs
Open-circuit voltage	1.2 ± 30 %	50 ± 20 %	1 ± 30 %	50 ± 20 %
Short-circuit current	8 ± 20 %	20 ± 20 %	6.4 ± 20 %	16 ± 20 %

7.4.1.2 Coupling/decoupling network

The EUT must be coupled with the signal generator and must be decoupled from the supply network as described in 7.3.1.2.

For I/O and communications lines, the series impedances of the decoupling network will limit the available bandwidth for data transmission. Desired coupling effects can be achieved through a capacitor or an arrestor, despite they must be carefully selected when coupling to interconnection lines due to waveform distortion by the coupling mechanism.

7.4.2 Test procedure

The test has to be performed under specific conditions in order to minimize the impact of environmental parameters on test results, regardless of the test type. Electromagnetic conditions shall guarantee correct operation of the EUT, so that test results are not to be affected. Climatic conditions shall ensure correct operation of both EUT and test equipment, and must fulfil the limits set by their respective manufacturers, unless the responsible committee for the generic or product standard states differs.

Two different test types are distinguished:

- At equipment level. The equipment level test shall be carried out in the laboratory on a single EUT. The test voltage shall not exceed the specified capability of the EUT's insulation, which is defined by the manufacturer
- At system level. In order to ensure the immunity level on the whole system where EUT is installed, a test at the system level is recommended to simulate the real installation

Both kinds of test are performed in accordance with a test plan which shall include the following data:

- Test level (voltage)
- Number of surges. Number of surge pulses unless otherwise specified by the relevant product standard:
    - For DC power ports and interconnection lines five positive and five negative surge pulses must be tested
    - For AC power ports five positive and five negative pulses each at 0º, 90º, 180º and at 270º must be tested

- Time between successive pulses must be 1 min or less
- Representative operating conditions of the EUT
- Locations to which the surges are applied

Since the test shall consider the non-linear current-voltage characteristic of the EUT, test voltage level has to be reached increasing the voltage in steps, according to the information specified by the manufacturer or in the test plan. All lower levels including the selected test level shall be satisfied. An example of test set up is given in the Figure 32.

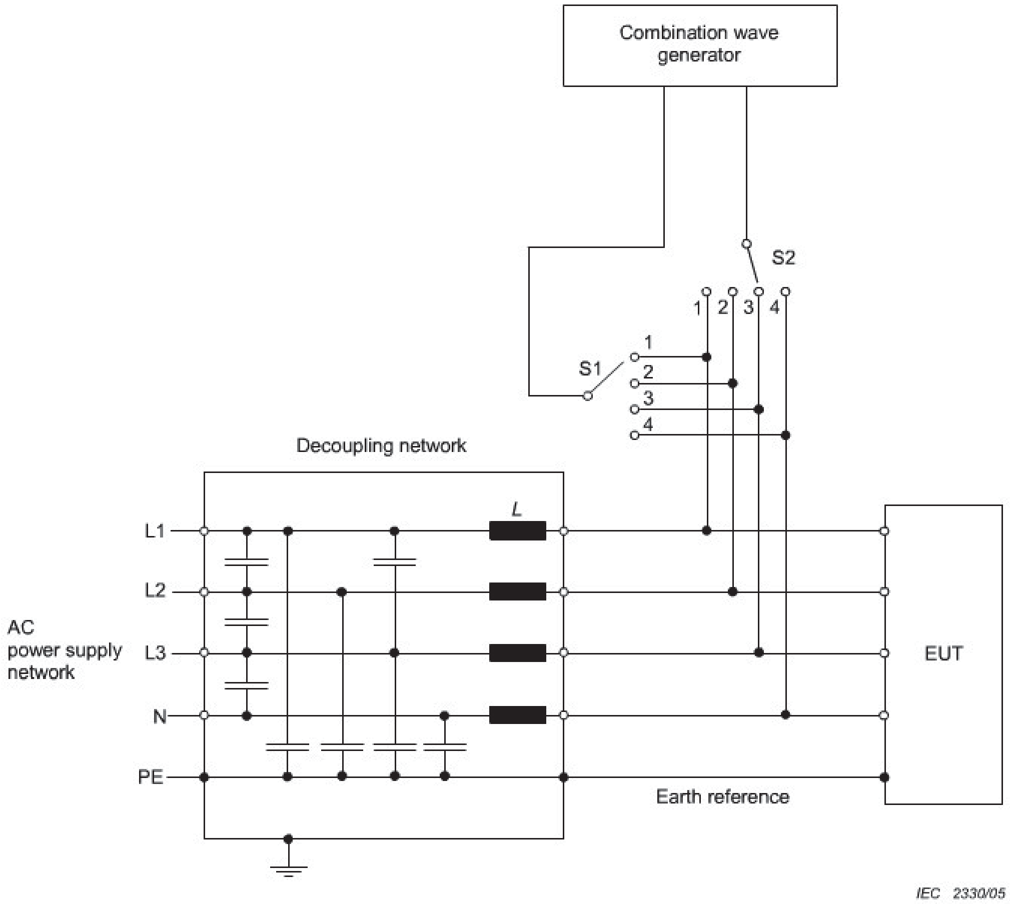

Figure 32. Example of test setup (line to line).

7.5 Immunity test – Conducted disturbances induced by radio-frequency fields

This test is performed with the aim to evaluate the performance of the apparatus when they are subjected to conducted disturbances induced by RF fields in the frequency range from 9 kHz up to 80 MHz. The test specifications are collected in the standard IEC 61000-4-6 [30].

7.5.1 Test equipment

The equipment required to carry out the tests are detailed below.

7.5.1.1 Test generator

The generator comprises all needed switchgear to generate and inject disturbances with the desired characteristics. The following equipment is required to supply the test signal to each port of the EUT; they can be used in a separate way or integrated in one test device:

- RF generators, G1 in Figure 33, able of covering the frequency band of interest and of being amplitude modulated by a 1 kHz sine wave with a modulation depth of 80 %
- Attenuator, T1, to control the level of the disturbance signal, its frequency range must be in accordance with the wave frequency band
- RF switch, S1, to connect and disconnect the EUT from the RF generator while measuring immunity
- Broadband power amplifiers, PA, to use only if the RF generator signal power does not reach sufficient levels
- LPF and/or high-pass filter (HPF). In some cases, may be necessary the use of filters to avoid harmonic-caused interferences with the EUT
- Attenuator, T2, (fixed ≥ 6 dB, Z_0 = 50 Ω), with sufficient power rated. T2 is provided to reduce the mismatch from the power amplifier to the coupling device

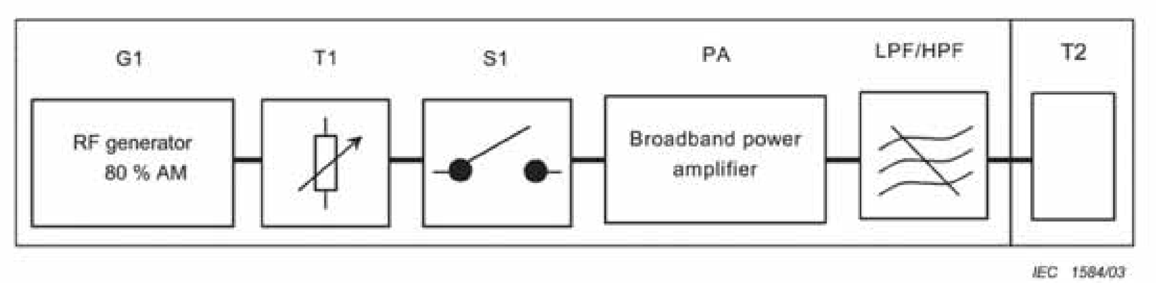

Figure 33. Test generator setup.

Table 20 shows the characteristics of the test generator with and without modulation.

Table 20. Characteristics of the test generator.

	Characteristics of the test generator
Output impedance	50 Ω
Harmonics and distortion	Any spurious spectra line shall be at least 15 dB below the carrier level
Amplitude modulation	Internal or external 80 % ± 5 % in depth 1 kHz ± 10 % sine wave
Output level	Sufficiently high to cover test level (see also Annex E of standard IEC 61000-4-8)

7.5.1.2 Coupling and decoupling devices

To couple the EUT from the signal generator and to decouple both apparatus from the network over the entire frequency range, coupling and decoupling devices shall be used. Table 21 shows the frequency band and the common-mode impedance seen at the EUT port, which is the main coupling device parameter.

Table 21. Main parameters of the combination of the coupling and decoupling device.

	Frequency band	
Parameter	0.15 MHz – 26 MHz	26 MHz – 80 MHz
$\|Z_{ce}\|$	150 Ω ± 20 Ω	150 Ω + 60 Ω – 45 Ω

The coupling and decoupling devices can be integrated in one component, or can be distributed as signal parts. The coupling and decoupling devices which can be used to perform the test are presented below:

- CDNs
- Clamp current
- EM clamp
- Direct injection devices

Preferred equipment consists of CDNs due to the test reproducibility and their AE protective capabilities. If they cannot be used, Figure 34 shows the selection rules to ensure the best injection method is selected.

7.5.2 Test procedure

The test has to be performed under specific conditions in order to minimize the impact of environmental parameters on test results, regardless of the test type. Electromagnetic conditions shall guarantee correct operation of the EUT, so that test results are not to be affected. Climatic conditions shall ensure correct operation of both EUT and test equipment, and must fulfil the limits set by their respective manufacturers, unless the responsible committee for the generic or product standard states differs.

The test shall be performed with the signal generator connected to the selected coupling device, only the EUT to be tested shall be connected, and any other cable not involved on the testing must be disconnected or accommodated with decoupling networks or CDNs. Where necessary, LPF and/or HPF shall be installed so as to prevent harmonic disturbances on the EUT, considering that the filter band stop should be properly selected to avoid additional harmonic affection on the EUT.

The disturbance signal is 80 % amplitude modulated with a 1 kHz sine wave and the frequency range to be swept takes from 150 kHz to 80 MHz. The test can be carried out increasing automatically the frequency of the signal generated to sweep the whole frequency band. If this is the case the increase in the step frequency cannot be bigger than 1 % of the previous step, and

the time for each step should be enough to register the response of the EUT (and always longer than 0.5 s).

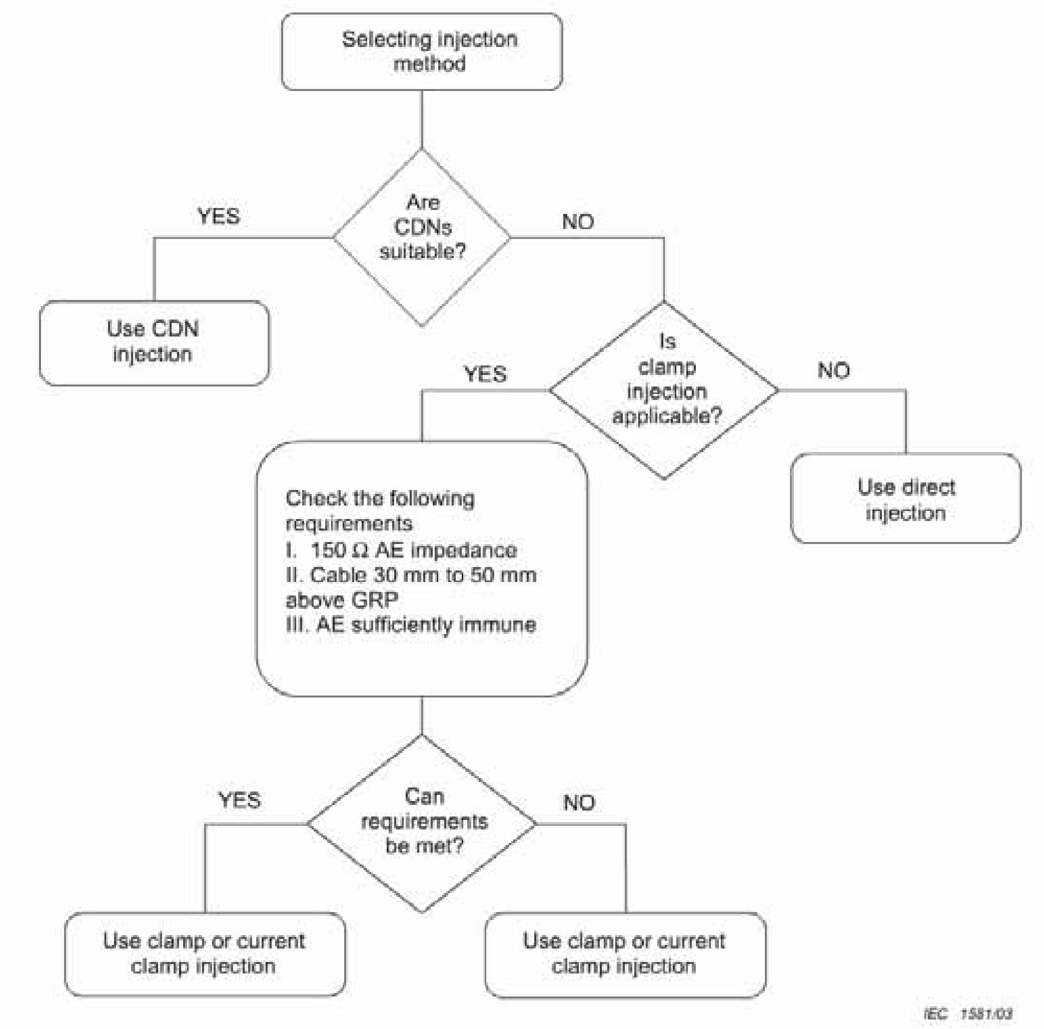

Figure 34. Injection method selection.

To avoid the EUT from be disturbed by transients due to the change of frequency on each step, some precautions should be adopted, for instance decreasing the signal strength a few dB below the test level. The EUT should be tested under all exercise modes selected for susceptibility.

Furthermore, in order to test the EUT, it must be connected between two 150 Ω common-mode impedances, the first is intended to link the EUT with the signal generator while the second to provide a return path for the current. With test methodology, the EUT is subjected to electric and magnetic fields resulting from the currents and voltages injected by the testing set-up, which simulate the fields emitted by international RF transmitters. An example of the immunity test to RF conducted disturbances equipment assembly is shown in Figure 35.

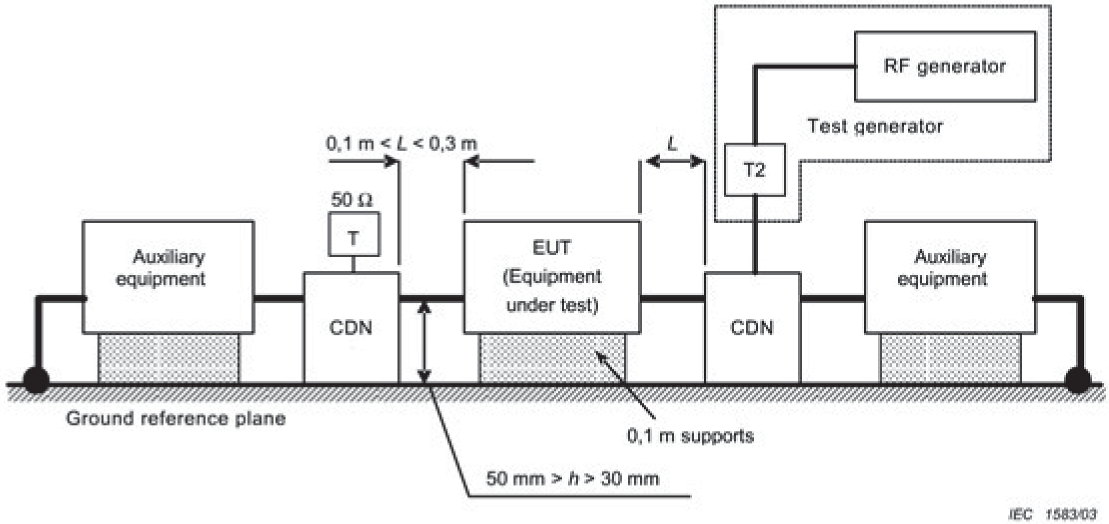

Figure 35. Example of the assembly for immuntity test to RF conducted disturbances.

7.6 Immunity test – Power frequency magnetic field

This test is performed with the aim to evaluate the performance of the apparatus when they are subjected to magnetic fields at power frequency (continuous and short duration field). The test purpose is to verify the immunity of the equipment when it is subjected to power fields related to the specific location and installation conditions of the equipment (for instance, proximity of equipment to the disturbance source). The test specifications are collected in the standard IEC 61000-4-8 [31].

7.6.1 Test equipment

The test equipment includes the current source (test generator), the inductive coil and auxiliary test instrumentation.

7.6.1.1 Test generator

The test generator consists of a current source based on a voltage regulator, a current transformer and a circuit which controls the current injection times. The generator shall be able to operate in both continuous and short duration mode. Figure 36 shows a test generator scheme for power frequency magnetic field.

The components in the scheme are the following.

- V_r, voltage regulation
- C, control circuit
- $T_{c,}$ current transformer

Since the currents to produce magnetic fields should be avoided, the connection between the current transformer and the inductive coil shall be as short as possible and the cable shall be twisted together. Table 22 shows the characteristic of the test generator.

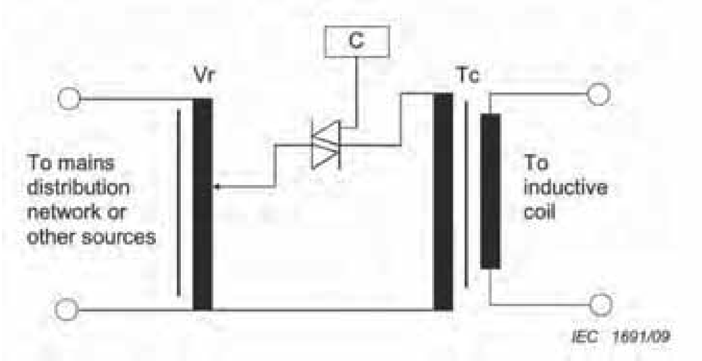

Figure 36. Example of schematic circuit of the test generator for power frequency magnetic field.

Table 22. Specifications of the generator for different inductive coils.

	With standard square coil 1 m x 1 m 1 turn	With standard rectangular coil 1 m x 2.6 m 1 turn	With other inductive coils
Output current range for continuous operation	1 A up to 120 A	1 A up to 120 A	As necessary to achieve required field strength in Table 4 of standard IEC 61000-4-8 [31]
Output current range for short duration	320 A up to 1200 A	500 A up to 1600 A	As necessary to achieve required field strength in Table 4 of standard IEC 61000-4-8 [31]
Current/Magnetic field waveform	Sinusoidal	Sinusoidal	Sinusoidal
Current distortion factor	≤ 8 %	≤ 8 %	≤ 8 %
Continuous mode	Up to 8 h	Up to 8 h	Up to 8 h
Short time operation	1 s up to 3 s	1 s up to 3 s	1 s up to 3 s
Transformer output	Floating not connected to PE	Floating not connected to PE	Floating not connected to PE

7.6.1.2 Inductive coil

Two types of inductive standard coils are suitable of being used during the test, specifically 1 m x 1 m coil and 1 m x 2.6 m coil. The field distribution of both coils is known; therefore none field verification nor field calibration is necessary, only the measuring of the current during the test is enough.

If working with lower testing currents is desirable or the EUT does not fit into the standard coils stated above, multi-turns coils or inductive coils with different dimensions can be used, verifying in any case the field distribution.

7.6.1.3 Test auxiliary instrumentation

The test instrumentation includes the current measuring system (sensor and instrument) for setting and measuring the current injected in the inductive coil. The accuracy of the measurement instrumentation shall be ±2%.

7.6.2 Test procedure

If there is no exposure, human requirements apply on the testing site, a distance of 2 m is recommended to avoid any potential hazard over the person that carries out the test. A test procedure shall be established, including:

- Verification of the laboratory reference conditions
- Preliminary verification of the correct operation of the equipment
- Carrying out the test
- Evaluation of the test results

The test has to be performed under specific conditions in order to minimize the impact of environmental parameters on test results, regardless of the test type. Electromagnetic conditions shall guarantee correct operation of the EUT, so that test results are not to be affected; otherwise, the test shall be performed into a Faraday cage. In particular, the power frequency field value of the laboratory shall be at least 20 dB lower than selected test level. Climatic conditions shall ensure correct operation of both EUT and test equipment, and must fulfil the limits set by their respective manufacturers, unless the responsible committee for the generic or product standard states differs. The test shall not be carried out if the relative humidity causes condensation on the EUT or on the test equipment.

The EUT performance shall be verified before the magnetic field test application. This magnetic field test is obtained by a current flowing through an inductive coil. An example of application of the test field by the immersion method is shown in the Figure 37.

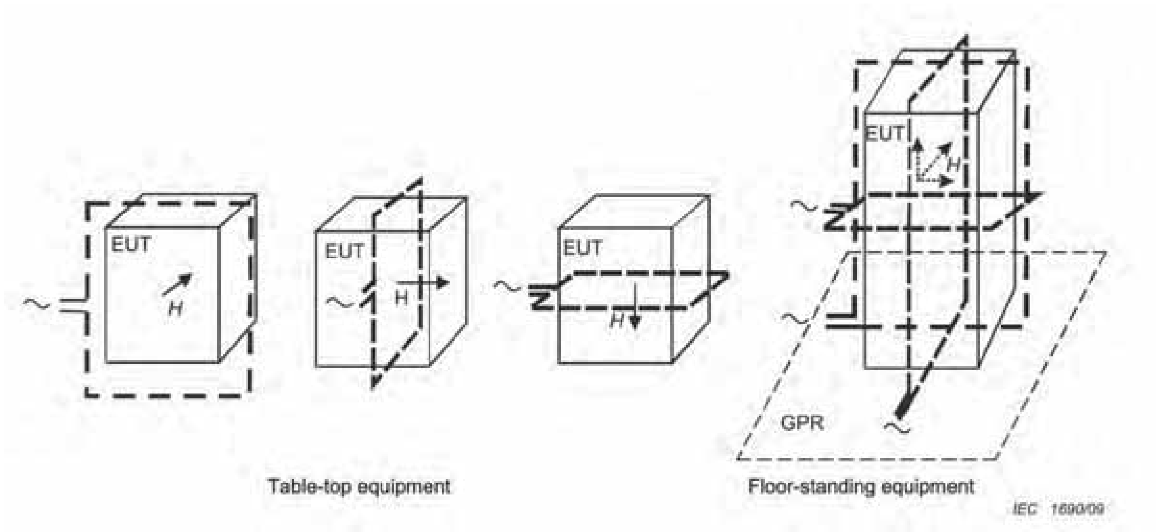

Figure 37. Example of application of the test field by the immersion method.

Product specification shall not be exceeded during the test, and signal and other functional electrical quantities shall be applied within their rated ranges. The selected test level determines the test field strength and test duration according to the different types of field (continuous or short duration field), detailed in the test plan.

Two different test types are distinguished depending on the EUT arrangement:

- Table-top equipment
- Floor-standing equipment

Regarding table-top equipment, the test the EUT shall be subjected to the test magnetic field as shown in the Figure 38. The plane of the inductive coil shall be rotated by 90º to prove different magnetic field orientation behaviour from the EUT.

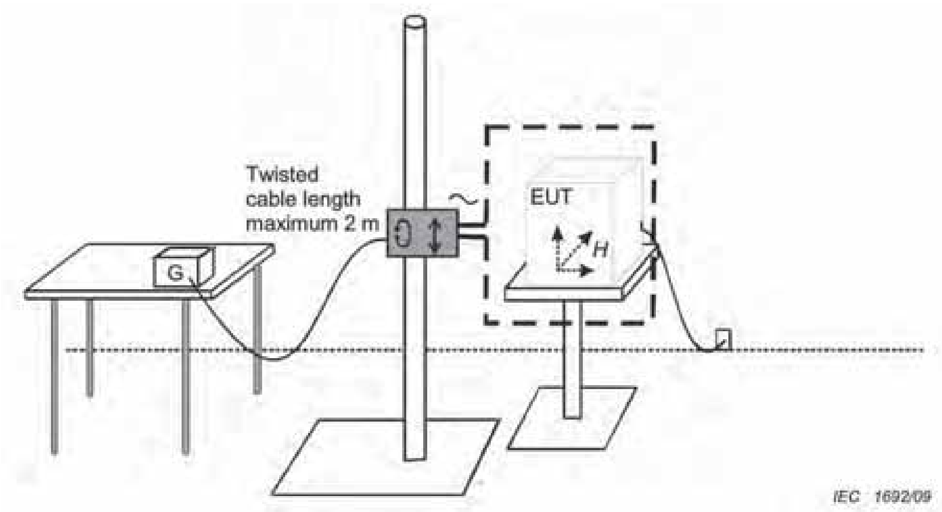

Figure 38. Example of the test set-up for table-top equipment.

For the floor-standing equipment, the EUT shall be subjected to the magnetic field test by using inductive coils of suitable dimensions as specified in Figure 38. In order to test the whole volume of the EUT for each perpendicular direction, the test shall be repeated by moving and shifting the inductive coils for each orthogonal direction, as presented on Figure 39.

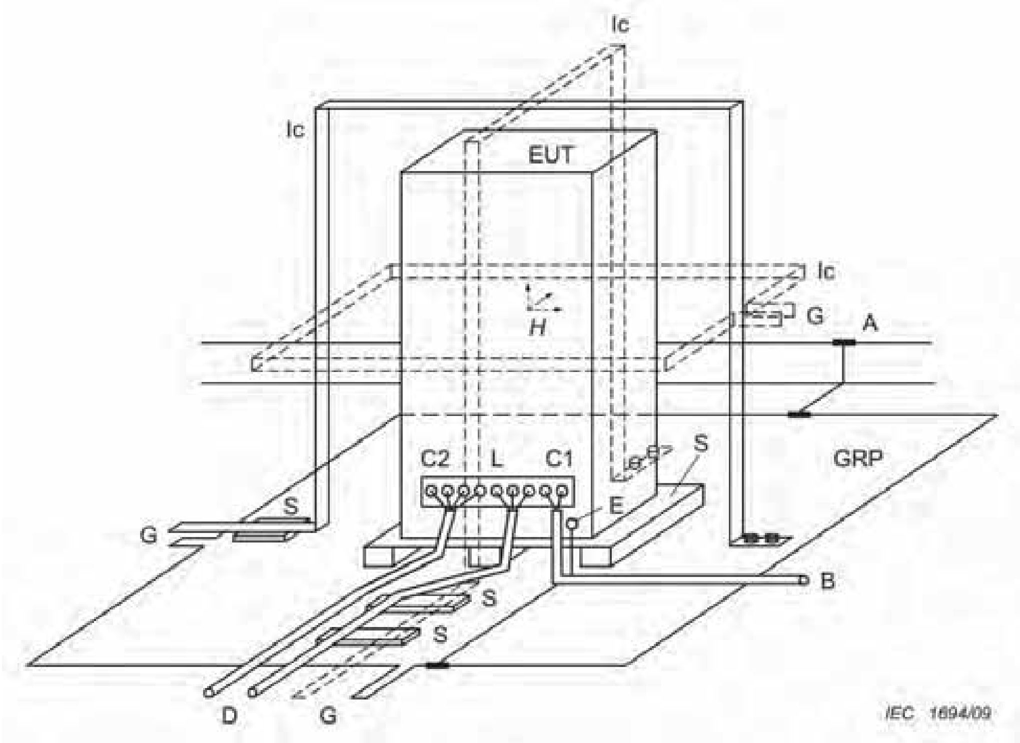

Figure 39. Example of the test set-up for floor-standing equipment.

The components shown in Figure 39 are the following:

- GRP, ground plane
- A, safety earth wire
- S, insulating support
- $I_{c,}$ Inductive coil
- E, earth terminal
- C1, power supply circuit
- C2, signal circuit
- L, communication line
- B, power supply source
- D, signal source
- G, test generator

If the size of the EUT is larger than the magnetic field volume induced by the inductive coil, or the magnetic field homogeneity is not enough, the test shall be repeated with the coil moved to different positions, in steps corresponding to 50% of the shortest side of the coil, so that the entire EUT is progressively immersed in the magnetic field with a homogeneity equal to 3 dB.

7.7 Immunity test – Voltage dips, short interruptions and voltage variations

This test is performed with the aim to evaluate the performance of the apparatus when they are subjected to voltage dips, short interruptions or voltage variations. This test only applies to electrical and electronic equipment whose rated current does not exceed 16 A per phase, and if the equipment is connected to 50 Hz or 60 Hz AC networks. The test specifications are collected in the standard IEC 61000-4-11 [32].

7.7.1 Test equipment

The equipment requirements to carry out the test are explained below.

7.7.1.1 Test generator

Two configurations are considered by the regulation for main supply disturbance simulation. One configuration involves two variable transformers and two switches, while the other configuration is based on a power amplifier. The schemes of these two possible configurations are given in Figure 40 and Figure 41.

In the scheme shown in Figure 40, both transformers have variable output voltages to simulate interruptions and voltage variations. Proper actuation on both switches allows voltage rises, drops and interruption simulation.

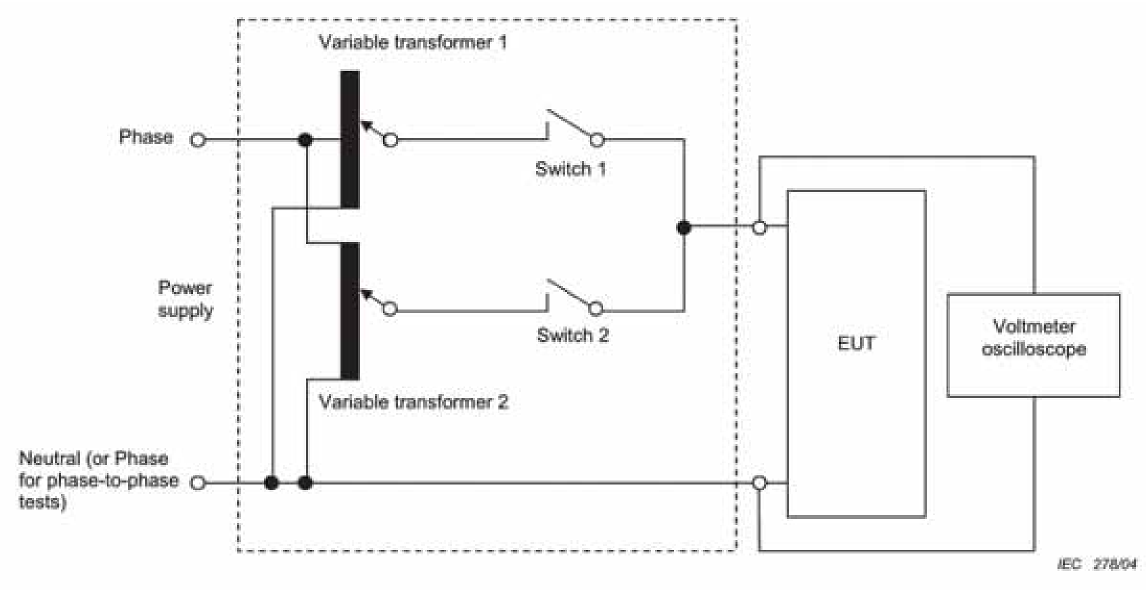

Figure 40. Schematic of test instrumentation for voltage dips, short interruptions and voltage variations using variable transformers and switches.

On the other hand, waveform generators and power amplifiers are a suitable alternative instead of variable transformers and switches set-up. This configuration also allows to test the EUT against frequency variations and harmonics, as presented in Figure 41.

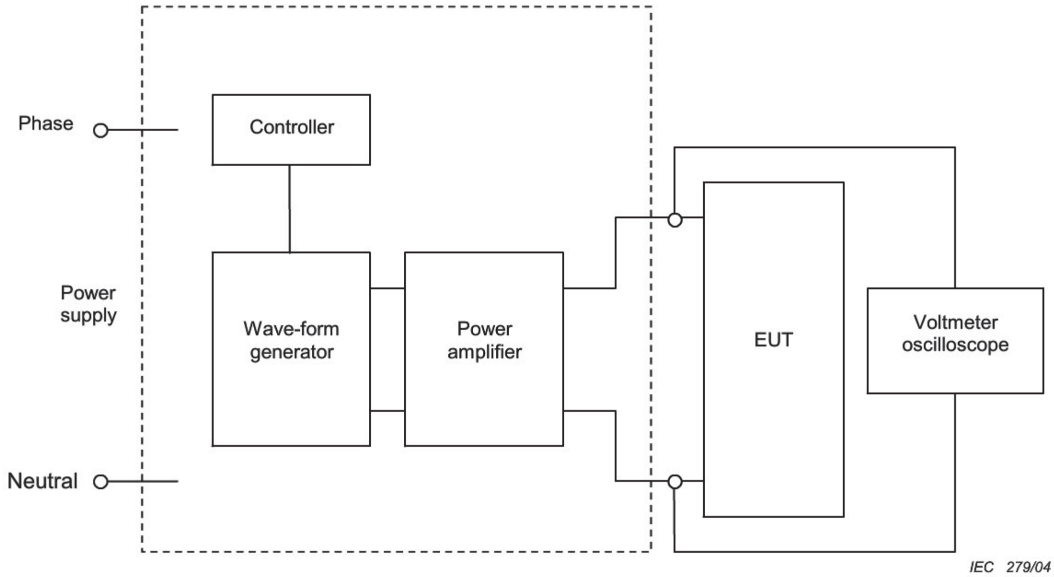

Figure 41. Schematic of test instrumentation for voltage dips, short interruptions and voltage variations using power amplifier.

The test generator shall prevent the emission of the heavy disturbances, which may influence the test results if injected in the power supply network. The following features are common to the generator instrumentation for voltage dips, short interruptions and voltage variations (except those indicated):

- Output voltage at no load: ± 5%
- Voltage change with load at the output of the generator: Less than 5% of UT under 100% output, 0 to 16 A, 80% output, 0 to 20 A, 70% output, 0 to 23 A, and 40% output, 0 to 40 A
- Output current capability: 16 A r.m.s. per phase at rated voltage. The generator shall be capable of carrying 20 A at 80% of rated value for a duration of 5 s. It shall be capable of carrying 23 A at 70% of rated voltage and 40A at40% of rated voltage for a duration of 3 s. (This requirement may be reduced according to the EUT rated steady-state supply current)
- Peak inrush current capability (no requirement for voltage variation tests): Not to be limited by the generator. However, the maximum peak capability of the generator need not exceed 1000 A for 250 V to 600 V mains, 500 A for 200 V to 240 V mains, or 250 A for 100 V to 120 V mains
- Instantaneous peak overshoot/undershoot of the actual voltage, generator loaded with 100 Ω resistive load: Less than 5% of U_T
- Voltage rise (and fall) time t_r (and t_f) during abrupt change, generator loaded with 100 Ω resistive load: Between 1 and 5 µs
- Phase shifting (if necessary): 0º to 360º

- Phase relationship of voltage dips and interruptions with the power frequency: Less than ± 10º
- Zero crossing control of the generators: ± 10º

Output impedance shall be predominantly resistive and low even during transitions.

7.7.1.2 Power source

The frequency of the test voltage shall be within ±2% of the rated frequency.

7.7.2 Test procedure

The test is performed according to a previously established test plan, which shall cover at least the next topics:

- The type designation of the EUT
- Information on possible connections and corresponding cables
- Input power port of equipment to be tested
- Representative operational modes of the EUT for the test
- Performance criteria used and defined in the technical specifications
- Operational mode(s) of the equipment
- Description of the test set-up

The recorder device should allow the EUT to operate at the operational mode status during and after the test. After each group of tests, EUT normal operation has to be verified.

The test is performed under specific conditions in order to minimize the impact of environmental parameters on test results. Therefore the climatic conditions shall be within any limits specified for the operation of the EUT and the test equipment by their respective manufacturers unless they are specified by the committee responsible for the generic or product standard. The test shall not be carried out if the relative humidity causes condensation on the EUT or on the test equipment. The electromagnetic conditions shall be such as to guarantee the correct operation of the EUT in order to the test result is not affected.

Main voltage signals should be registered within an accuracy of at least 2% during the test, and all representative operation modes shall be covered. For each representative mode of operation of the EUT, three dips/interruptions for each test level and duration selected should be carried out, respecting a minimum time between tests of at least 10 seconds.

In the case of voltage dips, changes in supply voltage shall occur at zero crossing of the voltage, and at additional angles defined as critical by product committees or individual product specifications. Furthermore, each individual voltage shall be tested in test of three-phase systems.

For short interruptions, the angle shall be defined by the product committee as the worst case. In the absence of definition, it is recommended to use 0º for one of the phases. For test of three-phase systems all the three phases shall be simultaneously tested.

8 Mitigation of electromagnetic disturbances

This chapter reviews shielding arrangement and screening against radiated disturbances and the mitigation of conducted disturbances. These arrangements include appropriate electromagnetic barriers for industrial, commercial, and residential installations. All mitigation methods discussed in this chapter are according with IEC TR 61000-5-6 [34].

Only if EMC between an apparatus and its environment is not achieved, disturbances shall be mitigated using additional components that work as disturbance contention method. In the case of conducted disturbances the barrier could be a combination of surge-protection devices (SPDs) and filters or other decoupling devices, and for radiated disturbances it could be a radiation screen or a filter comparable with the screen in the frequency range to consider.

8.1 Shielding

An apparatus can be shielded in order to either avoid exposure to radiated disturbances or to prevent affections on its environment due to self-emitted disturbances. These two-fold effects are shown in Figure 42.

Shielding techniques are based on surrounding the apparatus with screens made of different materials depending on the peculiarities of the electromagnetic field to be mitigated. As a “rule of thumb”, low-frequency magnetic fields are more difficult to screen than low-frequency electric fields and hence thicker shields with better material properties are necessary.

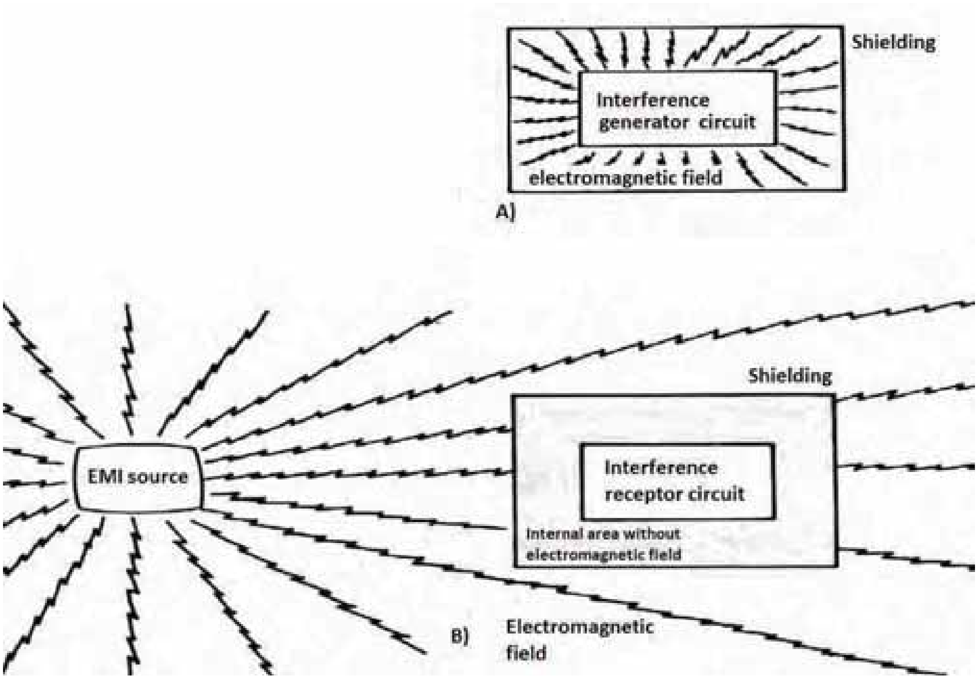

Figure 42. Shielding examples a) emmision; b) immunity.

The following factors must be taken into account on the design of effective enclosures:

- Disturbance currents, which should be carried out of the enclosure
- If any cable penetrates the enclosure, it must be properly filtered and screened to ground, so it is not affected by interferences
- For high-frequency magnetic fields, the electrical lengths of any of the different parts that compose the enclosure have to be smaller than one-tenth of the wavelength of the wave to be filtered
- Since to completely avoid apertures in the enclosures is not possible, the openings for ventilation, windows or for any other purpose should be minimized in order to maintain the shielding effectiveness in the frequency range desired

8.2 Filters

When the disturbance level is higher than the immunity level of the installed equipment, filters might be used to limit the frequency bandwidth of the disturbances and attenuate them. They are intended to protect electric circuits against continuous disturbances outside the frequency band of the intended signals, separate common-mode disturbances from differential-mode signals, and limit differential-mode bandwidth to the minimum necessary operational width.

There are two basic filter types, active and passive filters. The main difference between them is that active filters are in most cases not bi-directional, therefore their function is to avoid only generated disturbance instead of protecting the equipment. On the other hand passive filters can limit the bandwidth of the disturbances, they are based on resistors, inductors and capacitors, and they can be installed in parallel or in series with the equipment.

According to their bandwidth limitation capacities, passive filters can be classified as:

- LPFs to attenuate high frequencies disturbances
- HPFs to attenuate low frequencies disturbances
- Band-pass filters to attenuate signals with frequencies outside the pass-band
- Stop-band filters to attenuate a specific range of frequencies within the stop-band

The effects of the previously defined filters are shown in Figure 43. The LPF is the most frequently used in EMC applications.

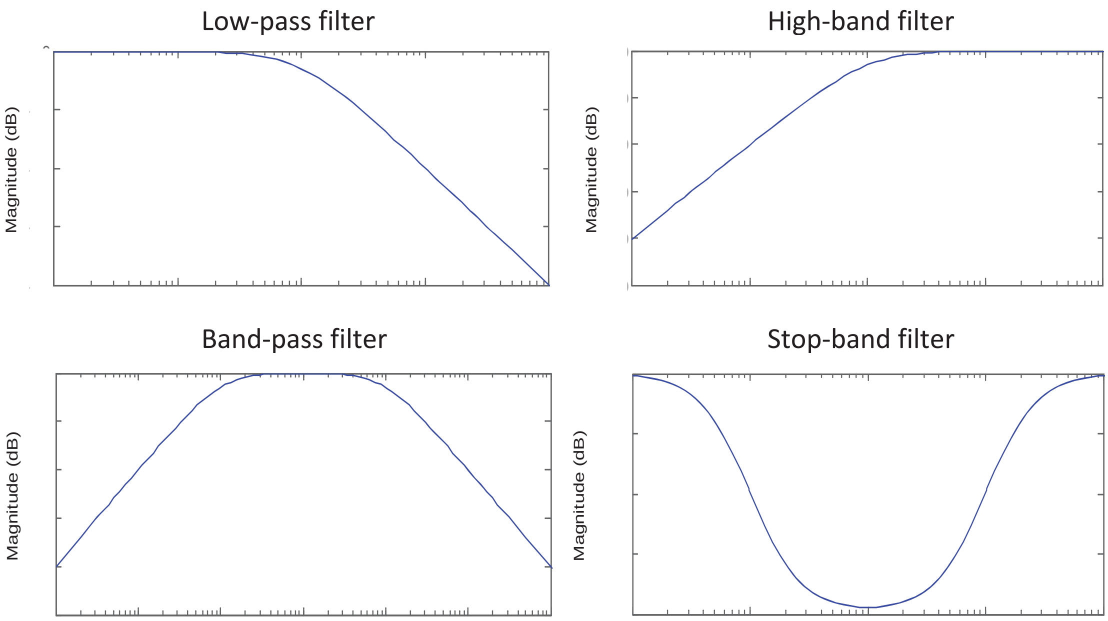

Figure 43. Bandwidth capacities of several passive filters.

Concerning their specific functional requirement a detailed analysis is necessary, bearing in mind:

- Disturbance source characteristics
  - Continuous disturbance
  - Transient disturbance
  - Frequency range of the disturbance

- Type of disturbance
  - Common-mode when interference appears on both signal leads
  - Differential mode when only appears on one signal
  - Mixed type

- Necessary attenuation (value related to the frequency range)

- Application conditions
  - Circuit to be filtered
  - Environmental conditions where the circuit is installed

- Safety aspects of the installation

Figure 44 and Figure 45 show the filter solution for common-mode and differential mode disturbances. Usually both types of disturbances appear simultaneously, so the filter has to be designed to respond against common-mode and differential-mode disturbances.

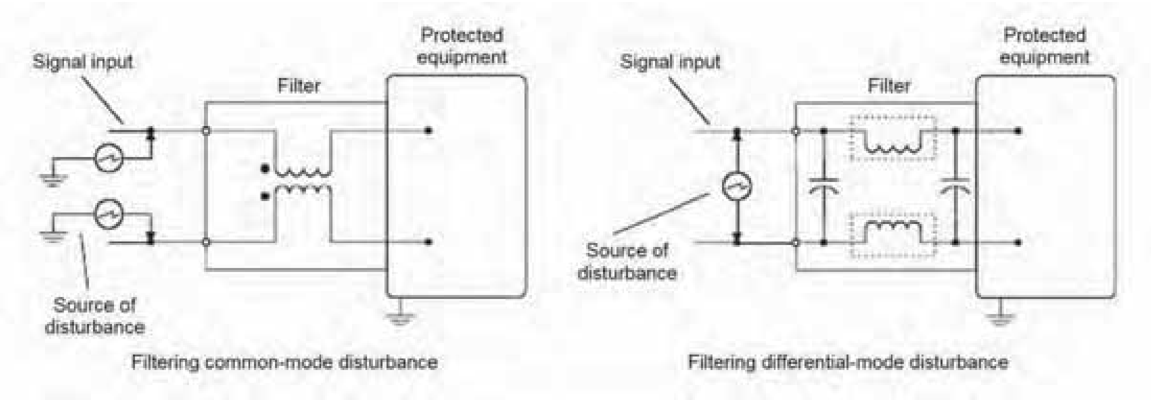

Figure 44. Prevention of interference on installed equipment.

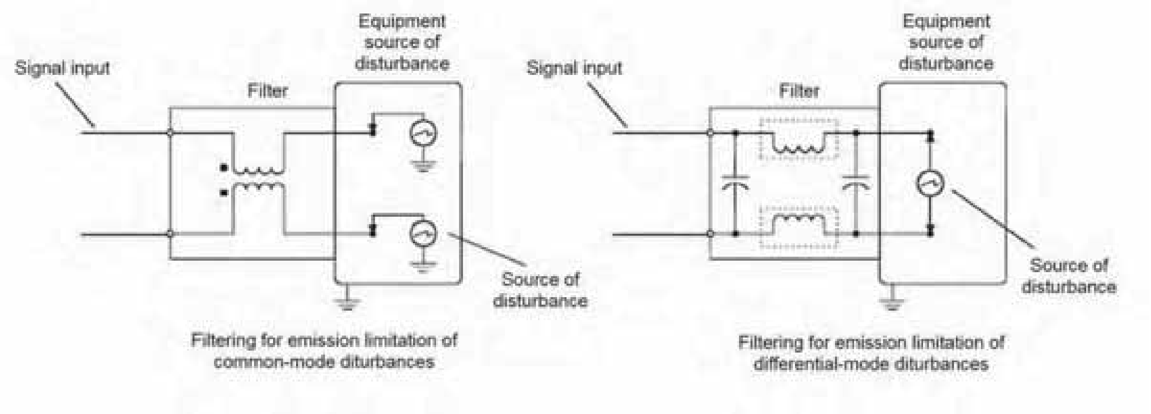

Figure 45. Reduction of electromagnetic disturbances in the power network and the environment.

8.3 Decoupling devices

Decoupling is generally achieved though isolation transformers usage. They are useful devices to break the conductive continuity of a circuit while maintaining passage of differential-mode signals[8]. Their design depends on the disturbances to be isolated, but their bandwidth covers up to a few kHz.

Isolation transformers act specifically against common-mode conducted disturbances and only up to some frequencies. For above frequencies the effect is null or might be even worse, caused by a voltage level increase on the secondary winding due to resonance effects. In the case of differential-mode disturbances, they are not attenuated when they pass to the secondary connected circuit. Therefore, proper application is limited to breaking a common-mode circuit at low frequencies.

Regarding power-line conditioning, there are several technologies capable of providing line isolation, voltage regulation and power factor correction with different levels of decoupling dependingon their constructive features. Saturable reactors and inductors can change the phase

[8] "Signals" are understood as normal operating communication signals or A.C./D.C. power.

of the line to modify output voltage; their main drawback is that they can generate non-linear components without significant decoupling levels. On the other hand, other transformer configurations such as ferro-resonant and tap-changing transformers provide better decoupling capabilities, which can be improved with the installation of inter-winding screens, filters and SPDs.

Finally, other decoupling methods aim to eliminate physical electrical contact to avoid conducted disturbances. Available options cover optical links, in the form of opto-coupler or optical fibre transmission systems. Opto-couplers transmit electrical signals with no-contact by means of a modulated light beam created and captured by a generator-sensor pair, integrated in small semiconductor packages.

8.4 Surge-protective devices

SPDs protect power and communication circuits against high frequency events in the form of surge voltages or surge currents. They are usually installed in combination with filters, since SPDs mitigate surges and filters act against continuous occurrences.

As can be seen in Figure 46, this devices offer a low impedance alternative way to alter the course of the surge current while producing a small or negligible voltage drop between the equipment terminals. Since SPDs are connected between the point to be protected and ground, two components are needed to act against common-mode disturbances and one for differential mode.

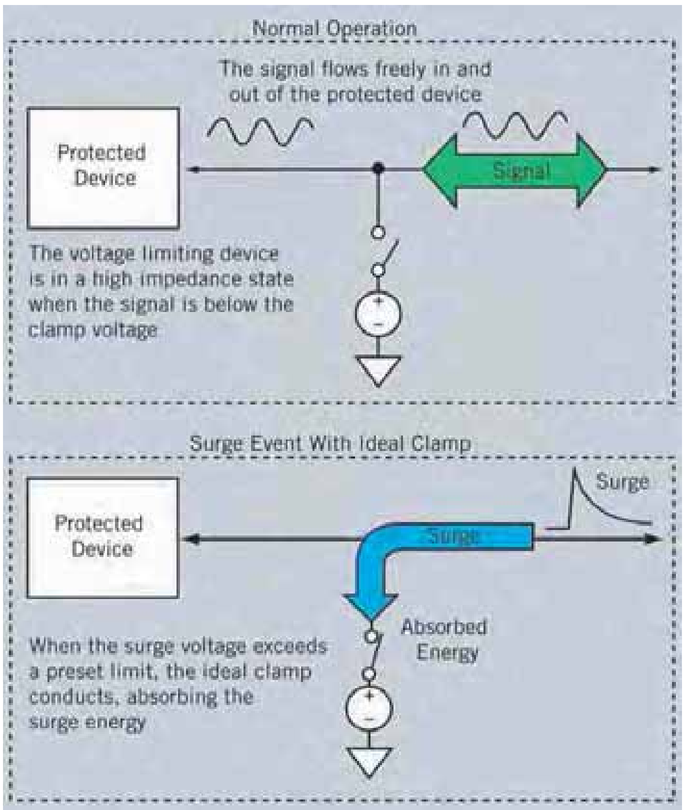

Figure 46. SPDs behavoiur against surge voltages.

For complete mitigation, device behaviour may cover one or several stages:

- Relatively slow-response, high-energy device
- Relatively faster response, with limited energy capability
- Final filtering or limiting of the residual overvoltage from upstream SPDs

Typical protective devices use two different operating methods:

- Voltage-limiting type SPDs. These devices are based on the non-linear behaviour of the impedance of certain materials when voltage is applied. At rated voltage, its impedance is very high but the impedance decreases when the voltage rises up, leading to significant power dissipation capacities. Representative components for this type of behaviour are metal-oxide varistors and silicon avalanche diodes, which have to be properly sized for every specific application
- Voltage-switching type SPDs. These devices have high impedances under stationary conditions, when a voltage surge appears, impedance is dramatically decreased, leading to high current modification ranges in the SPDs terminals. Examples of these components are spark gaps, gas tubes and thyristors

9 Conclusions

Manufacturers must certificate their apparatuses in order to accomplish the electromagnetic compatibility requirements established by regulations. The compliance with regulations assure the ability of the equipment to work satisfactorily in its electromagnetic environment, without introducing intolerable electromagnetic disturbances to other equipment in that environment and being immune to the electromagnetic disturbances produced by other equipment.

The analysed standards establish both emission limits and performance criteria to assess equipment immunity. Furthermore, all tests to be performed with the aim to certificate the equipment operates according to regulations are specified on those standards. It has to be noted that the requirements and test procedures may vary, depending on the equipment characteristics or the environment where the equipment is intended to operate.

An optimal approach to accomplish with electromagnetic requirements is to perform good practices during the design and manufacture stages. But, in case the test results do not meet the requirements, several corrective measures may be adopted in order to mitigate the electromagnetic effects. The main options consist of shielding the apparatus or adding devices as filters or decoupling equipment. These corrective measures may be applied to achieve compliance with the immunity requisites as well as to meet the emission limits.

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