

INTERNATIONAL STANDARD



BASIC EMC PUBLICATION

**Electromagnetic compatibility (EMC) –
Part 4-12: Testing and measurement techniques – Ring wave immunity test**

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IEC 61000-4-12

Edition 3.0 2017-07
REDLINE VERSION

INTERNATIONAL STANDARD



BASIC EMC PUBLICATION

**Electromagnetic compatibility (EMC) –
Part 4-12: Testing and measurement techniques – Ring wave immunity test**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.100.20

ISBN 978-2-8322-4625-2

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-12: Testing and measurement techniques –
Ring wave immunity test

FOREWORD

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International Standard IEC 61000-4-12 has been prepared by subcommittee 77B: High frequency phenomena, of IEC technical Committee 77: Electromagnetic compatibility.

It forms Part 4-12 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107.

This third edition cancels and replaces the second edition published in 2006. This edition constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

- a) addition of a mathematical modelling of ring wave waveform;
- b) new Annex B on selection of generators and test levels;
- c) new Annex C on explanatory notes;
- d) new Annex D on measurement uncertainty;
- e) addition of high speed CDN;
- f) addition of a calibration procedure for CDN.

The text of this International Standard is based on the following documents:

CDV	Report on voting
77B/764/CDV	77B/774/RVC

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

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

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

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

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- withdrawn,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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

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

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

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

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

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

This part is an International Standard which gives immunity requirements and test procedures related to ring waves. It should be noted that edition 1 of IEC 61000-4-12, published in 1995, covered immunity tests against two phenomena, ring waves and damped oscillatory waves. This situation was changed in edition 2, published in 2006, where IEC 61000-4-12 covered the ring wave phenomena only and the damped oscillatory wave phenomenon was moved into a new standard IEC 61000-4-18.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-12: Testing and measurement techniques – Ring wave immunity test

1 Scope ~~and object~~

This part of IEC 61000 relates to the immunity requirements and test methods for electrical and electronic equipment, under operational conditions, to ~~non-repetitive damped oscillatory transients (ring waves)~~ occurring in low-voltage power, control and signal lines supplied by public and non-public networks.

The object of this document is to establish ~~the immunity requirements and~~ a common reference for evaluating ~~in a laboratory the performance of electrical and electronic equipment intended for residential, commercial and industrial applications, as well as of equipment intended for power stations and substations, as applicable~~ the immunity of electrical and electronic equipment when subjected to ring waves. The test method documented in this part of IEC 61000 describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon.

NOTE As described in IEC Guide 107, this is a basic EMC publication for use by product committees of the IEC. As also stated in Guide 107, the IEC product committees are responsible for determining whether this immunity test standard ~~should be~~ is applied or not, and if applied, they are responsible for determining the appropriate test levels and performance criteria. TC 77 and its sub-committees are prepared to co-operate with product committees in the evaluation of the value of particular immunity test ~~and test levels~~ for their products.

This document defines:

- test voltage and current waveforms;
- a range of test levels;
- test equipment;
- test setups;
- test procedures.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 60050(161): International Electrotechnical Vocabulary (IEV) – Chapter 161: Electro-magnetic compatibility~~

IEC 60050 (all parts), *International Electrotechnical Vocabulary (IEV)* (available at www.electropedia.org)

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-161 (all parts) as well as the following apply.

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

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

~~NOTE—Several of the most relevant terms and definitions from IEC 60050-161 are presented among the definitions below.~~

~~3.1~~

~~burst~~

~~sequence of a limited number of distinct pulses or an oscillation of limited duration~~

~~[IEV 161-02-07]~~

3.1.1

calibration

set of operations which establishes, by reference to standards, the relationship which exists under specified conditions, between an indication and a result of a measurement

Note 1 to entry: This term is based on the "uncertainty" approach.

Note 2 to entry: The relationship between the indications and the results of measurement can be expressed, in principle, by a calibration diagram.

[SOURCE: IEC 60050-311:2001, 311-01-09]

3.1.2

coupling

interaction between circuits, transferring energy from one circuit to another

3.1.3

coupling network

CN

electrical circuit for the purpose of transferring energy from one circuit to another

3.1.4

coupling/decoupling network

CDN

combination of a coupling network and a decoupling network

3.1.5

decoupling network

DN

electrical circuit for the purpose of preventing test voltages applied to the equipment under test (EUT) from affecting other devices, equipment, or systems which are not under test

3.1.6

immunity (to a disturbance)

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

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

3.1.7**port**

particular interface of ~~the EUT~~ an equipment, which couples this equipment with the external electromagnetic environment (IEC 60050-161:1990, 161-01-01) and through which the equipment is influenced by the environment

[SOURCE: IEC 60050-161:1990, 161-01-27]

3.1.8**ring wave**

damped oscillation, whose damping time constant is of the order of one period

[SOURCE: IEC 60050-161:1990, 161-02-30]

3.1.9**rise time**

T_r

interval of time between the instants at which the instantaneous value of an impulse first reaches 10 % value and then the 90 % value

[SOURCE: IEC 60050-161:1990, 161-02-05, modified – the content of the note has been included in the definition and “pulse” has been changed to “impulse”]

3.1.10**transient** (adj and noun)

pertaining to or designating a phenomenon or a quantity which varies between two consecutive steady states during a time interval short compared with the time-scale of interest

[SOURCE: IEC 60050-161:1990, 161-02-01]

3.1.11**verification**

set of operations which is used to check the test equipment system (e.g. the test generator and ~~the its interconnecting cables) and~~ to demonstrate that the test system is functioning ~~within the specifications given in Clause 6~~

Note 1 to entry: The methods used for verification may be different from those used for calibration.

~~NOTE 2 – The procedure of 6.1.2 and 6.2.2 is meant as a guide to insure the correct operation of the test generator and other items making up the test set-up, so that the intended waveform is delivered to the EUT.~~

Note 2 to entry: For the purposes of this basic EMC standard this definition is different from the definition given in IEC 60050-311:2001, 311-01-13.

3.2 Abbreviated terms

AE	Auxiliary equipment
CD	Coupling device
CDN	Coupling/decoupling network
CLD	Clamping device
CN	Coupling network
DN	Decoupling network
EMC	Electromagnetic compatibility
EUT	Equipment under test
GDT	Gas discharge tube
MU	Measurement uncertainty

PDF	Probability density function
PE	Protective earth
RGP	Reference ground plane
RWG	Ring wave generator
SPD	Surge protective device

4 General

4.1 Description of the phenomenon

The ring wave (described in Figure 1) is ~~a typical~~ an oscillatory transient, induced in low-voltage cables due to the switching of electrical networks and reactive loads, faults and insulation breakdown of power supply circuits or lightning. It is, in fact, the most diffused phenomenon occurring in power supply (high voltage, medium voltage, low voltage) networks, as well as in control and signal lines.

The ring wave is representative of a wide range of electromagnetic environments of residential, as well as industrial installations. It is suitable for checking the immunity of equipment in respect of the above-mentioned phenomena, which give rise to impulses characterized by sharp front-waves that, in the absence of filtering actions, are in the order of 10 ns to a fraction of μs . The duration of these impulses may range from 10 μs to 100 μs .

The rise time and duration of the ~~parameters~~ impulse are ~~subject to modification, depending~~ dependent on the propagation characteristics of the media and the path.

The propagation of the wave in the lines (power and signal) is always subject to reflections, due to the mismatching impedance (the lines are terminated ~~on their own~~ with loads or connected to protection devices, input line filters, etc.). These reflections produce oscillations, whose frequency is related to the propagation speed. The presence of parasitic parameters (e.g. stray capacitance of components like motors, transformer windings, etc.) are ~~other~~ conditioning additional influencing factors.

~~The rise time is reduced to slowing down due to the low-pass characteristic of the line involved in the propagation. This modification is more relevant for the fast rise times (in the order of 10 ns), and less relevant for values in the range of a fraction of μs .~~

~~The resultant phenomenon at the equipment ports is an oscillatory transient, or ring wave. This ring wave with a defined 0,5 μs rise time and 100 kHz oscillation frequency has been determined to be typical and is widely used by some industries for testing products.~~

The rise time can be increased by the low-pass characteristics of the line. This effect is more relevant for fast rise times (in the order of 10 ns), and less relevant for slow rise times (in the order of 1 μs).

Another cause of the ring wave is lightning, which itself is characterized by a unidirectional waveform (standard 1,2/50 μs impulse). Circuits subjected to the indirect effects of lightning (inductive coupling among lines) are influenced by the derivative of the primary impulse and the coupling mechanisms involved, which ~~gives rise to~~ can cause oscillations. The characteristics of the resulting ring wave depend on the reactive parameters of the ground circuits, metal structures involved in the lightning current flow, and the propagation in the low-voltage transmission lines.

The phenomenon, which is created by the above mentioned effects at the equipment ports, is an oscillatory transient or a ring wave. Oscillatory transients are covered in IEC 61000-4-18. A ring wave with a defined 0,5 μs rise time and 100 kHz oscillation frequency has been determined to be typical and is widely used for testing products.

The formula of the ideal waveform of Figure 1, $w(t)$, is as follows:

$$w(t) = A \cdot K \cdot \frac{\left(\frac{t}{t_1}\right)^n}{1 + \left(\frac{t}{t_1}\right)^n} \cdot \exp\left(-\frac{t}{t_2}\right) \cdot \cos(\beta t)$$

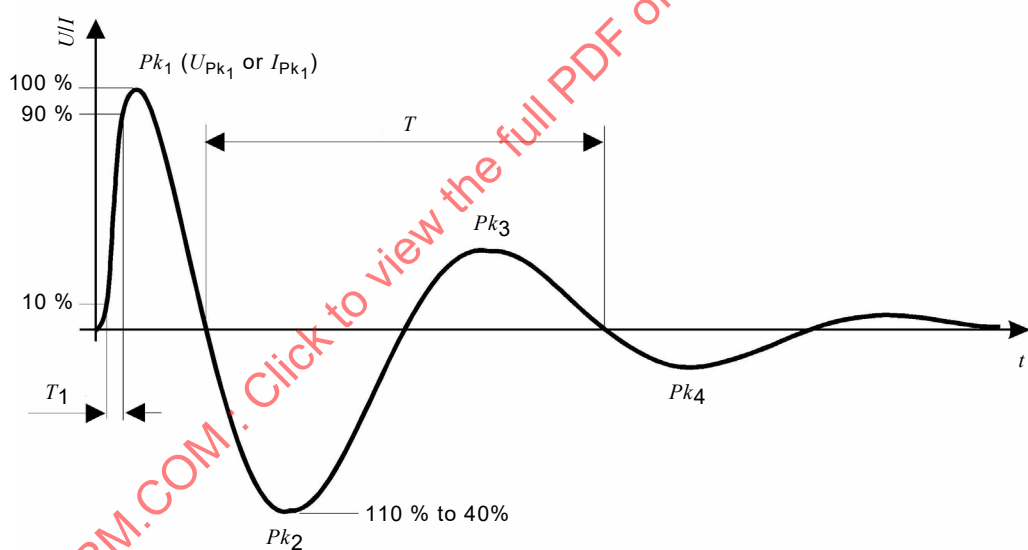
with

$$t_2 = \frac{T}{2} \cdot \frac{1}{\ln R} = 7,21 \mu\text{s} \text{ and } \beta = \frac{2\pi}{T} \text{ and } T = 10 \mu\text{s}$$

where the parameters for oscillation period $T = 10 \mu\text{s}$ are:

$$A = 1; K = 1,81; n = 1,83; t_1 = 0,507 \mu\text{s}$$

NOTE R is the ratio between Pk_2 and Pk_3 , Pk_3 and Pk_4 . The value of R ensures that the ratios Pk_2/Pk_3 , Pk_3/Pk_4 are in the range specified by this document. The value of R cannot be too small otherwise the ratio Pk_1/Pk_2 exceeds the specified tolerance. $R = 2$ has been selected. The parameters n and t_1 are adjusted to obtain $T_1 = 0,5 \mu\text{s}$.



Key

- T_1 Rise time
 T Oscillation period

NOTE Only Pk_1 is specified for the current waveform.

**Figure 1 – Waveform of the ring wave
(open-circuit voltage and short-circuit current)**

Other IEC standards, such as IEC 61000-4-5, refer to the 1,2/50 μs standard lightning impulse, which may be considered to be complementary to the ring wave described in this document.

It is the responsibility of the product committees to define the most appropriate test, according to the phenomenon considered as relevant.

4.2 Relevant parameters

4.2.1 Repetition rate

The repetition rate of the transient is directly related to the frequency of occurrence of the primary phenomenon (lightning and switching). It is higher whenever the primary cause is the load switching in control lines, and less frequent in the case of faults and lightning. The occurrence may typically range from ~~1/s to 1/month or 1/year~~ once per second down to once per year.

The repetition rate may be increased in order to reduce the duration of the test. ~~However, It should be selected according to the characteristics of the transient protectors involved the protection device used for mitigation/suppression of transients.~~

4.2.2 Phase angle

Equipment failures related to the ring wave on power supply sources can depend on the phase angle of the AC mains at which the transient is applied. When a protection element operates during a ring wave test, ~~power follow might follow current~~ may occur depending on the phase angle at which the transient occurs. ~~Power follow~~ Follow current is the current from the connected power source that flows through a protective element, or from any arc in the EUT both during and following the transient.

For semiconductors, the phenomenon may be related to the conduction state of the device at the time the ring wave occurs. Semiconductor parameters that ~~might~~ may be involved, include forward and reverse recovery characteristics and secondary breakdown performance.

Devices most likely to fail in a phase-related way are semiconductors involved in the power input circuitry. Other devices in different areas of the EUT ~~might~~ can also exhibit such failure modes.

5 Test levels

The preferred test levels for the ring wave applicable to power, signal and control ports of the equipment, are given in Table 1. The test level is defined as the voltage of the first peak (maximum or minimum) in the test waveform (Pk_1 in Figure 1).

Different test levels may apply to power, signal and control ports. ~~The level(s) used for signal and control ports shall not differ by more than one level from that used for power supply ports.~~

Table 1 – Test levels for ring wave

Level	Open-circuit test voltage	
	kV	
	Line-to-line	Line-to-ground ^b
1	0,25	0,5
2	0,5	1
3	1	2
4	2	4
X ^a	* Special	* Special

^a "X" can be any level, above, below or in between the others. This level ~~can be given in the product standard~~ shall be specified by product committees and/or equipment specification.

^b For symmetrical interconnection lines the test can be applied to multiple lines simultaneously with respect to ground, i.e. "lines to ground".

~~The applicability of the ring wave test, shall refer to the product specification.~~

~~The test levels from Table 1 should be selected in accordance with the most realistic installation and environmental conditions.~~

~~The immunity tests are correlated with these levels in order to establish a performance level for the environment in which the equipment is expected to operate, taking into account the primary phenomena and the installation practices which determine the classes of the electromagnetic environment.~~

~~The selection of the test levels should be done on the basis of the applicability to a given location or installation.~~

The test levels shall be selected according to the installation conditions; classes of installation are given in Annex C. Annex A gives information on test levels.

The test shall be applied at all test levels in Table 1 up to and including the specified test level (see 8.3).

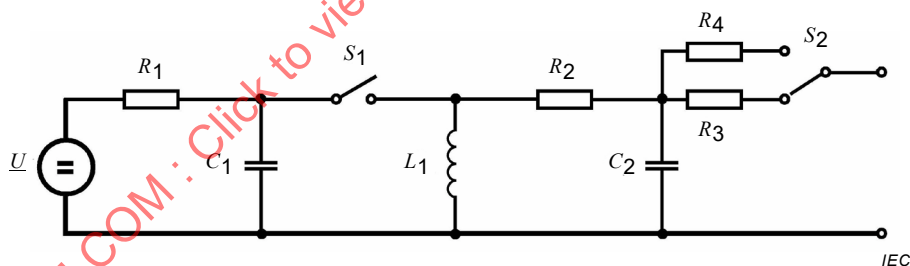
For selection of the test levels for the different interfaces, refer to Annex B.

6 Test equipment instrumentation

6.1 Test Ring wave generator

6.1.1 Ring wave generator circuit

The generator output shall have the capability to operate under short-circuit conditions. A block diagram of a representative ring wave generator is shown in Figure 2.



Key

U :	high-voltage source	R_3 :	30 Ω resistor
C_1 :	energy storage capacitor	R_4 :	12 Ω resistor
C_2 :	filter capacitor	L_1 :	oscillating circuit coil
R_1 :	charging resistor	S_1 :	high-voltage switch
R_2 :	filter resistor	S_2 :	output impedance selector

Figure 2 – Example of schematic circuit of the ring wave generator

6.1.2 Impedance values

Two values of impedance (see R_3 and R_4 in Figure 2) have been selected as follows:

- 12 Ω when testing AC/DC power ports and shielded interconnection lines
- 30 Ω when testing unshielded interconnection lines

~~These values are applicable, respectively, to short and long branch circuits, corresponding to the relative distance of the power supply source from the main distribution network. They represent a technical compromise, because they include the need to test EUT ports normally interfaced with low impedance circuits, according to the values given in IEC 60816. In addition, they cover the requirements to test the transients protection devices, such as the metal oxide varistors, Zener diodes, etc., installed in the EUT.~~

6.1.3 Performance characteristics of the ~~test~~ ring wave generator

A generator with a floating output shall be used.

The ~~test~~ generator is a single-shot ring wave generator with the following characteristics, measured ~~as it is to be applied to the EUT port at the output of the generator. If applied via a coupling/decoupling network, the characteristics are to be as specified at the output of that network.~~

~~The generator output shall be floating. This condition is necessary to test EUT control and signal ports in line-to-line mode. It is not necessary for power ports and line-to-ground mode tests of control and signal ports.~~

~~The generator shall have provisions to prevent the emission of heavy disturbances that may be injected in the power supply network, or may influence the test results.~~

~~Specifications:~~

- voltage rise time (T_1 in Figure 1): 0,5 μ s $\pm$ 30 % (open-circuit condition);
- current rise time (T_1 in Figure 1): ~~≤ 1~~ 0,2 μ s to 1,0 μ s (short-circuit condition);
- voltage oscillation frequency, ~~Note 1~~ (1/T in Figure 1): 100 kHz $\pm$ 10 %;

NOTE 1 Oscillation frequency is defined as the reciprocal of the period between the first and third zero crossings after the initial peak.

- decay ~~ing~~ (Voltage only; see Figure 1)
 - 0,4 < Ratio of Pk_2 to Pk_1 < 1,1
 - 0,4 < Ratio of Pk_3 to Pk_2 < 0,8
 - 0,4 < Ratio of Pk_4 to Pk_3 < 0,8
 - No requirements for ~~other peaks~~ Pk_5 onwards.
- ~~transients' repetition:~~ 1 to 60 transients per minute;
- repetition rate 1/min or faster
- output impedance, ~~Note 2:~~ 12 Ω and 30 Ω $\pm$ 20 % (switchable) see Table 2;

NOTE 2 The output impedance is calculated ~~as~~ from the open-circuit voltage U_{PK1} divided by the short circuit current I_{PK1} .

- ~~open circuit voltage (Pk_1 -value See Figure 1)~~ 250 V to 4 kV ($\pm$ 10 %)
- ~~short circuit current (Pk_1 -value See Figure 1)~~ 333 A $\pm$ 10 % for 12 Ω generator setting; 133 A $\pm$ 10 % for 30 Ω generator setting;
- ~~phase relationship with the power frequency:~~ in a range between 0° to 360° relative to the phase angle of the a.c. line voltage to the equipment under test, with a tolerance of $\pm 10^\circ$
- ~~polarity of the first half period:~~ positive and negative.

- open-circuit voltage U_{Pk1} (see Figure 1) adjustable from 0,25 kV to the required test level
- short-circuit current I_{Pk1} (see Figure 1) see Table 2
- phase shifting in a range between 0° to 360° relative to the phase angle of the AC line voltage to the EUT with a tolerance of $\pm 10^\circ$
- polarity of Pk_1 (see Figure 1) positive and negative

Table 2 – Relationship between peak open-circuit voltage and peak short-circuit current

Open-circuit peak voltage $\pm 10\%$ at generator output	Short-circuit peak current $\pm 10\%$ at 12 Ω generator output	Short-circuit peak current $\pm 10\%$ at 30 Ω generator output
0,25 kV	20,8 A	8,3 A
0,5 kV	41,7 A	16,7 A
1,0 kV	83,3 A	33,3 A
2,0 kV	166,7 A	66,7 A
4,0 kV	333,3 A	133,3 A

The waveform of the ring wave (open-circuit voltage and short-circuit current) with peak points marked, is given in Figure 1. An example of a schematic circuit of the generator is given in Figure 2.

6.1.3 Verification of the characteristics of the test generator

The verification procedure is meant as a guide to insure the correct operation of the test generator, coupling/decoupling networks, and other items making up the test set-up so that the intended waveform is delivered to the EUT.

In order to make it possible to compare the results of different test generators, the most essential characteristics shall be verified.

The characteristics to be verified in accordance with the parameters of 6.1.2 are the following:

- rise time (voltage and current);
- oscillation frequency;
- decaying;
- repetition frequency;
- open-circuit voltage;
- short-circuit current.

The verifications shall be carried out with voltage or current probes (as applicable) and with oscilloscope or other equivalent measurement instrumentation with 20 MHz minimum bandwidth. The waveform characteristics shall be verified at the EUT port of each CDN used for the immunity test, or directly at the output of the test generator if no CDN is to be used. The permissible inaccuracy of the measurements is $\pm 10\%$.

6.1.4 Calibration of the ring wave generator

The test generator characteristics shall be calibrated in order to establish that they meet the requirements of this document. For this purpose the following procedure shall be undertaken.

The generator output shall be connected to a measurement system with a sufficient bandwidth (minimum 20 MHz), voltage and current capability to monitor the characteristics of the waveform.

The characteristics of the generator shall be measured both under open-circuit (load greater than or equal to 10 kΩ) and short-circuit conditions at the same set voltage.

All performance characteristics stated in 6.1.3, with the exception of phase shifting and repetition rate, shall be met at the output of the generator. Phase shifting performance shall be met at the output of the CDN at 0°, 90°, 180° and 270° at one polarity.

6.2 Coupling/decoupling networks ~~specifications~~

~~The coupling/decoupling network (CDN) provides both the ability to apply the test voltage in either line-to-ground or line-to-line mode to the mains, signal and control ports of the EUT (equipment under test), and prevents test voltage from affecting any auxiliary equipment needed to perform the test. The waves shall be within the tolerances of 6.1.2 at the EUT port of the CDN. However, if non-linear coupling devices such as gas arrestors or breakdown avalanche diodes are used, the characteristics of the ring waveform can be changed significantly.~~

~~The specifications, common to the networks for power supply, as well as for the input/output ports, are given below. Additional unique specifications are given in 6.2.1 and 6.2.2.~~

~~The coupling network shall be provided with coupling capability suitable for the selected impedance of the test generator, i.e. 3 μF (minimum).~~

~~The coupling capacitors may be replaced by other types of coupling devices such as arrestors or clamping circuits.~~

~~The coupling/decoupling network shall be provided with a dedicated earth terminal.~~

~~Verification to the specifications of 6.1.2 shall be carried out with an oscilloscope, or equivalent measuring instrument having a minimum bandwidth of 20 MHz.~~

6.2.1 ~~Coupling/decoupling network for a.c./d.c. power supply ports~~

~~The output waveforms from the coupling/decoupling network shall meet the same requirements set forth in 6.1.2 for the test generator itself.~~

~~The a.c. mains voltage drop at the EUT connector of the coupling/decoupling network shall be less than 10 % at the specified current rating of the coupler.~~

~~Specifications:~~

~~The residual surge voltage on the power supply inputs of the decoupling network when the EUT is disconnected shall not exceed 15 % of the applied test voltage or twice the rated peak voltage of the coupling/decoupling network, whichever is higher.~~

- ~~— insulation withstand capability of the coupling devices with the 1,2/50 μs wave: 5 kV;~~
- ~~— current capability: as required for the EUT;~~
- ~~— number of phases: as required for the EUT.~~

~~NOTE Minimum values of line-to-ground and line-to-line mode decoupling may not be sufficient to protect auxiliary equipment being used to facilitate the test.~~

~~6.2.2 Coupling/decoupling network for signal and control ports~~

~~The network has the same specifications as given in 6.2.1 with the exception below:~~

~~The residual surge voltage on the power supply inputs of the decoupling network when the EUT is disconnected shall not exceed 15 % of the applied test voltage or twice the rated peak voltage of the coupling/decoupling network, whichever is higher.~~

~~The minimum decoupling attenuation may not be sufficient to protect auxiliary signal sources, and additional protection devices may be required.~~

~~The network may consist of single units in order to give the possibility of testing input/output ports with single circuits or grouping of circuits (for example, multi-wire with a common).~~

6.2.1 General

Each coupling/decoupling network (CDN) consists of a coupling network and a decoupling network as shown in the examples of Figure 4 through Figure 10.

NOTE The coupling capacitors can be part of the CDN or part of the generator or discrete external components.

The coupling network shall be provided with a coupling capacitor suitable for the selected impedance of the test generator, i.e. $\geq 3 \mu\text{F}$.

On the AC or DC power lines, the decoupling network provides relatively high impedance to the ring wave transient but at the same time allows current to flow to the EUT. This impedance allows the voltage waveform to be developed at the output of the coupling/decoupling network and prevents the ring wave current from flowing back into the AC or DC power supply. High voltage capacitors are used as the coupling element, sized to allow the full waveform durations to be coupled to the EUT. The coupling/decoupling network for the AC or DC power supply shall be designed so that the open-circuit voltage waveform and short-circuit current waveform meet the requirements of Table 3.

For I/O and communication lines, the series impedance of the decoupling network limits the available bandwidth for data transmission. Coupling elements can be capacitors, in cases where the line tolerates the capacitive loading effects, clamping devices or arrestors. When coupling to interconnection lines, the waveforms may be distorted by the coupling mechanisms which are described in 6.2.3.

The coupling/decoupling network for the unshielded interconnection lines shall be designed so that the open-circuit voltage waveform and short-circuit current waveform meet the requirements of Table 5 and Table 7.

Each coupling/decoupling network shall satisfy the requirements of 6.2.2 or 6.2.3 and shall meet the calibration requirements in 6.3. Their use is made according to the flowchart in Figure 3:

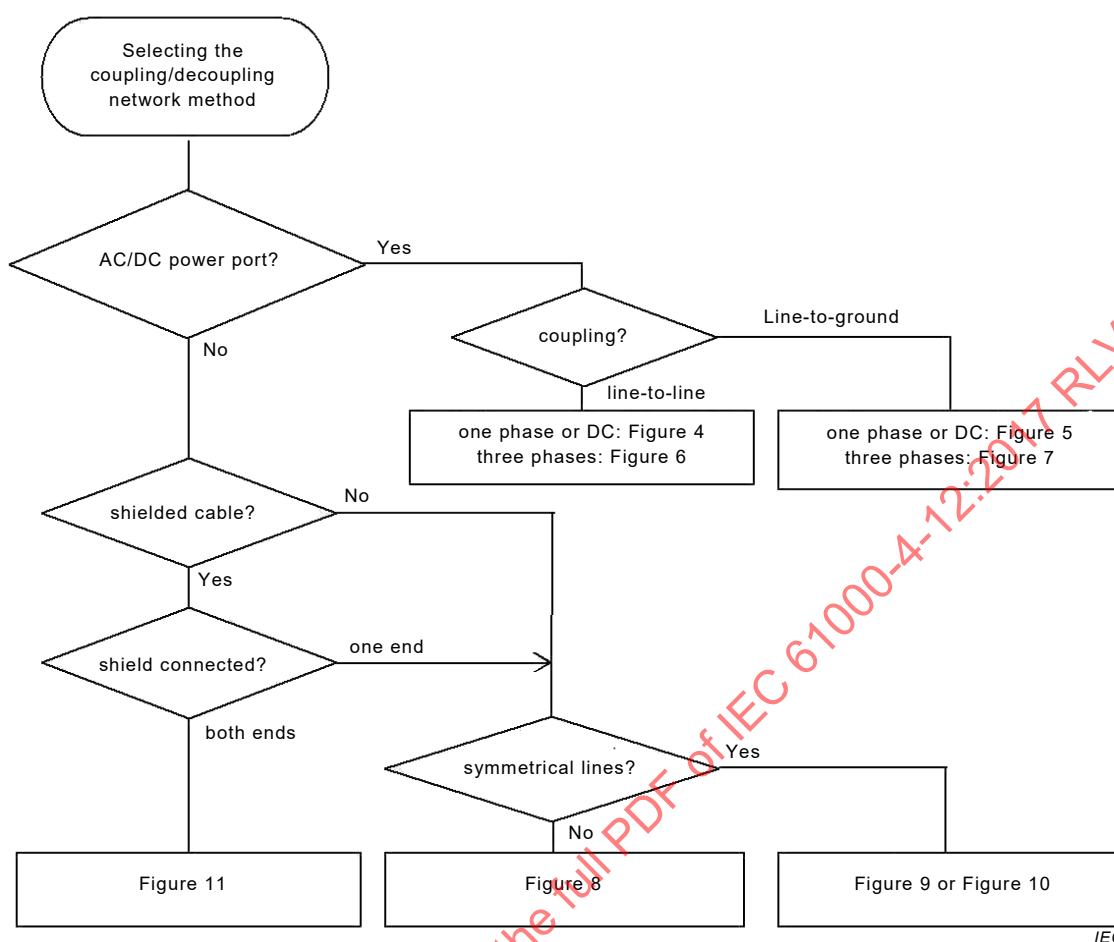


Figure 3 – Selection of coupling/decoupling method

6.2.2 Coupling/decoupling networks for AC/DC power port rated up to 63 A per line

The peak amplitude Pk_1 and rise time shall be verified for voltage under open-circuit conditions and for current under short-circuit conditions, at the EUT port as well as the oscillation period in addition to the voltage under open-circuit conditions. The waveform parameters measured at the EUT port of the CDN are dependent upon the generator source and as such are only valid for the particular generator/CDN combination tested. The CDN shall be connected to a measuring system with a sufficient bandwidth, voltage and current capability to monitor the characteristics of the waveforms.

NOTE The surge and ring wave originate from the same disturbance sources. The ring wave is the outcome of the involved cable layout and the surge protective device (SPD) between the disturbance source and the power outlet. For currents larger than 63 A the cable layout forms usually a part of the EUT and therefore the EUT is tested in accordance with IEC 61000-4-5.

The decoupling inductance shall be selected by the CDN manufacturer so that the voltage drop across the CDN shall not exceed 10 % of the CDN input voltage at the specified current rating, but should not exceed 1,5 mH.

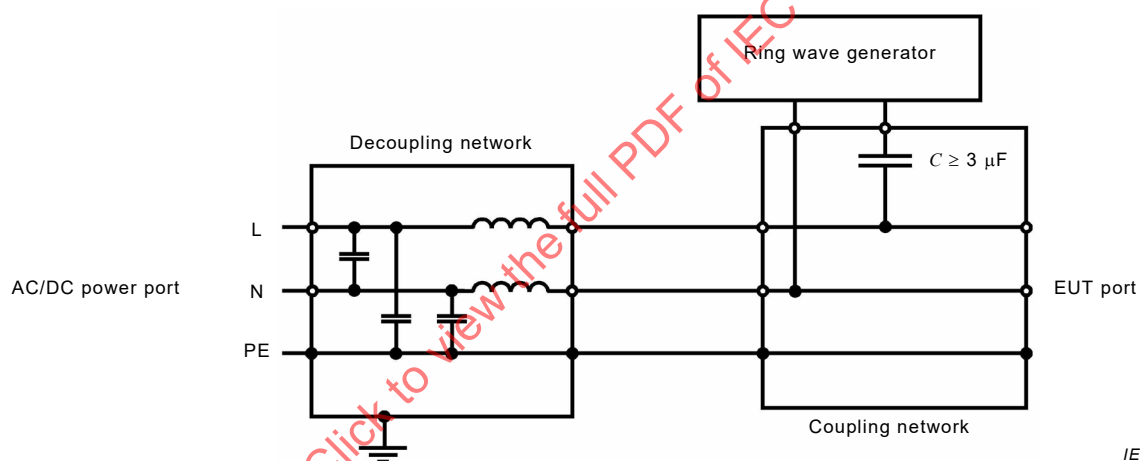
To prevent unwanted voltage drops in the CDN, the value of the decoupling element shall be reduced for CDNs rated at > 16 A. As a consequence, the peak current can vary within the tolerances given in Table 3 below.

Table 3 – Ring wave specification at the EUT power port of the CDN

Ring wave parameter under short-circuit condition	Peak current
Peak current I_{pk1}	
Current rating ≤ 16 A	+10 –10 %
16 A < current rating ≤ 32 A	+10 –10 %
32 A < current rating ≤ 63 A	+10 –25 %
NOTE The current rating is the CDN rating.	

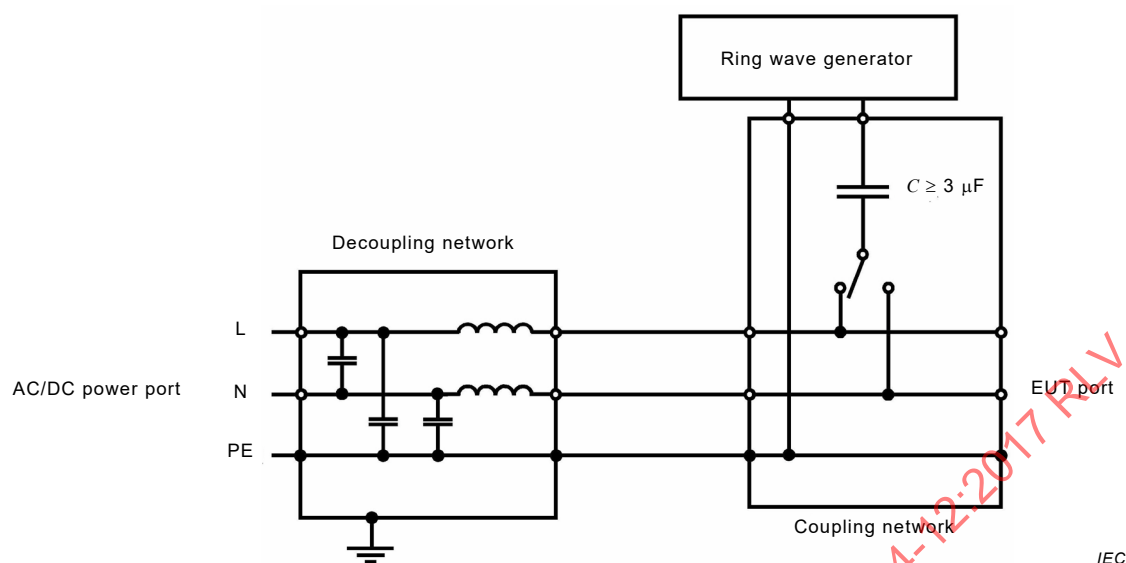
All performance characteristics stated in 6.1.3, with the exception of the repetition rate, shall be met at the output of the CDN. Phase shifting performance shall be met at 0°, 90°, 180° and 270° at one polarity.

The above mentioned characteristics are applicable for single-phase systems (line, neutral, protective earth) and three-phase systems (three-phase wires, neutral and protective earth).



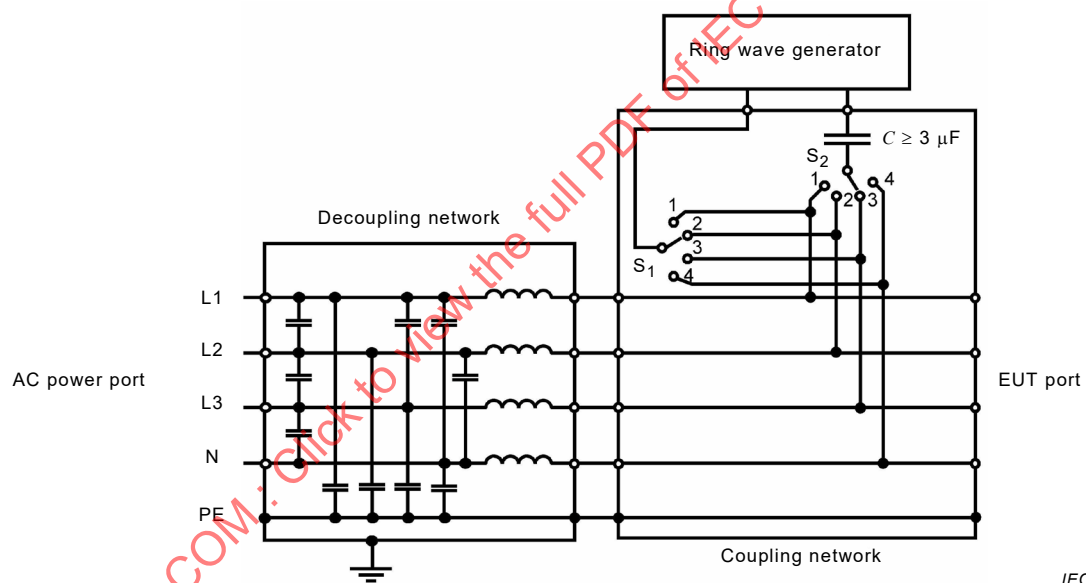
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Figure 4 – Example of coupling network and decoupling network for capacitive coupling on AC/DC lines: line-to-line coupling



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Figure 5 – Example of coupling network and decoupling network for capacitive coupling on AC/DC lines: line-to-ground coupling

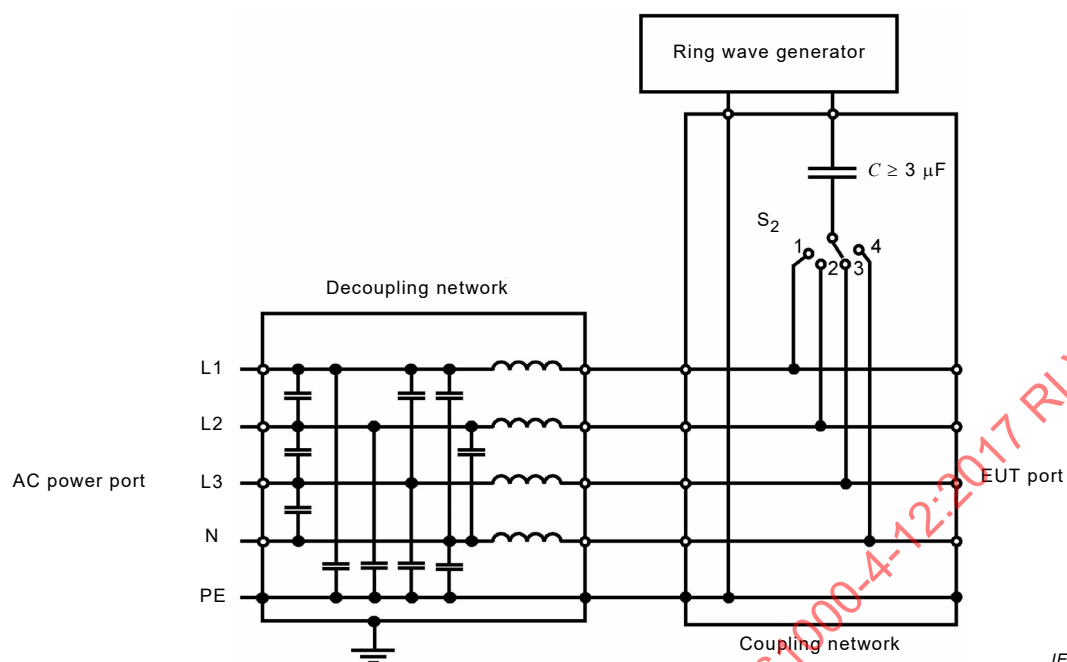


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Switches S_1 and S_2 are used to select individual lines for test.

During testing, the position of switch S_2 is different from the position of switch S_1 .

Figure 6 – Example of coupling network and decoupling network for capacitive coupling on AC lines (three phases): line L3-to-line L2 coupling



Switch S_2 is used to select individual lines for test.

Figure 7 – Example of coupling network and decoupling network for capacitive coupling on AC lines (three phases): line L3-to-ground coupling

6.2.3 Coupling/decoupling networks for interconnection lines

6.2.3.1 General

The coupling method shall be selected as a function of interconnection cable types, the circuits, and the operational conditions supported by the product specification/standard.

Coupling to unshielded lines requires coupling devices (CDs) that ensure sufficient insulation between the interconnection lines and the ring wave generator, but allow efficient transfer of the ring wave impulse.

Any CDs, such as capacitors or gas discharge tubes (GDTs) capable of meeting the coupling and insulation functions may be used.

Coupling using capacitors maintains waveform integrity, but may have filtering effects on fast data transfer.

Avalanche devices like GDTs have a low parasitic capacitance and allow connection to most types of interconnection lines. The breakdown voltage of the coupling device shall be selected to be as low as possible, but higher than the maximum working voltage of the lines to be tested.

All CDNs shall meet the calibration requirements in 6.3.

Current compensated inductors shall be used in the decoupling network if the signal lines are symmetrical.

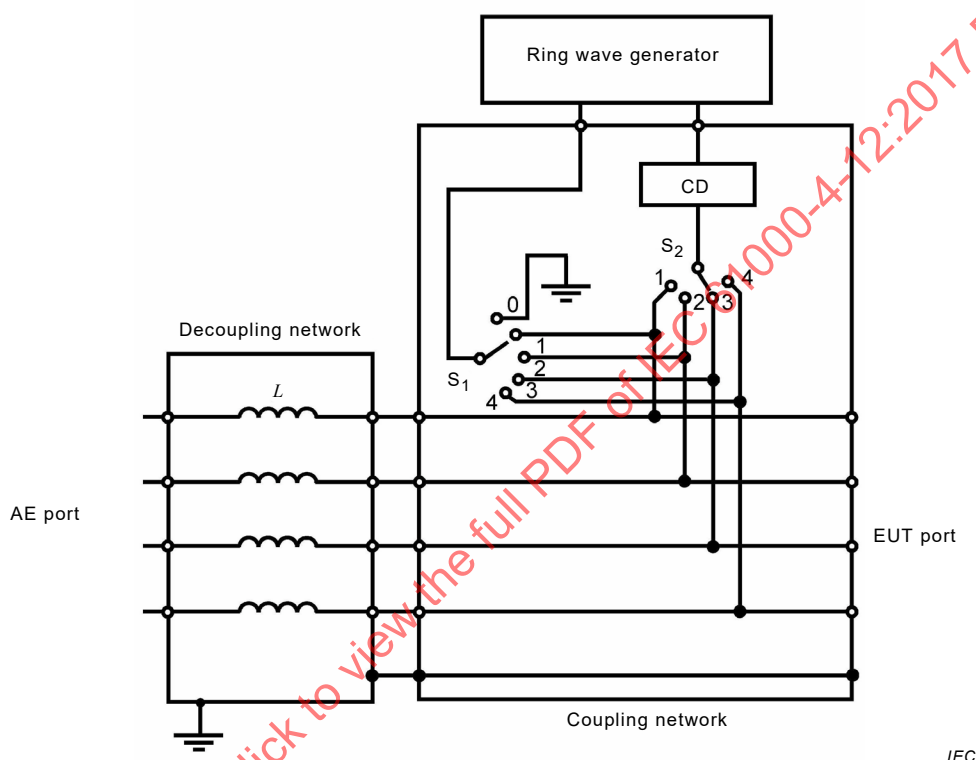
The required decoupling performance on the AE side depends on the application specification and determines the value of the decoupling elements (inductors, resistors, capacitors, GDTs, clamping devices, etc.) to be used. In order to ensure the best possible decoupling

performance and AE protection, a case specific analysis is required for the choice of the decoupling elements.

6.2.3.2 Coupling/decoupling of ring waves to unshielded unsymmetrical interconnection lines

Coupling to unshielded unsymmetrical interconnection lines can be to both line-to-line and line-to-ground. Decoupling is provided with one decoupling choke per line.

An example of a coupling/decoupling network for unshielded unsymmetrical interconnection lines is shown in Figure 8.



- 1) Switch S_1
 - line-to-ground: position 0
 - line-to-line: positions 1 to 4
- 2) Switch S_2 : Positions 1 to 4
 - during testing, the position of switch S_2 is different from the position of switch S_1

NOTE For details of CD: see Table 5.

Figure 8 – Example of coupling network and decoupling network for unshielded unsymmetrical interconnection lines: line-to-line and line-to-ground coupling

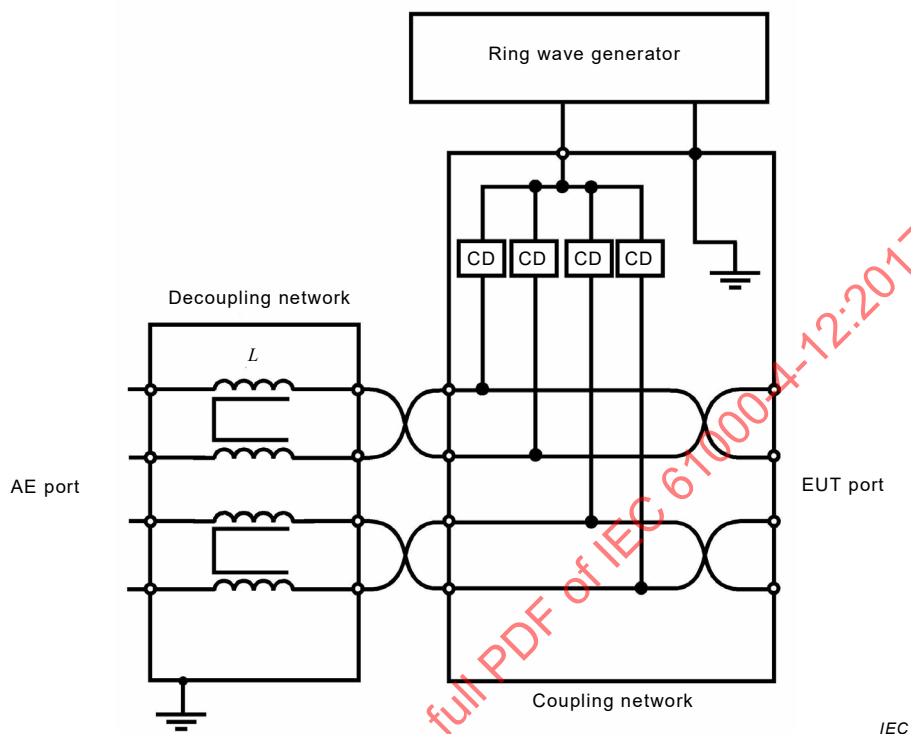
6.2.3.3 Coupling/decoupling of ring waves to unshielded symmetrical interconnection lines

Due to the characteristic nature of unshielded wiring, coupling to symmetrical interconnection lines (twisted pairs) is always in common mode, i.e. coupling between all lines to ground.

The energy transfer from the ring wave generator to the EUT is considered to be a constant which is independent from the number of lines in the cable. The CDN shall be selected to match the number of lines/pairs existing in the cable; however, for cables with more than eight lines/four pairs the pairs shall be split and linked through several eight-line/four-pair CDNs.

Common mode chokes are used for decoupling, allowing fast data transfer and ensuring efficient common mode decoupling.

One example of a coupling/decoupling network for unshielded symmetrical interconnection lines is shown in Figure 9.



L with current compensation may include all four coils or only pairs (as shown in Figure 9) to be effective.

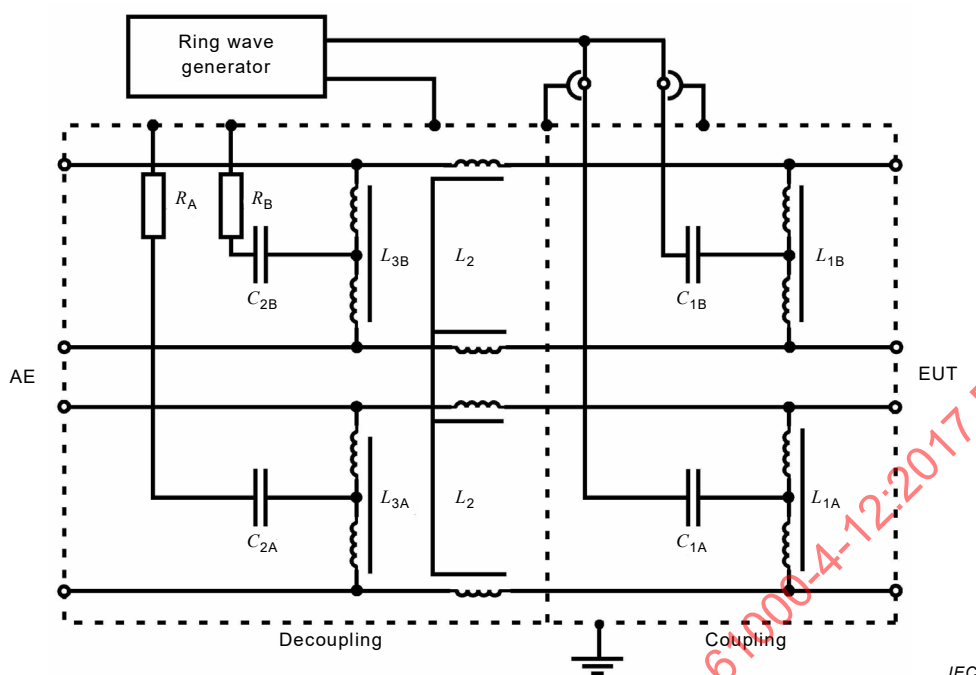
NOTE For details of CD: see Table 7.

Figure 9 – Example of coupling and decoupling network for unshielded symmetrical interconnection lines: lines-to-ground coupling

For high-speed interconnection lines, the examples given in Figure 9 and Figure 10 can be used.

In order to avoid the coupling and decoupling capacitors having a filtering effect on the data transfer, a balanced high frequency design associating the coupling capacitors with coupling chokes is required.

Figure 10 shows an example of a coupling and decoupling network for a two-pair symmetrical interconnection lines. A similar design with four-pair symmetrical interconnection lines allows tests with an interconnection speed up to 1 Gbit/s (Ethernet).



R_A , R_B , C_1 , C_2 , L_1 , L_2 , L_3 : All components are selected so that the specified impulse parameters are met.

NOTE The generator impedance is 30 Ω for two pairs as shown or multiple pairs.

Figure 10 – Example of coupling and decoupling network for unshielded symmetrical interconnection lines: lines-to-ground coupling via capacitors

Where normal functioning cannot be achieved because of the impact of the CDN on the EUT, product committees should specify appropriate operation or that no ring wave test is required.

6.3 Calibration of coupling/decoupling networks

6.3.1 General

In order to compare the test results from different CDNs, the CDN shall be calibrated periodically. For this purpose, the following procedure is necessary to measure the most essential characteristics of the CDN. The waveform parameters measured at the EUT port of the CDN are dependent upon the generator source and as such are only valid for the particular generator/CDN combination tested.

The measuring equipment used for the calibration of the CDN shall satisfy the same requirements applicable to the calibration of the generator (see 6.1.4).

6.3.2 Calibration of CDNs for AC/DC power port rated up to 63 A per line

The characteristics of the CDN shall be measured under open-circuit conditions (load greater than or equal to 10 k Ω) and under short-circuit conditions (less than 0,1 Ω) at the same set voltage.

The residual ring wave voltage measured between coupled lines and ground on the AC/DC power port of the decoupling network with EUT and mains supply not connected shall not exceed 15 % of the maximum applied test voltage or twice the rated peak voltage of the CDN, whichever is higher.

The unwanted ring wave voltage measured between non-coupled lines and ground with EUT and mains supply not connected shall not exceed 15 % of the maximum applied test voltage (open-circuit).

NOTE Due to the structure of the coupling/decoupling network a significant part of the test voltage can appear as a line-to-line voltage during line-to-ground coupling. This voltage can be higher than the corresponding line-to-line test level in the case of a high impedance EUT (see 7.3. for further information).

All performance characteristics stated in 6.2.2, Table 3, shall be met at the EUT port of the CDN with the AC/DC power port left in an open-circuit condition.

6.3.3 Calibration of CDNs for interconnection lines

6.3.3.1 General

It is recommended and sufficient to calibrate the CDNs for interconnection lines in the same configuration (same coupling and decoupling elements fitted) that will be used for testing.

The residual ring wave voltage measured between the coupled lines and ground on the AE side of the CDN, with the EUT and AE equipment disconnected, shall be measured and recorded so that users of the CDN may determine if the protection is sufficient for use with a particular AE.

6.3.3.2 Calibration of CDNs for unsymmetrical interconnection lines

The measurements shall be performed with the impulse applied to one coupling path at a time.

The peak voltage, the rise time, the oscillation period and the ratio between peaks shall be measured for the CDN rated impulse voltage at the EUT port according to Table 4.

The peak current and the rise time shall be measured for the CDN rated impulse voltage at the EUT port according to Table 4.

The inputs of the DN at the AE side shall be short-circuited to PE for the impulse voltage and impulse current measurement at the EUT port.

The residual voltage value depends on the protection requirements of the AE. Therefore no limits are given in this document.

**Table 4 – Summary of calibration process for CDNs
for unsymmetrical interconnection lines**

	Coupling	Measuring	AE side	EUT side
Ring wave voltage at EUT side	Single line to PE	Single line Peak voltage, rise time, voltage oscillation period, ratio between peaks	All lines shorted to PE	Open-circuit
Ring wave current at EUT side	Single line to PE	Single line Peak current, rise time	All lines shorted to PE	Short-circuit
Ring wave voltage at EUT side	Single line-to-line	Single line Peak voltage, rise time, voltage oscillation period, ratio between peaks	All lines shorted to PE	Open-circuit
Ring wave current at EUT side	Single line-to-line	Single line Peak current, rise time	All lines shorted to PE	Short-circuit
Residual voltage on AE side (with protection elements)	Single line to PE	Line to PE at a time Peak voltage	Open-circuit	Open-circuit

The intention of this calibration process is to check the proper function of the components, the saturation of decoupling chokes, the decoupling effect of the DN part, the current capability and the coupling effect of the CN part. The coupling method described in the above paragraphs has an influence on the voltage and current wave forms. The parameters for the calibration are defined in Table 5.

Table 5 – Ring wave waveform specifications at the EUT port of the CDN for unsymmetrical interconnection lines

Coupling method	RWG output voltage ^{a,b,c}	U_{pk1} at CDN EUT port	Voltage rise time T_1	Voltage oscillation period T	I_{pk1} at CDN EUT port	Current rise time T_1
		$\pm 10 \%$	$\pm 30 \%$	$\pm 10 \%$	$\pm 10 \%$	
Line to PE CD $\geq 3 \mu\text{F}$	4 kV	4 kV	0,5 μs	10 μs	133,3 A	0,2 μs to 1,0 μs
Line to PE CD = GDT	4 kV	4 kV	0,5 μs	10 μs	133,3 A	0,2 μs to 1,0 μs
Line-to-line CD $\geq 3 \mu\text{F}$	4 kV	4 kV	0,5 μs	10 μs	133,3 A	0,2 μs to 1,0 μs
Line-to-line CD = GDT	4 kV	4 kV	0,5 μs	10 μs	133,3 A	0,2 μs to 1,0 μs
^a It is recommended to calibrate the CDN at the highest rated impulse voltage, as this will minimise the effects of the switching noise generated by CLDs and GDTs. The value shown in the table is for a generator setting of 4 kV and 30 Ω. In case the CDN is rated for another maximum impulse voltage, the calibration shall be done at this maximum rated impulse voltage. The short-circuit peak current specification shall be adapted accordingly. For example, if the maximum voltage is 1 kV the short-circuit current value shown in this table shall be multiplied by 1/4. ^b Coupling via gas arrestors, clamping or avalanche devices will show some switching noise on the impulse waveform. Working with the highest possible impulse voltage will minimise their impact on measurements; it is recommended to neglect the switching noise for the front times and duration values measurements. ^c The values shown in this table are for a ring wave generator with ideal values. In case the ring wave generator generates parameter values close to the tolerances, the additional tolerances of the CDN may generate values out of the tolerances for the ring wave generator-CDN combination.						

6.3.3.3 Calibration of CDNs for symmetrical interconnection lines

The measurements shall be performed as indicated in Table 6 at the CDN rated impulse voltage. The peak voltage and current, the rise time and the oscillation period shall be measured at the EUT port according to Table 6.

The inputs of the DN at the auxiliary equipment (AE) shall be short-circuited to PE for the voltage and current measurements at the EUT port.

The residual voltage value depends on the protection requirements of the AE. Therefore no limits are given in this document.

NOTE The open-circuit voltage between wires of different pairs can also be measured. A differential voltage between pairs can produce false failures in EUTs that are designed to operate in highly balanced networks. No limit has been proposed for this value as the tolerance is dependent upon the design of the EUT.

**Table 6 – Summary of calibration process for CDNs
for symmetrical interconnection lines**

	Coupling	Measuring	AE side	EUT side
Ring wave voltage at EUT side	Common mode – all lines to PE	All lines shorted together Peak voltage, rise time, voltage oscillation period, ratio between peaks	All lines shorted to PE	Open-circuit – all lines connect together
Ring wave current at EUT side	Common mode – all lines to PE	All lines shorted together Peak current, rise time	All lines shorted to PE	All lines shorted to PE
Residual voltage on AE side (with protection elements)	Common mode – all lines to PE	Each line to PE in turn Peak voltage	Open-circuit	Open-circuit

The intention of this calibration process is to check the proper function of the components, the saturation of decoupling chokes, the decoupling effect of the DN part, the current capability and the coupling effect of the CN part. The coupling method described in the above paragraphs has an influence on the voltage and current wave forms. The parameters for the calibration are defined in Table 7.

**Table 7 – Ring wave waveform specifications at the EUT port
of the CDN for symmetrical interconnection lines**

Coupling method	RWG output voltage ^{a, b, c}	U_{pk1} at CDN EUT port	Voltage rise time T_1	Voltage oscillation period T	I_{pk1} at CDN EUT port	Current rise time T_1
		± 10 %	± 30 %	± 10 %	± 10 %	
Common mode CD ^d	2 kV	2 kV	0,5 µs	10 µs	66,7 A	0,2 µs to 1,0 µs

^a It is recommended to calibrate the CDN at the highest rated impulse voltage, as this will minimise the effects of the switching noise generated by CLDs and GDTs. The value shown in the table is for a generator setting of 2 kV and 30 Ω. In case the CDN is rated for another maximum impulse voltage, the calibration shall be done at this maximum rated impulse voltage. The short-circuit peak current specification shall be adapted accordingly. For example, if the maximum voltage is 4 kV, the short-circuit current value shall be multiplied by 2.

^b Coupling via gas arrestors, clamping or avalanche devices will show some switching noise on the impulse wave. Working with the highest possible impulse voltage will minimise their impact on measurements, however, it is recommended to neglect the switching noise for the peak values measurements.

^c The values shown in this table are for a ring wave 30 Ω generator with ideal values. In case the ring wave generator generates parameter values close to the tolerances, the additional tolerances of the CDN may generate values out of the tolerances for the ring wave generator-CDN combination.

^d The CD can be based upon capacitors, gas arrestors, clamping devices, avalanche devices or any method that allows the wanted data of the EUT to function correctly and at the same time meet the impulse waveform parameters of this table.

7 Test setup

7.1 Test equipment

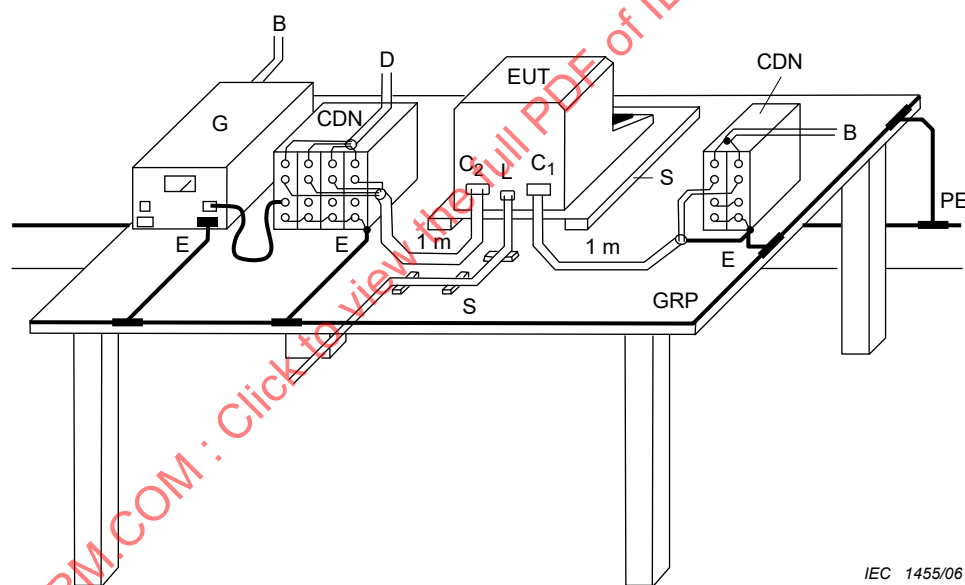
The following equipment is part of the test setup:

- earthing connections, ground (reference) plane (GRP);
- measurement instrumentation;
- equipment under test;
- auxiliary instrumentation equipment when required;
- cables (of specified type and length);
- coupling/decoupling networks;
- test ring wave generator;
- reference ground plane for tests to shielded lines as described in 7.6 and Figure 11.

Examples of test set-up are given in the following figures:

Figure 3 — Example of test set-up for table-top equipment using the ground reference plane;

Figure 4 — Example of test set-up for floor-standing equipment using the ground reference plane.

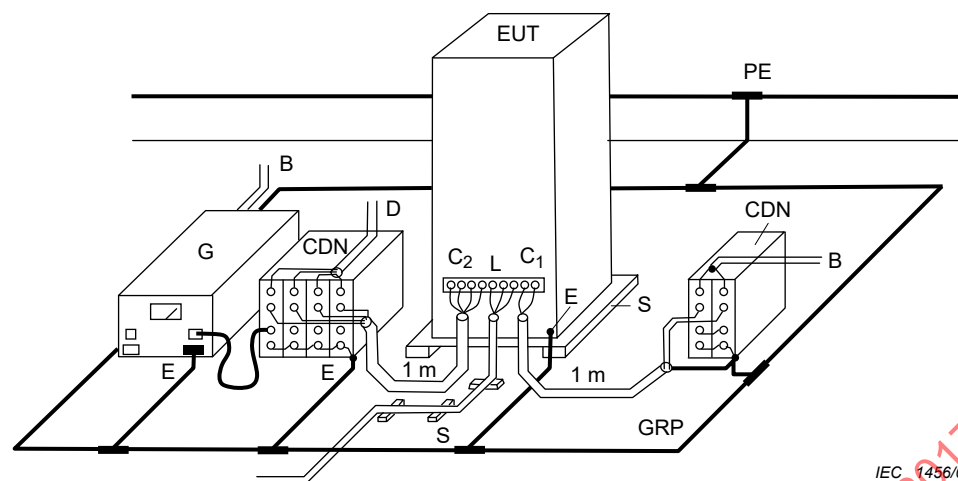


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NOTE — Earth connections should be as short as practically possible.

- | | |
|----------------------------|------------------------------------|
| PE: — protective earth | EUT: — equipment under test |
| B: — power supply source | G: — test generator |
| C1: — power supply port | L: — communication port |
| C2: — input/output port | GRP: — ground reference plane |
| D: — signal/control source | CDN: — coupling/decoupling network |
| E: — earth connection | S: — insulating support |

Figure 3 — Example of test set-up for table-top equipment using the ground reference plane



NOTE Earth connections should be as short as practically possible.

PE: protective earth	EUT: equipment under test
B: power supply source	G: test generator
C1: power supply port	L: communication port
C2: input/output port	GRP: ground reference plane
D: signal/control source	CDN: coupling/decoupling network
E: earth connection	S: insulating support

Figure 4 – Example of test set-up for floor-standing equipment using the ground reference plane

7.1 Test of power supply ports

The test voltage shall be applied through the coupling/decoupling network.

In general, the impedance of the test generator shall be as follows:

- EUT ports connected to major feeders shall be tested with 12 Ω generator impedance;
- EUT ports connected to outlets shall be tested with 30 Ω generator impedance.

Product committees may specify tests using either 12 Ω or 30 Ω generator impedance as required.

7.2 Test of input/output ports

The test voltage shall be applied via the coupling/decoupling network, provided the network is suitable for the operating signal of the EUT ports.

The impedance of the coupling path shall be 12 Ω or 30 Ω .

7.3 Test of communication ports

The test of communication ports of a system (fast operating signals involved) with the application of test voltage via the coupling/decoupling network may cause degradation of the operating signals. In that situation, the test voltage shall be applied between the cabinets of the equipment interconnected (EUT 1 and EUT 2), according to Figure 13. The output impedance of the test generator shall be 12 Ω .

The maximum cable length for this test is 20 m.

~~The signal cables shall be connected according to the product specifications, which shall give information on any protection measure to be taken.~~

~~Whenever EUT 1 is an auxiliary equipment (simulator), a preliminary verification of the immunity of the simulator shall be made; in case of lack of immunity of the simulator, and whenever no provisions can be taken to avoid susceptibility, the test will be carried out with the following objectives:~~

- ~~— the communication port is not damaged;~~
- ~~— the communication is corrupted only during the application of the test voltage;~~
- ~~— the EUT performances, other than ones related to communications, are not affected.~~

7.4 — Earthing connections

~~In performing the tests, the safety earthing requirements of the manufacturer of the EUT and of the test equipment shall be observed.~~

~~In setting up the test configuration, the earthing of the test generator, of the coupling/decoupling network, of EUT and auxiliary equipment may be achieved by using an existing ground reference plane (GRP), or proper earthing connections.~~

7.4.1 — Ground reference plane

~~Where a ground reference plane (GRP) is used, it should be a metal sheet (copper or aluminium) of 0,25 mm minimum thickness. Other metals may be used, but in that case they should have 0,65 mm minimum thickness.~~

~~If the GRP is used, the EUT, auxiliary equipment, and the test equipment shall be placed on the GRP and connected to it. The connections to the GRP shall be as short as possible.~~

~~The minimum size of the GRP is 1 m × 1 m; the final size depends on the dimensions of the EUT. The GRP shall be projected beyond the EUT and its auxiliary equipment by at least 0,1 m on all sides.~~

~~The GRP shall be connected to the safety earth system of the laboratory.~~

7.4.2 — Explicit earthing connections

~~Ring wave tests may be performed without a GRP in order to satisfy national safety regulations. However, repeatability may be effected. When testing is performed without the GRP, it is important to minimize coupling to other conductors (including protective earth conductors) and equipment not intended to be part of the test configuration.~~

~~To accomplish this, protective earth (PE) of each unit (test generator, coupling/decoupling network and EUT) is connected to the PE input terminal of the coupling/decoupling network.~~

~~It is also necessary that the test generator case shall be connected to the PE, but the generator output terminals shall be floating.~~

7.5 — Equipment under test

~~The equipment under test shall be arranged and connected according to the equipment installation specifications.~~

~~The minimum distance between the EUT and all other conductive structures (for example, the walls of a shielded room), except the GRP beneath the EUT, shall be 0,5 m.~~

~~The operating signals for exercising the EUT may be provided by auxiliary equipment, or by a simulator.~~

~~The input and output circuits connected to auxiliary equipment shall be provided with decoupling networks to prevent interference to that equipment.~~

~~The cables supplied or specified by the equipment manufacturer shall be used or, in their absence, unshielded cables shall be adopted, of the type suitable for the signals involved.~~

~~The coupling/decoupling network shall be inserted in the circuits 1 m from the EUT and connected to the GRP.~~

~~The communication lines (data lines) shall be connected to the EUT by the cables given in the technical specification or standard for this application. They shall be elevated 0,1 m above the GRP and be at least 1 m in length.~~

~~Details for table-top and floor-standing equipment are as follows.~~

~~7.5.1 Table-top equipment~~

~~The EUT and cables shall be isolated from the GRP, if used, by an insulating support 0,1 m ± 0,01 m in height.~~

~~An example of the test set-up for table-top equipment is given in Figure 3.~~

~~7.5.2 Floor-standing equipment~~

~~Where a GRP is used, floor-standing equipment shall be placed on a 0,1 m ± 0,01 m thickness insulating support.~~

~~The EUT shall be connected to the earthing system according to the manufacturer's installation specifications.~~

~~The equipment cabinets shall be connected to the GRP via a connection of minimum length starting from the earth terminal of the EUT. No additional connections are allowed.~~

~~An example of the test set-up for floor-standing equipment is given in Figure 4.~~

~~7.6 Coupling/decoupling networks~~

~~If the coupling/decoupling network is a unit separated from the test generator itself, the test generator shall be placed close to the coupling/decoupling network and connected to the latter through a line no longer than 1 m in length. The coupling/decoupling networks shall be connected to the GRP, where used, through a connection as short as possible.~~

~~For an EUT that is not supplied with a mains power cable, a 1 m mains cable shall be used. If a mains cable longer than 1 m is supplied with the EUT, the excess length of the cable shall be gathered into a flat coil with 0,2 m diameter and situated at a distance of 0,1 m above the GRP.~~

- ~~• EUT supplied with non-detachable molded cable~~

~~It shall be tested with the actual length provided.~~

- ~~• EUT supplied with detachable cable, molded at both ends and specified in the manufacturer's manual~~

~~It shall be tested with the specified cable. However, if the manufacturer specifies more than one length of pre-molded cable, then the shortest length shall be used for testing.~~

7.2 Verification of the test instrumentation

The purpose of verification is to ensure that the test setup is operating correctly. The test setup includes:

- the ring wave generator;
- the CDN;
- the interconnection cables of the test equipment.

To verify that the system is functioning correctly, the following signal should be checked:

- ring wave present at the output terminal of the CDN.

It is sufficient to verify that the ring wave is present at any level by using suitable measuring equipment (e.g. oscilloscope) without an EUT connected to the system.

NOTE Test laboratories can define an internal control reference value assigned to this verification procedure.

7.3 Test setup for ring waves applied to EUT power ports

The ring wave shall be applied to the EUT power supply terminals via the capacitive coupling network (see Figure 4, Figure 5, Figure 6 and Figure 7). Decoupling networks are required in order to avoid possible adverse effects on equipment not under test that may be powered by the same lines and to provide sufficient decoupling impedance to the ring wave so that the specified wave may be applied on the lines under test.

The selection of the CDN specification from Table 3 shall be made to match the current rating of the EUT (for example: an EUT rated at 5 A shall be tested using a CDN fulfilling the specifications of a 16 A rated CDN). Any higher current rated CDN can be used if it meets the specification requirements in Table 3 for the relevant lower current rating of the EUT (for example: a CDN rated 63 A can be used for testing an EUT rated at 5 A, if it meets the specification requirements of a 16 A rated CDN).

If not otherwise specified the power cord between the EUT and the coupling network shall not exceed 2 m in length.

For the purpose of generating the specifications within this document, power ports have been considered to be those ports directly connected to either an AC mains supply or a DC mains supply (distribution network).

Product committees may decide that power ports not connected to distribution networks require testing according to this document using a CDN defined in 6.3.3.

DC mains supply ring wave testing is applied between the lines (e.g. 0 V to -48 V) and between each line in turn and ground (e.g. 0 V to ground and -48 V to ground).

No line-to-ground ring waves are applied for double-insulated products (i.e. products without any dedicated earth terminal).

Product committees may decide if line-to-ground ring wave testing is applicable to double-insulated products with earthed connections other than PE.

7.4 Test setup for ring waves applied to unshielded unsymmetrical interconnection lines

The CDN shall not influence the specified functional conditions of the circuits to be tested.

An example of a coupling network is given in Figure 8.

If not otherwise specified, the interconnection line between the EUT and the coupling network shall not exceed 2 m in length.

No line-to-ground ring waves are applied for double-insulated products (i.e. products without any dedicated earth terminal).

7.5 Test setup for ring waves applied to unshielded symmetrical interconnection lines

Examples of coupling networks for symmetrical interconnection lines are given in Figure 9 and Figure 10.

NOTE If coupling arrestors are used, test levels below the ignition point of the coupling arrestor (the ignition point is about 300 V for a gas arrestor with a rated voltage of 90 V) cannot be specified.

If not otherwise specified the interconnection line between the EUT and the coupling network shall not exceed 2 m in length.

For ring wave testing to high speed interconnection lines, no ring wave test shall be applied when normal functioning cannot be achieved because of the impact of the CDN on the EUT.

No line-to-ground ring waves are applied for double-insulated products (i.e. products without any dedicated earth terminal).

7.6 Test setup for ring waves applied to shielded lines

The EUT is isolated from ground and the ring wave is applied to its metallic enclosure; the termination (or auxiliary equipment) at the port(s) under test is grounded. This test applies to equipment with one or more shielded cables (see Figure 11).

NOTE 1 The reference ground plane mentioned in Figure 11 represents a low impedance reference. A dedicated cable or a metal plate can be used.

All connections to the EUT other than the port(s) under test shall be isolated from ground by suitable means such as safety isolating transformers or a suitable decoupling network.

No line-to-ground ring waves are applied for double-insulated products (i.e. products without any dedicated earth terminal).

The length of the cable between the port(s) under test and the device attached to the other end of the cable (AE in Figure 11) shall be:

- 20 m (preferred length), or
- the shortest length over 10 m, where the manufacturer provides pre-assembled cables used in actual installations.

No test shall be required for cables which according to the manufacturer's specification are ≤ 10 m.

The cable between the EUT and the AE shall be non-inductively bundled or wound as a bifilar coil and shall be placed on an insulated support.

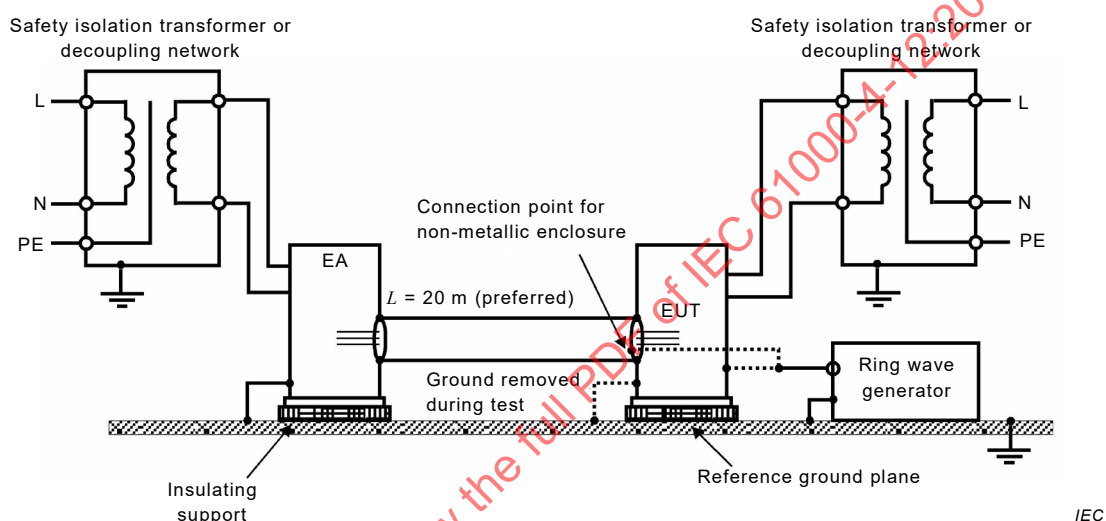
Rules for application of the ring wave to shielded lines:

- a) Shields grounded at both ends:
 - the test shall be carried out according to Figure 11.
- b) Shields grounded at one end:
 - the test shall be carried out according to 7.4 or 7.5 (see Figure 3) because the shield does not provide any protection against ring waves induced by magnetic fields.

NOTE 2 In this case, ring wave testing is not applied to the shield.

For EUTs which do not have metallic enclosures, the ring wave is applied directly to the shielded cable at the EUT side.

Ring wave tests do not apply to antenna ports (see Table B.2).



It is permissible for the power to the EUT and/or the AE to be provided via a decoupling network, rather than via the isolating transformer shown. In this case, the EUT's protective earth connection should not be connected to the decoupling network.

DC supplied EUT and/or AE should be powered through the decoupling networks.

Where it is necessary to isolate the AE equipment from the ring wave, the ground connection on the AE side of the cable under test may be achieved by connecting directly to the connector shield rather than the AE chassis. Where further insulation is required and the cable may be extended without impacting the integrity of the shield (e.g. using a coaxial barrel connector or a shielded Ethernet cable coupler) the connection to ground may be made to the shield of the extension coupler. In this case the length of the cable is measured between the EUT and the coupler and not between the EUT and AE. The cable length between the coupler and AE is not critical.

Figure 11 – Example of test setup for ring waves applied to shielded lines

7.7 Protective earth connection

Ring wave tests may be performed without an RGP in order to satisfy national safety regulations. However, repeatability may be affected. When testing is performed without the RGP, it is important to minimise coupling to other conductors (including protective earth conductors) and equipment not intended to be part of the test configuration.

To accomplish this, protective earth (PE) of each unit (test generator, coupling/decoupling network and EUT) is connected to the PE input terminal of the coupling/decoupling network.

It is also necessary that the test generator case shall be connected to the PE, but the generator output terminals shall be floating.

8 Test procedure

8.1 General

~~The performance of the test equipment shall be checked prior to the test. This check can usually be limited to the existence of the ring wave at the output of the coupling/decoupling network.~~

The test procedure includes:

- the ~~preliminary~~ verification of the ~~correct operation of the equipment~~ test instrumentation according to 7.2;
- the ~~verification~~ establishment of the laboratory reference conditions;
- the confirmation of the correct operation of the EUT;
- the execution of the test;
- the evaluation of the test results (see Clause 9).

~~If not otherwise specified in the product standard, a minimum of five positive and five negative transients shall be applied at a maximum rate of 1/s, depending on the generator impedance, EUT and other transient protectors involved in the test.~~

~~Product committees shall define the impedance of the test generator to be used for the different EUT ports and the time interval between each transient.~~

~~Information on the maximum repetition rate is given in 4.2. Other repetition rates or limits may be provided by the product standard or product specification.~~

8.2 Laboratory reference conditions

~~In order to minimize the impact of environmental parameters on test results, the tests shall be carried out in the climatic and electromagnetic reference conditions as specified in 8.1.1 and 8.1.2.~~

8.2.1 Climatic conditions

Unless otherwise specified by the committee responsible for the generic or product standard, the climatic conditions in the laboratory shall be within any limits specified for the operation of the EUT and the test equipment by their respective manufacturers.

Tests shall not be performed if the relative humidity is so high as to cause condensation on the EUT or the test equipment.

~~NOTE – Where it is considered that there is sufficient evidence to demonstrate that the effects of the phenomenon covered by this standard are influenced by climatic conditions, this should be brought to the attention of the committee responsible for this standard.~~

8.2.2 Electromagnetic conditions

The electromagnetic conditions of the laboratory shall be such as to guarantee the correct operation of the EUT so as not to influence the test results.

8.3 Execution of the test

~~The test shall be carried out on the basis of a test plan, including verification of the performances of the EUT, as defined in the product standard, or in its absence, by the technical specification.~~

~~The EUT shall be in the normal operating conditions.~~

Verification shall be performed. It is preferable to perform the verification prior to the test (see 7.2).

The test shall be performed according to a test plan which shall specify the test setup, including:

- ~~— type of test that will be carried out;~~
- ~~— polarity of the test voltage (both polarities are mandatory);~~
- ~~— number of applications of the test voltage;~~
- ~~— duration of the test;~~
- ~~— mode of application of the test voltage (line-to-ground, line-to-line, between cabinets);~~
- ~~— sequence of application of the test voltage to the EUT ports;~~
- ~~— synchronization angle and phase for testing power supply (only for ring wave);~~
- ~~— auxiliary equipment.~~
- test level;
- number of impulses (for each coupling path):
number of ring wave impulses unless otherwise specified by the relevant standard:
 - for DC power ports and interconnection lines five positive and five negative ring wave impulses;
 - for AC power ports five positive and five negative impulses each at 0°, 90°, 180° and at 270°;
- time between successive impulses: 1 min or less;
- representative operating conditions of the EUT;
- EUT ports to be tested;
- test generator and the internal impedance selected for each test;
- applied test levels.

~~The power supply, signal and other functional electrical quantities shall be applied within their rated range. If the actual operating signal sources are not available, they may be simulated. Preliminary verification of equipment performances shall be carried out on the completed test set up before applying the test voltage.~~

~~The test voltage shall be applied to the EUT.~~

~~The EUT shall be verified according to the product standard or, in its absence, by the technical specifications, which will specify the applicability of the ring wave.~~

~~Under no circumstances shall the test level, the impedance of the generator and repetition rate exceed the product specification.~~

~~a) Line-to-ground test~~

- ~~— The test voltage shall be applied, through the coupling network, between each circuit and earth (GRP).~~
- ~~— One of the terminals of the test generator shall be connected to earth (GRP). The other terminal of the generator shall be connected through a single line to each input terminal of the coupling network in turn.~~
- ~~— Examples of the application of the prescriptions related to the different types of EUT ports are given in the following figures:~~

- ~~Figure 6 AC/DC power supply port, single phase, line-to-ground test;~~
- ~~Figure 8 Example of test setup for capacitive coupling on a.c. lines (3-phase); line L3 to ground coupling;~~
- ~~Figure 9 Example of test setup for unshielded unsymmetrical interconnection lines; line-to-line and line-to-ground coupling via capacitors;~~
- ~~Figure 10 Example of test setup for unshielded unsymmetrical interconnection lines; line-to-line and line-to-ground coupling via arrestors;~~
- ~~Figure 11 Example of test setup for unshielded unsymmetrical interconnection lines; line-to-line and line-to-ground coupling via a clamping circuit;~~
- ~~Figure 12 Example of test setup for unshielded symmetrical interconnection lines (communication lines); lines-to-ground coupling via arrestors.~~

b) Line-to-line test

- ~~The test voltage shall be applied, through the coupling network, between each representative combination of the terminals of the circuit under test.~~
- ~~The output of the test generator shall be floating.~~
- ~~Examples of the application of the prescriptions related to the different types of EUT ports are given in the following figures:~~
 - ~~Figure 5 AC/DC power supply port, single phase, line-to-line test;~~
 - ~~Figure 7 Example of test setup for capacitive coupling on a.c. lines (3-phases); line L3 to line L1 coupling;~~
 - ~~Figure 9 Example of test setup for unshielded unsymmetrical interconnection lines; line-to-line and line-to-ground coupling via capacitors;~~
 - ~~Figure 10 Example of test setup for unshielded unsymmetrical interconnection lines; line-to-line and line-to-ground coupling via arrestors;~~
 - ~~Figure 11 Example of test setup for unshielded unsymmetrical interconnection lines; line-to-line and line-to-ground coupling via a clamping circuit.~~

Power ports (AC or DC) can be input ports or output ports.

Ring waves to output ports are recommended in applications where ring waves are likely to enter the EUT via those output ports (e.g. switching of loads with large power consumption).

When testing three-phase systems, the synchronization of phase angles shall be taken from the same line under test, for example when applying ring wave impulses between L2 and L3, the phase angle synchronization shall be the voltage between L2 and L3.

No synchronization is applied in case of absence of mains supply voltage between the coupled lines, for example between N and PE in TN-S power distribution systems. In this case, five positive impulses and five negative impulses shall be applied.

Ring waves to low voltage DC input/output ports (≤ 60 V) are not applied when secondary circuits (isolated from the AC mains) are not subject to transient overvoltages (i.e. reliably-grounded, capacitively-filtered DC secondary circuits where the peak-to-peak ripple is less than 10 % of the DC component).

NOTE 1 In the case of several identical circuits, representative tests on a selected number of circuits can be sufficient.

If testing done at rates faster than one per minute causes failures and tests done at one per minute do not, the test done at one per minute prevails.

NOTE 2 Product committees can select different phase angles and either increase or reduce the number of ring waves per phase if appropriate for their products.

NOTE 3 Most protectors in common use have limited average power capabilities even though their peak power or peak energy handling capabilities can deal with high currents. Therefore, the time between two ring waves depends on the built-in protection devices of the EUT.

NOTE 4 Further information on the application of the tests is given in Clause C.2.

When testing line-to-ground, the lines are tested individually in sequence, if there is no other specification.

The test procedure shall also consider the non-linear current-voltage characteristics of the equipment under test. Therefore all lower test levels (see Table 1) including the selected test level shall be tested.

9 Evaluation of test results

The test results shall be classified in terms of the loss of function or degradation of performance of the equipment under test, relative to a performance level defined by its manufacturer or the requestor of the test, or agreed between the manufacturer and the purchaser of the product. The recommended classification is as follows:

- a) normal performance within limits specified by the manufacturer, requestor or purchaser;
- b) temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention;
- c) temporary loss of function or degradation of performance, the correction of which requires operator intervention;
- d) loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.

The manufacturer's specification may define effects on the EUT which may be considered insignificant, and therefore acceptable.

This classification may be used as a guide in formulating performance criteria, by committees responsible for generic, product and product-family standards, or as a framework for the agreement on performance criteria between the manufacturer and the purchaser, for example where no suitable generic, product or product-family standard exists.

10 Test report

The test report shall contain all the information necessary to reproduce the test. In particular, the following shall be recorded:

- the items specified in the test plan required in Clause 8 of this document;
- identification of the EUT and any associated equipment, for example brand name, product type, serial number;
- identification of the test equipment, for example brand name, product type, serial number;
- any special environmental conditions in which the test was performed, for example shielded enclosure;
- any specific conditions necessary to enable the test to be performed;
- performance level defined by the manufacturer, requestor or purchaser;
- performance criterion specified in the generic, product or product-family standard;
- any effects on the EUT observed during or after the application of the test disturbance, and the duration for which these effects persist;

- the rationale for the pass/fail decision (based on the performance criterion specified in the generic, product or product-family standard, or agreed between the manufacturer and the purchaser);
- any specific conditions of use, for example cable length or type, shielding or grounding, or EUT operating conditions, which are required to achieve compliance;
- test configuration (hardware) including the coupling method used;
- test configuration (software).

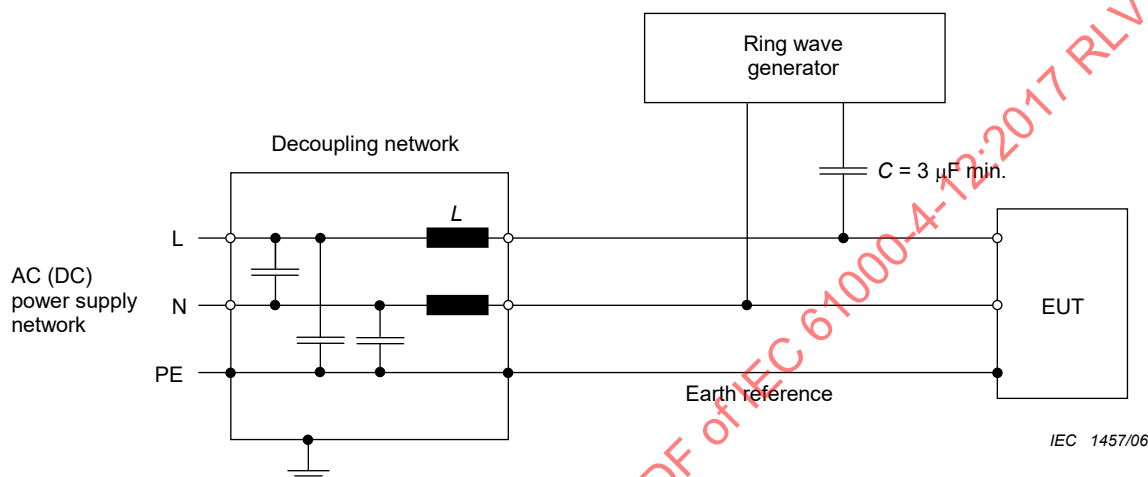


Figure 5 – AC/DC power supply port, single phase, line-to-line test

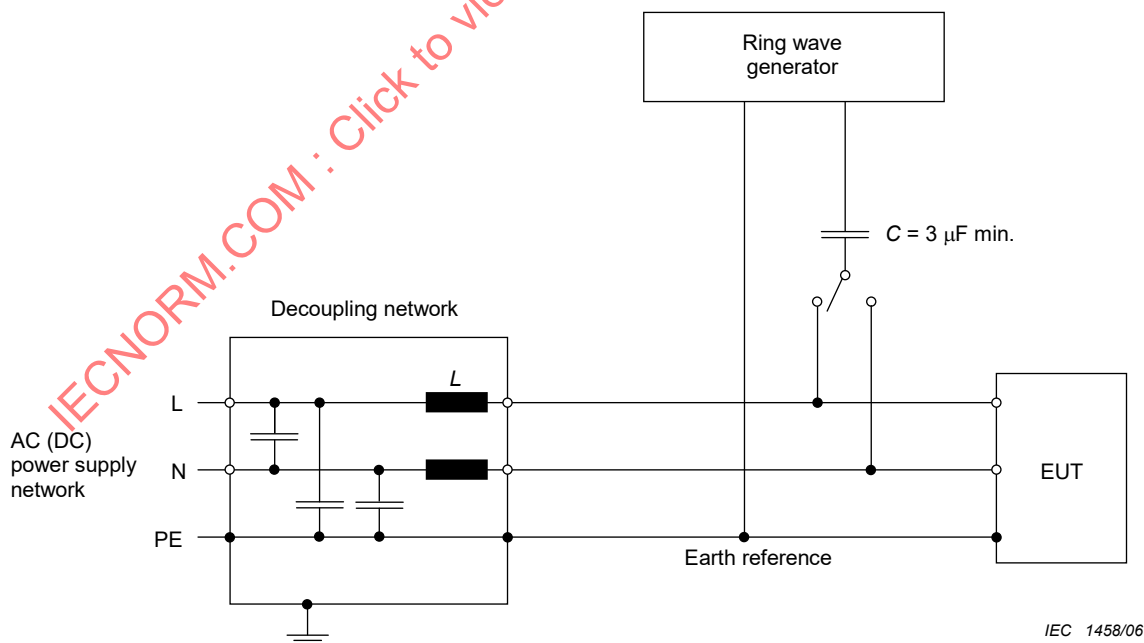
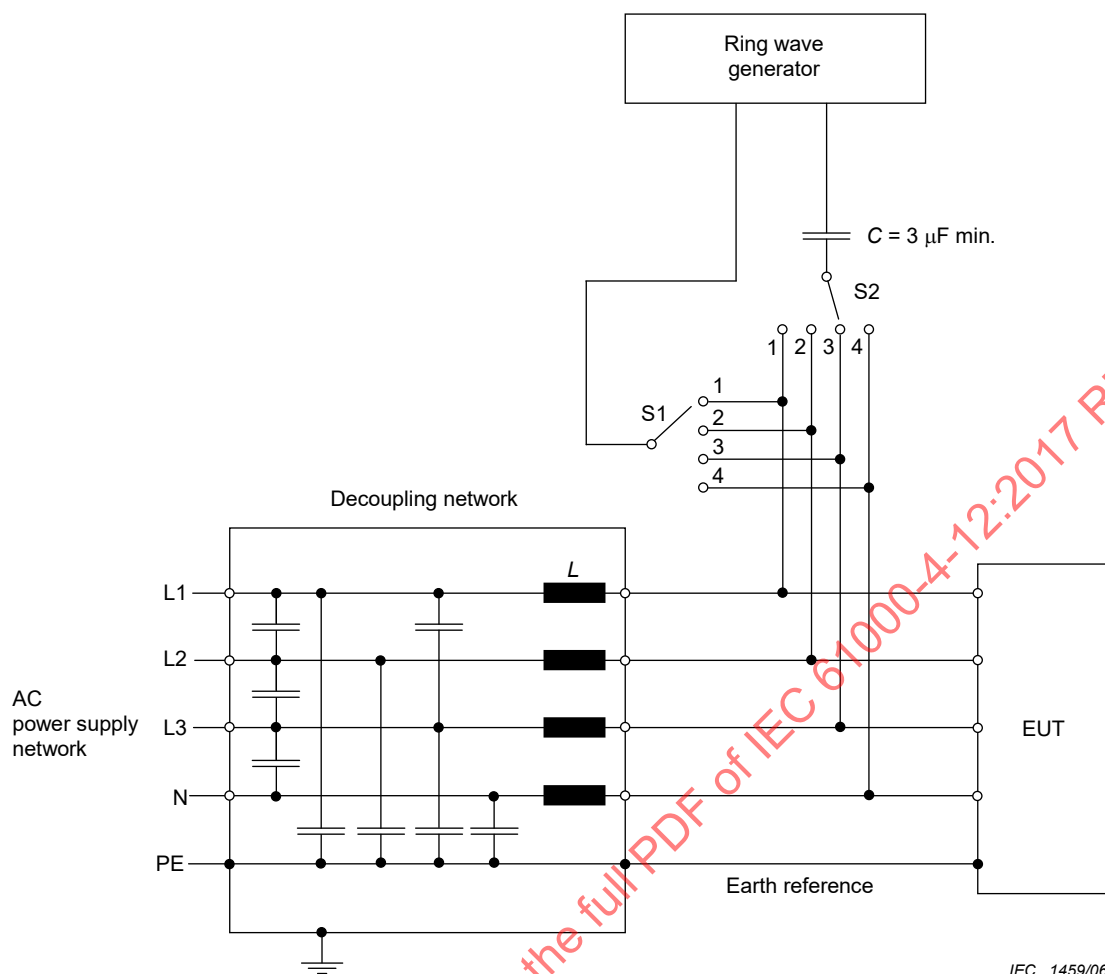
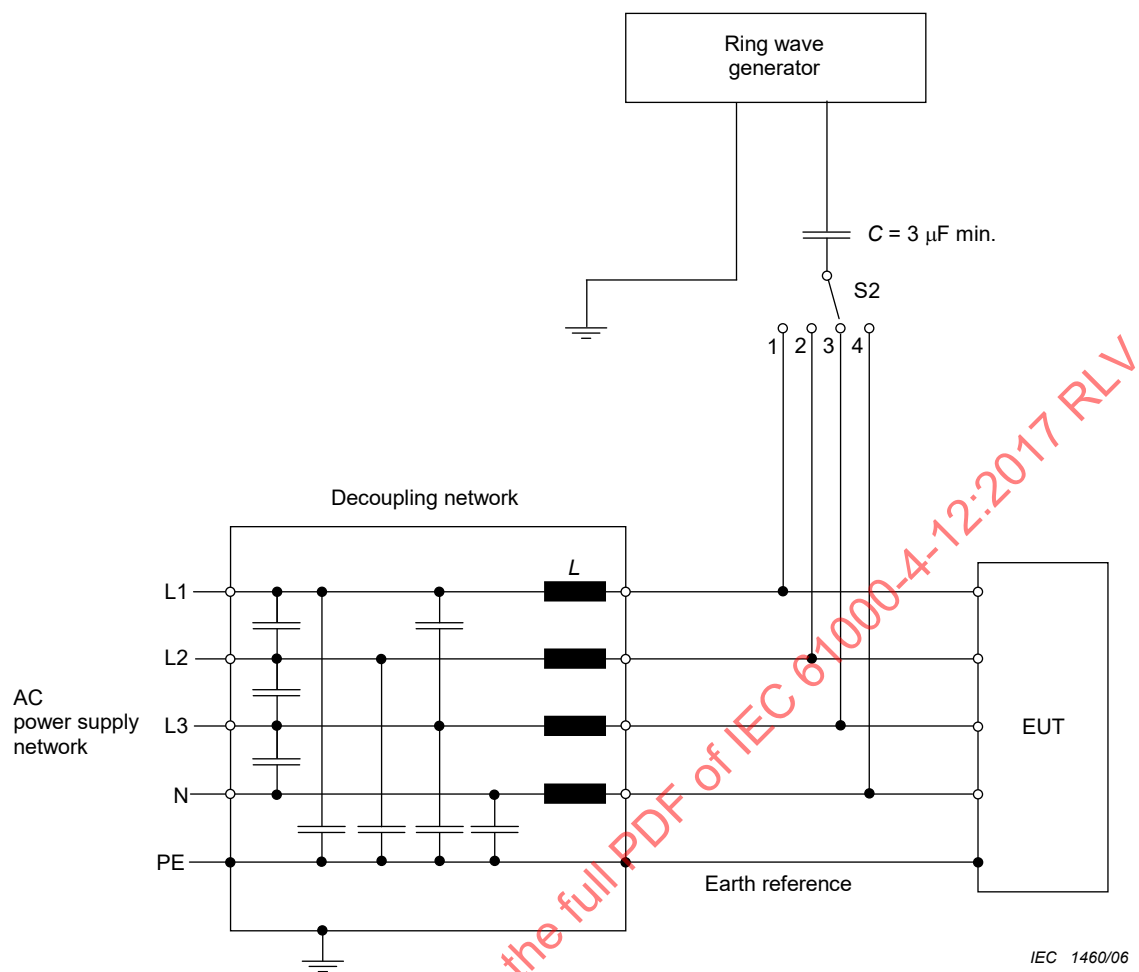


Figure 6 – AC/DC power supply port, single phase, line-to-ground test



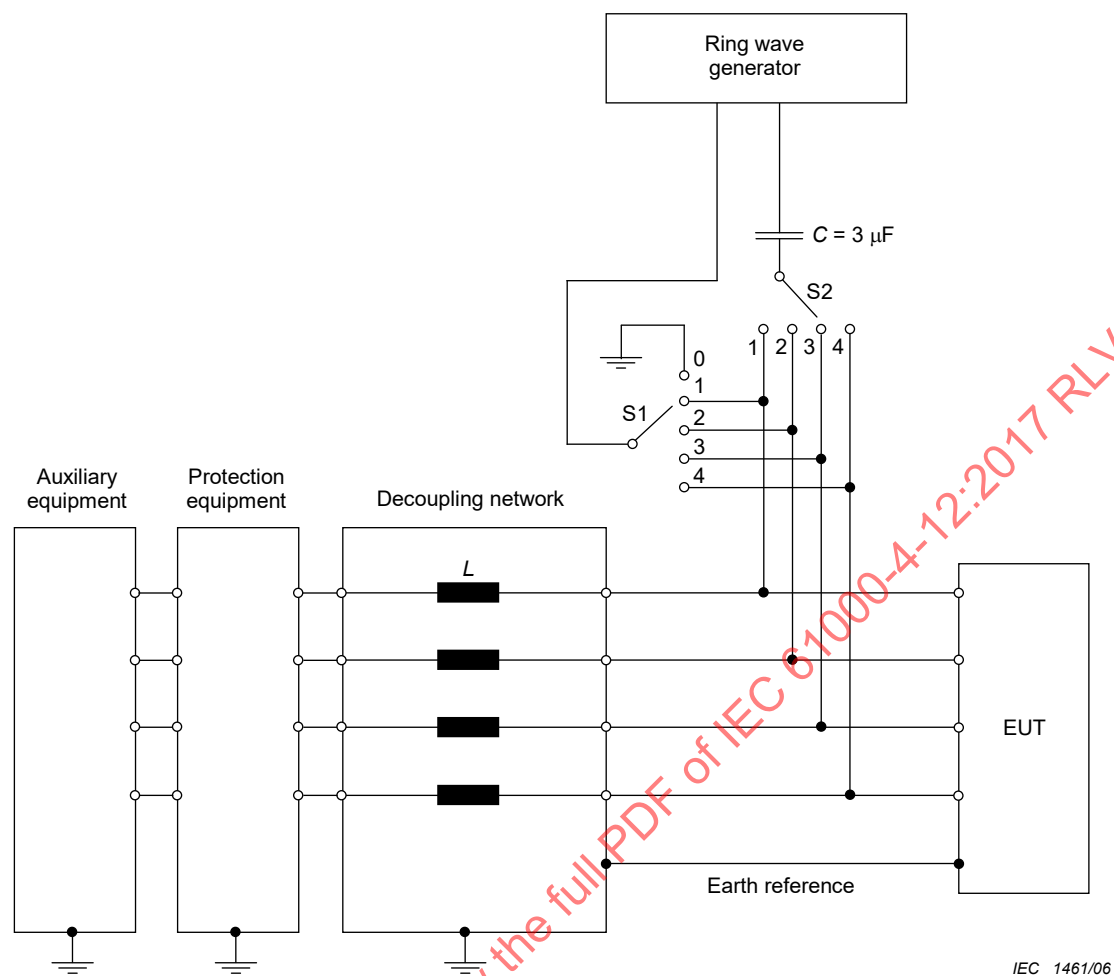
- 1) ——— Switch S1
 ——— line to line: positions 1 to 4
 2) ——— Switch S2
 ——— during the test positions 1 to 4, but not in the same position with switch S1

Figure 7 – Example of test setup for capacitive coupling on a.c. lines (3 phases) – line L3 to line L1 coupling



Switch S2 is used to select individual lines for test.

Figure 8 – Example of test setup for capacitive coupling on a.c. lines (3 phases) – line L3 to ground coupling

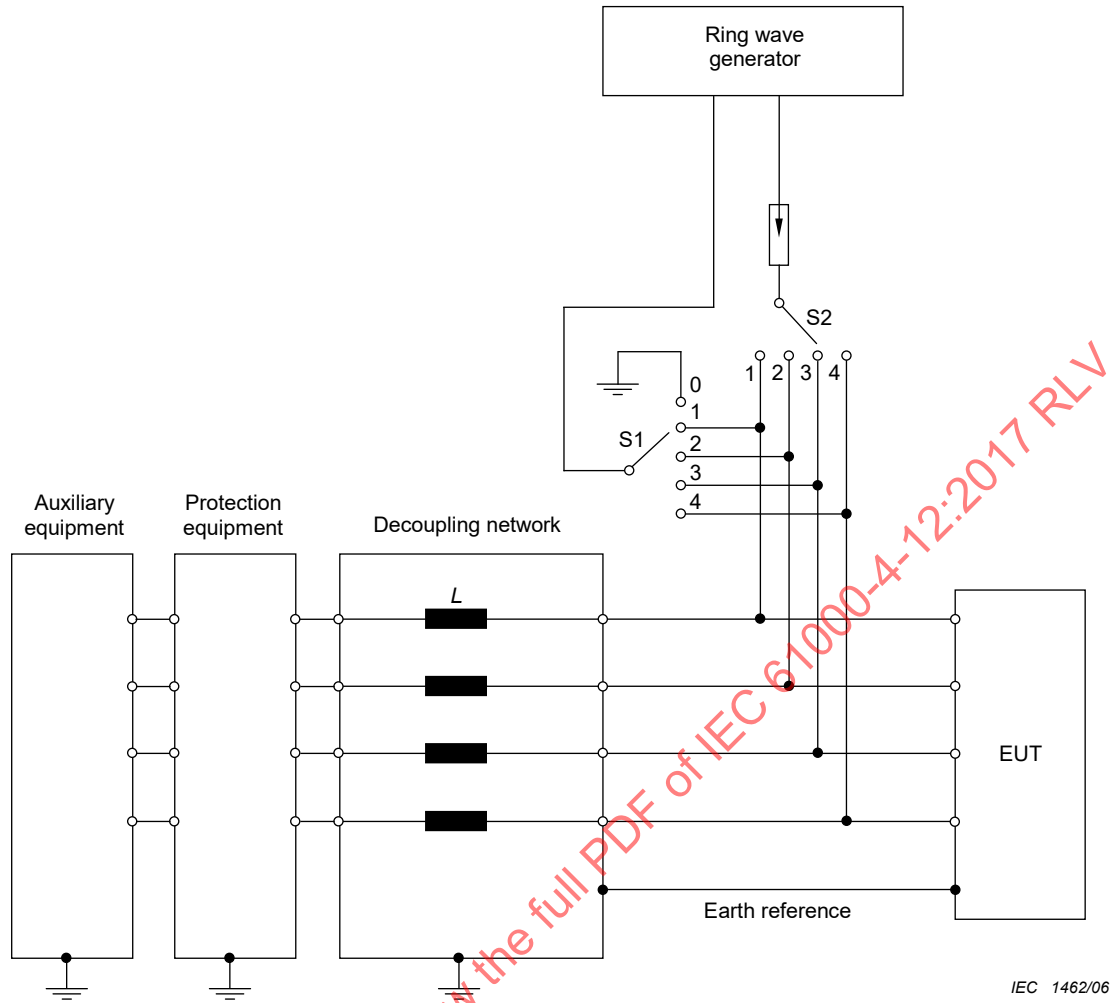


IEC 1461/06

- 1) — Switch $S1$
 — line to ground: position 0
 — line to line: positions 1 to 4
 2) — Switch $S2$

— during the test positions 1 to 4, but not in the same position with switch $S1$

Figure 9 — Example of test setup for unshielded unsymmetrical interconnection lines — line to line and line to ground coupling via capacitors



1) — Switch S1

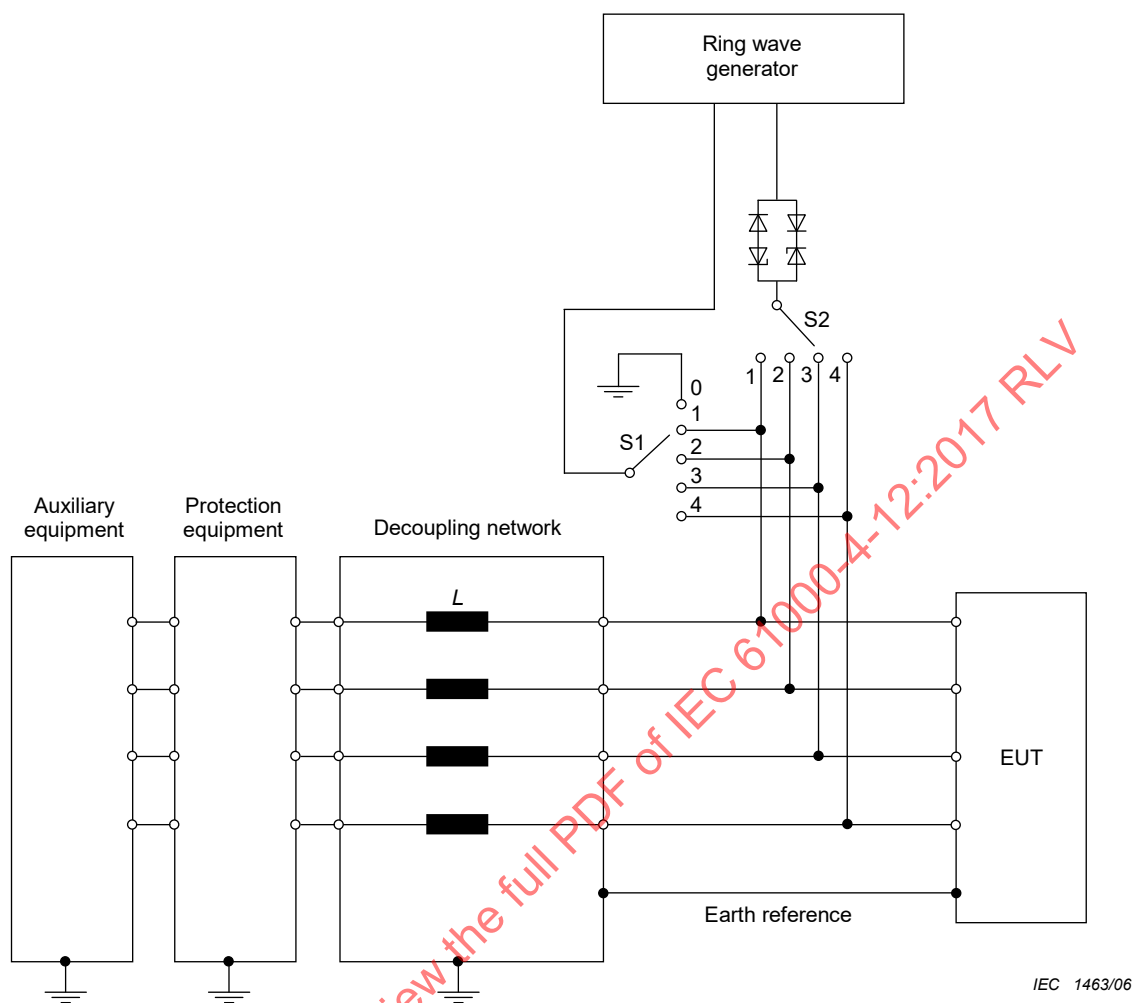
— line to ground: position 0

— line to line: positions 1 to 4

2) — Switch S2

— during the test positions 1 to 4, but not in the same position with switch S1

Figure 10 — Example of test setup for unshielded unsymmetrical interconnection lines — line-to-line and line-to-ground coupling via arrestors

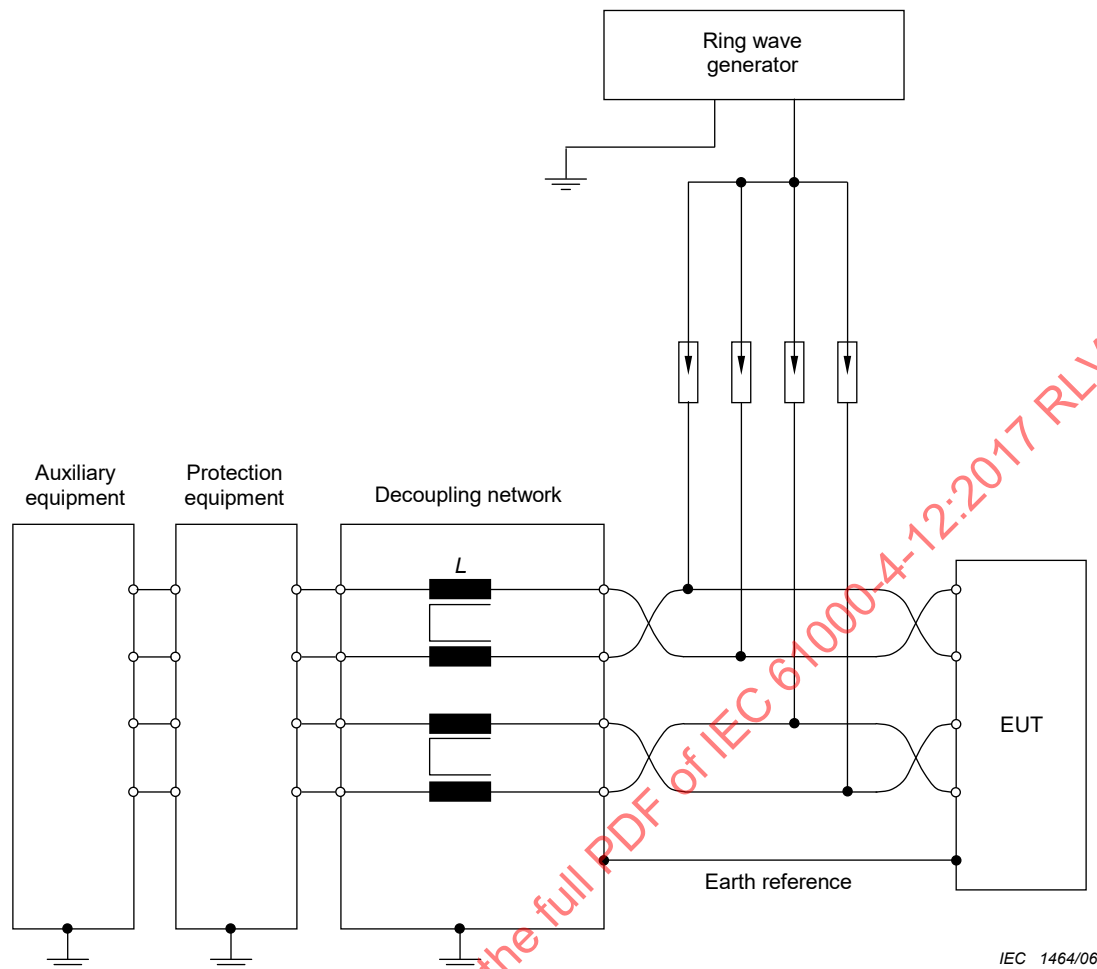


IEC 1463/06

- 1) — Switch S1
 — line to ground: position 0
 — line to line: positions 1 to 4

2) — Switch S2
 — during the test positions 1 to 4, but not in the same position with switch S1

Figure 11 — Example of test setup for unshielded unsymmetrical interconnection lines — line to line and line to ground coupling via a clamping circuit



NOTE The gas arrestors shown can be replaced by a clamping circuit such as that shown in Figure 11.

Figure 12 – Example of test setup for unshielded symmetrical interconnection lines (communication lines) – lines-to-ground coupling via arrestors

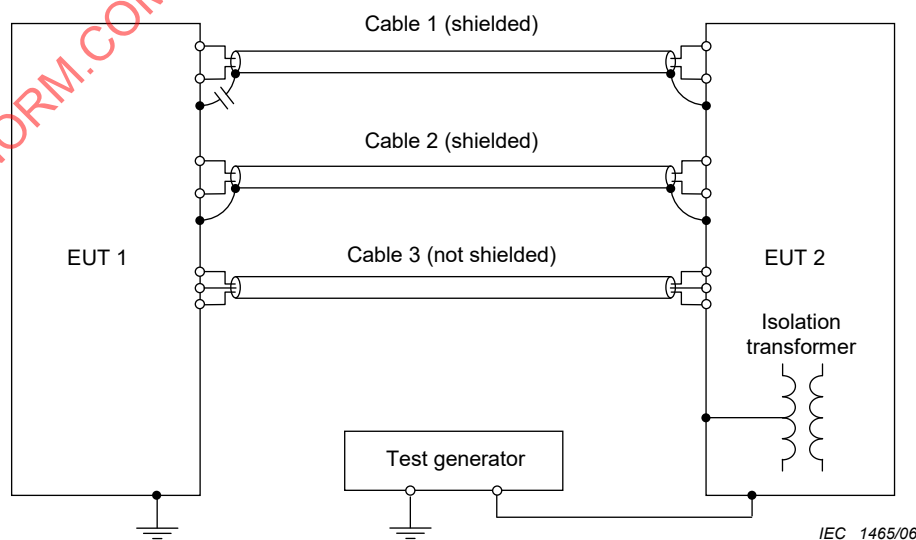


Figure 13 – Test of a system with communication ports with fast operating signals (generator output earthed)

Annex A (informative)

Information on test levels for the ring wave

As stated in Clause 5, the relevance of the phenomena may be used in order to determine the most appropriate test level, selected on the basis of the following guide:

Level 1

- Switching: — power supply port connected to protected local power source (e.g. uninterruptible power system, power converter);
- input/output ports connected to cables running in parallel with power cables of the class under consideration.
- Lightning: — power supply, input/output ports of equipment in control room.

Level 2

- Switching: — power supply port directly connected to mains distribution systems of residential area;
- power supply port of equipment in industrial and electrical plants, decoupled from mains power distribution system through isolation transformers, protection devices, etc.;
- input/output ports connected to cables running in parallel with power cables of the class under consideration.
- Lightning: — power supply, input/output ports connected to shielded cables.

Level 3

- Switching: — power supply port connected to dedicated power distribution systems in electrical and industrial plants;
- input/output ports connected to cables running in parallel with the power cables of the class under consideration.
- Lightning: — power supply port connected to unshielded cables;
- power supply, input/output ports connected to outdoor cables provided with shielding provisions (for example, metallic cable trays).

Level 4

- Switching: — power supply port connected to power source characterized by heavy inductive loads in industrial or electrical plants;
- input/output ports connected to cables running in parallel with the power cables of the class under consideration.
- Lightning: — power supply, input/output ports connected to outdoor cables without shielding provisions.

- Level x** — Special situations to be analyzed.

Annex A

(informative)

Information on electromagnetic environments, installation classes and test levels

The relevance of the ring wave phenomena for immunity testing depends on the electromagnetic environment where equipment is intended to be operated. Based on common installation practices which are representative for the electromagnetic environment concerned, a guide for the selection of levels for ring waves testing may be based on the following classification. According to the description of the ring wave phenomenon (see 4.1), effects of switching and of lightning are considered.

Class 0 Well-protected electrical environment, often within a special room. All incoming cables are provided with overvoltage (primary and secondary) protection. The units of the electronic equipment are interconnected by a well-designed grounding system, which is not significantly influenced by the power installation or lightning. The electronic equipment has a dedicated power supply (see Table B.1).

Class 1

Switching: the power supply port of the EUT is connected to protected local power source (for example uninterruptible power system, power converter). The cables of EUT input/output ports run in parallel with power cables of this class.

Lightning: power supply, input/output ports of equipment are installed in partly protected areas (for example in a control room)

The requirements of this class are covered by test level 1 as defined in Table 1.

Class 2 Switching: the power supply port of the EUT is directly connected to the public mains distribution systems of the residential area or is decoupled from a private mains power distribution system through isolation transformers, protection devices, etc. The cables of EUT input/output ports run in parallel with power cables of this class.

Lightning: power supply, input/output ports are connected to shielded cables.

The requirements of this class are covered by test level 2 as defined in Table 1.

Class 3 Switching: the power supply port of the EUT is connected to dedicated power distribution systems in electrical and industrial plants. The cables of EUT input/output ports run in parallel with power cables of this class.

Lightning: the power supply port is connected to unshielded cables; power supply, input/output ports connected to outdoor cables are provided with mitigation measures (for example, metallic cable trays).

The requirements of this class are covered by test level 3 as defined in Table 1.

Class 4 Switching: the power supply port of the EUT is connected to power sources characterized by switching of heavy inductive loads in electrical and industrial plants. The cables of EUT input/output ports run in parallel with power cables of this class.

Lightning: power supply, input/output ports are connected to outdoor cables without shielding provisions.

The requirements of this class are covered by test level 4 as defined in Table 1.

Class 5 Switching: electronic equipment connected to telecommunication cables and overhead power lines in a non-densely populated area.

Lightning: All these cables and lines are provided with overvoltage (primary) protection. Outside the electronic equipment there is no widespread grounding

system (exposed plant). The interference voltages due to lightning (currents up to 100 kA) can be extremely high.

The requirements of this class are covered by test level 4 as defined in Table 1.

Class X The minor or major electromagnetic separation of interference sources from equipment circuits, cables, lines etc., and the quality of the installations may require the use of a higher or lower test level than those described above. This may need a case-by-case assessment.

It should be noted that the lines of equipment (e.g. cabling, bus bars, overhead lines) associated to electromagnetic environments with higher test levels can penetrate into locations being assigned to an environment with lower test levels. In such cases a re-assessment of the latter location with respect to the suitable test levels should be carried out.

A manufacturer should test its equipment on the basis of the specified test levels to confirm the equipment level immunity, for example with secondary protection at the ports of the EUT for a level of 0,5 kV. The users of the plant or those responsible for the installation should then apply measures (e.g. shielding, bonding, grounding protection) necessary to ensure that the interference voltage caused by, for example, switching does not exceed the chosen immunity level.

The above selection of test levels in terms of electromagnetic environments should be used as a guide only. There might be cases where a location might be assigned to one of the above types of electromagnetic environments but due to the features of the equipment concerned or other circumstances a different test level than that associated to that type of electromagnetic environment might be more appropriate. Corresponding assessment should be done by the parties involved (e.g. product committees).

Annex B (informative)

Selection of generators and test levels

B.1 General

The selection of the test levels should be based on the installation conditions and may be specified in product or product family standards. Where there are no defined levels, Table B.1 and Table B.2 should be used, together with the information given in Annex A. These values are included for illustration only and do not form a recommendation or requirement. The values have been chosen only for explanatory purposes and are not put forward as some recommended practice.

B.2 The classification of environments

The classification of environments is listed as follows:

Class 0: Well-protected electrical environment, often within a special room

Class 1: Partly protected electrical environment

Class 2: Electrical environment where the cables are well-separated, even at short runs

Class 3: Electrical environment where cables run in parallel

Class 4: Electrical environment where the interconnections run as outdoor cables along with power cables, and cables are used for both electronic and electric circuits

Class 5: Electrical environment for electronic equipment connected to communication cables and overhead power lines in a non-densely populated area

Class x: Special conditions specified in the product specification

To demonstrate the system level immunity, additional measures relevant to the actual installation conditions, for example primary protection, should be taken. Additional information is given in Annex C.

B.3 The definition of port types

The following ports are defined:

Intra-system port:

- The port is connected to ports within the same system.

Internal port:

- Only connected to cables within the same building.
- The port is not intended to provide a service that can be directly connected to an outdoor connection.
- The port will not have a conductive connection to a cable which leaves the building via other equipment (e.g., via a splitter).

External port:

- The port is intended to connect directly to lines which exit a building.
- The port has a conductive connection to a cable which leaves the building via other equipment (e.g., via a splitter).

B.4 Selection of the test levels

Examples of the selection of test levels are given in Table B.1 and Table B.2.

Table B.1 – Power ports: Selection of the test levels (depending on the installation class)

Installation class	Test levels (kV)							
	AC power supply and AC I/O		AC power supply and AC I/O		DC power supply and DC I/O		DC power supply and DC I/O	
	external ports ^a		internal ports ^{a d}		external ports ^a		internal ports ^{a d}	
	Coupling mode		Coupling mode		Coupling mode		Coupling mode	
	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground
0	NA	NA	NA	NA	NA	NA	NA	NA
1	NA	0,5	NA	NA	NA	NA	NA	NA
2	0,5	1,0	NA	NA	NA	NA	NA	NA
3	1,0	2,0	1,0	2,0	NA	NA	NA	NA
4	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b
5	c, b	c, b	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b

^a No test is advised if the cable length is shorter than or equal to 10 m.

^b Where the port is always intended to be used with specified primary protection, testing is performed with the primary protection in place to ensure coordination with the protection elements. If primary protection is required to protect the interface but not provided, testing is also performed at the maximum let through level of the specified primary protection and with a typical primary protector.

^c Depends on the class of the local power supply system.

^d The testing of intra-system ports is generally not required.

The testing of intra-system ports is generally not required.

**Table B.2 – Circuits/lines: Selection of the test levels
(depending on the installation class)**

Installation class	Test levels (kV)											
	Unsymmetrical operated circuits/lines ^{a, c, e}				Symmetrical operated circuits/lines ^{a, c, e}				Shielded circuits/lines ^{a, d, e}			
	External port		Internal port		External port		Internal port		External port		Internal port	
	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground
0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	NA	NA	NA	0,5	NA	NA	NA	0,5	NA	NA	NA	NA
2	NA	NA	0,5	1,0	NA	NA	NA	1,0	NA	NA	NA	1,0
3	NA	NA	1,0	2,0	NA	NA	NA	2,0	NA	NA	NA	2,0
4	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b
5	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b
^a No test is advised for data connections intended for cables shorter than 10 m. ^b Where the port is always intended to be used with specified primary protection, testing is performed with the primary protection in place to ensure coordination with the protection elements. If primary protection is required to protect the interface but not provided, testing is also performed at the maximum let through level of the specified primary protection and with a typical primary protector. ^c Line-to-line transients (transverse) may occur in networks where SPDs (surge protective devices) with connection to ground are used for protection. Such ring waves are outside the scope of this document. This phenomenon can however be simulated by applying common mode ring waves through the defined primary protection elements. ^d The testing of ports connecting to antennas is outside the scope of this document. ^e The testing of intra-system ports is generally not required.												

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Annex C (informative)

Explanatory notes

C.1 Different source impedance

The selection of the source impedance of the generator depends on the kind of cable/conductor/line, i.e. AC power supply, DC power supply, shielded interconnection or unshielded interconnection lines, etc. and on the expected impedance of the power supply network depending on the proximity to the power supply source (e.g. generator, transformer) (see 6.1.2).

C.2 Application of the tests

C.2.1 Equipment level immunity

The test is intended to be carried out in the laboratory on a single EUT. The immunity of the EUT thus tested refers to equipment level immunity.

Preferential ranges of test levels are given in Table B.1 and Table B.2. The ring wave test is applicable to external connections only (i.e. connections outside of the cabinet/housing).

It is highly recommended that the test voltage does not exceed the specified capability of the EUT's insulation to withstand high-voltage stress.

If it is possible to test at the system level (see C.2.2), it is not necessary to test at the equipment level, especially in cases where the shield of the interconnection cable is part of the protection measure.

C.2.2 System level immunity

A test carried out in the laboratory refers to an EUT, but immunity at the EUT level does not necessarily assure the immunity of a system which contains that EUT. In order to ensure system level immunity, a test at the system level is recommended to simulate the real installation as closely as possible. This simulated installation should be comprised of individual EUTs and should also include protective devices (surge protective devices (SPDs)) if they are requested by the system application manual or stipulated by the system/network operator. The real length and type of interconnection lines should be used, all of which could affect the overall system protection level.

Annex D (informative)

Measurement uncertainty (MU) considerations

D.1 General

The reproducibility of EMC tests relies on many factors, or influences, that affect the test results. These influences may be categorized as random or systematic effects. The compliance of the realized disturbance quantity with the disturbance quantity specified by this document is usually confirmed through a set of measurements (e.g. measurement of the rise time of an impulse with an oscilloscope by using a voltage or current probe). The result of each measurement includes a certain amount of measurement uncertainty (MU) due to the imperfection of the measuring instrumentation as well as to the lack of repeatability of the measurand itself.

In order to evaluate MU it is necessary to:

- a) identify the sources of uncertainty, related both to the measuring instrumentation and to the measurand,
- b) identify the functional relationship (measurement model) between the influence (input) quantities and the measured (output) quantity,
- c) obtain an estimate and standard uncertainty of the input quantities,
- d) obtain an estimate of the interval containing, with a high level of confidence, the true value of the measurand.

In immunity tests estimates and uncertainties are evaluated for the parameters of the disturbance quantity (e.g. rise time, peak and oscillation period). As such, they describe the degree of agreement of the disturbance quantity with the relevant specifications of this basic standard.

These estimates and uncertainties, derived for a particular disturbance quantity, do not describe the degree of agreement between the simulated electromagnetic phenomenon, as defined in the basic standard, and the real electromagnetic phenomenon in the world outside the laboratory.

Since the effect of the parameters of the disturbance quantity on the EUT is a priori unknown and in most cases the EUT shows a nonlinear behaviour, a single estimate and uncertainty numbers cannot be defined for the disturbance quantity. Therefore each of the parameters of the disturbance quantity will be accompanied by the corresponding estimate and uncertainty. This yields to more than one uncertainty budget.

D.2 Legend for ring wave parameters

- | | |
|--------|--|
| T_1 | rise time of the ring wave (voltage or current, 10 % to 90 %) |
| T | period of the ring wave (voltage, time interval between the first and third zero crossings after the initial peak) |
| Pk_1 | first peak of the ring wave (voltage or current) |
| Pk_2 | second peak of the ring wave (voltage) |
| Pk_3 | third peak of the ring wave (voltage) |
| Pk_4 | fourth peak of the ring wave (voltage) |

NOTE The meaning and the relations among the symbols $u(x_i)$, c_i , $u_i(y)$, $u_c(y)$, $U(y)$ and y are explained in IEC TR 61000-1-6.

D.3 Uncertainty contributors to the ring wave measurement uncertainty

The following list shows the contributors used to assess both the measuring instrumentation and test setup influences:

- reading of peak value
- bandwidth of the measuring system
- shape of the impulse response of the measuring system
- oscilloscope vertical axis measurement error
- measurement system, measurand and setup repeatability (type A)
- calibration of oscilloscope
- calibration of voltage and current probes

D.4 Uncertainty of the generator output voltage and current measurement

D.4.1 General

In the case of the ring wave immunity test, the disturbance quantities are the impulse voltage and current generated by the test generator plus CDN combination and applied to the EUT. As discussed in Clause D.1, an uncertainty budget for each measured parameter of the disturbance quantity is required. The parameters of these disturbance quantities are the rise time T_1 of the (open-circuit) voltage and (short-circuit) current waveforms, the amplitude of the first peak Pk_1 of the voltage and current waveforms, the voltage waveform frequency $1/T$, decaying of voltage waveform (ratio between Pk_2 and Pk_1 , Pk_3 and Pk_2 , Pk_4 and Pk_3) and waveform repetition frequency. The evaluation of the measurement uncertainty of the voltage waveform frequency, the decaying of the voltage waveform and the waveform repetition frequency, although required, are less demanding. Therefore attention is focused here on the waveform rise time and peak (both voltage and current).

The approach adopted here to evaluate the impulse MU is described in D.4.5 and D.4.6. Table D.1 and Table D.2 give examples of uncertainty budgets for the amplitude of the first peak and the rise time parameters, respectively. Tables 1 and 2 include the input quantities that are considered most significant for this example, the details (numerical values, type of probability density function, etc.) of each contributor to MU and the results of the calculations required for determining the uncertainty budget.

D.4.2 Rise time of the ring wave

The measurand is the ring wave open-circuit voltage and short-circuit current rise time calculated by using the functional relationship

$$T_1 = \sqrt{(T_{90\%} - T_{10\%} + \delta R)^2 - T_{MS}^2}$$

where

$$T_{MS} = \frac{\alpha}{B}$$

and:

$T_{10\%}$ time at 10 % of the first peak amplitude

$T_{90\%}$ time at 90 % of the first peak amplitude

δR correction for non-repeatability

- T_{MS} rise time of the step response of the measuring system (10 % to 90 %)
 B –3 dB bandwidth of the measuring system
 α coefficient whose value is 360 ± 40 (B in kHz and T_{MS} in μs)

Table D.1 – Example of uncertainty budget for ring wave rise time (T_1)

Symbol	Estimate	Unit	Error bound	Unit	Probability density function (PDF)	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
$T_{10\%}$	0,07	μs	0,005 0	μs	triangular	2,45	0,002 0	–1,001	1	0,002 0	μs
$T_{90\%}$	0,64	μs	0,005 0	μs	triangular	2,45	0,002 0	1,001	1	0,002 0	μs
δR	0	μs	0,025	μs	normal ($k=1$)	1,00	0,025	1,001	1	0,025	μs
α	360	$\mu s \cdot kHz$	40	$\mu s \cdot kHz$	rectangular	1,73	23,1	$-1,58 \cdot 10^{-6}$	1/kHz	0,000 04	μs
B	20 000	kHz	500	kHz	rectangular	1,73	288,7	$2,84 \cdot 10^{-8}$	$\mu s/kHz$	0,000 01	μs
$u_c(y) = \sqrt{\sum u_i(y)^2}$										0,025 2	μs
$U(y) = 2 u_c(y)$										0,05	μs
y										0,57	μs

$T_{10\%}, T_{90\%}$: is the time reading at 10 % or 90 % of the first peak amplitude. The error bound is obtained assuming a sampling frequency of 100 MS/s and trace interpolation capability of the scope (triangular probability density function). Were this not the case, a rectangular probability density function should be assumed. Only the contributor to MU due to the sampling rate is considered here, for additional contributors see D.4.5. The readings are assumed to be $T_{10\%} = 0,07 \mu s$ and $T_{90\%} = 0,64 \mu s$.

T_{MS} : is the calculated rise time of the step response of the measuring system. The coefficient α depends on the shape of the impulse response of the measuring system. The range 360 ± 40 is representative of a wide class of systems, each having a different shape of the impulse response (see D.4.5 and Table D.3). The bandwidth B of the measuring system can be experimentally obtained (direct measurement of the bandwidth) or calculated from the bandwidth B_i of each element of the measurement system (essentially a voltage and current probe, a cable and a scope) by using the following formula:

$$\frac{1}{B} = \sqrt{\left(\frac{1}{B_1}\right)^2 + \left(\frac{1}{B_2}\right)^2 + \dots}$$

An estimate of 20 MHz and a 500 kHz error bound of a rectangular probability density function are assumed for B .

δR : is the 10 % to 90 % rise time non-repeatability. It quantifies the lack of repeatability in the measurement of $T_{90\%} - T_{10\%}$ due to the measuring instrumentation, the layout of the measurement setup and the ring wave generator itself. It is determined experimentally. This is a type A evaluation based on the formula of the experimental standard deviation $s(q_k)$ of a sample of n repeated measurements q_j and given by

$$s(q_k) = \sqrt{\frac{1}{n-1} \sum_{j=1}^n (q_j - \bar{q})^2}$$

where $\bar{q}$ is the arithmetic mean of the q_j values. An error bound $s(q_k) = 25$ ns (1 standard deviation of a normal probability density function) and an estimate of 0 ns are assumed.

NOTE For the open-circuit voltage and short-circuit current the uncertainty budgets are similarly obtained. In the case of the voltage waveform T_{MS} includes the bandwidth of the voltage probe, while it includes the bandwidth of the current probe in the case of the current waveform. The functional relationship is the same in both cases.

D.4.3 Peak of the ring wave

The measurand is the first peak of the short-circuit current of the ring wave obtained by using the functional relationship

$$Pk_1 = \frac{V_{Pk1}}{Z_T} \cdot \frac{1 + \delta R + \delta V}{1 - \left(\frac{\beta}{B}\right)^2}$$

where

V_{Pk1} impulse voltage peak reading

Z_T transfer impedance (or sensitivity) or the current probe or shunt

δR correction for non-repeatability

δV DC vertical accuracy of the scope

B – 3 dB bandwidth of the current measuring system

β coefficient whose value is (142 ± 16) kHz

Table D.2 – Example of uncertainty budget for the peak of the short-circuit current of the ring wave (I_{Pk1})

Symbol	Estimate	Unit	Error bound	Unit	Probability density function (PDF)	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
V_{Pk1}	0,321	V	0,000 6	V	triangular	2,45	0,000 26	1 000	1/ Ω	0,256	A
Z_T	0,001	Ω	0,000 05	Ω	rectangular	1,73	0,000 03	$3,21 \cdot 10^5$	A/ Ω	9,267	A
δR	0	1	0,03	1	normal ($k=1$)	1,00	0,030	321,0	A	9,630	A
δV	0	1	0,02	1	rectangular	1,73	0,011 6	321,0	A	3,707	A
β	142	kHz	16	kHz	rectangular	1,73	9,238	$2,3 \cdot 10^{-4}$	A/kHz	0,002 11	A
B	20 000	kHz	500	kHz	rectangular	1,73	288,7	$-1,6 \cdot 10^{-6}$	A/kHz	0,000 47	A
							$u_c(y) = \sqrt{\sum u_i(y)^2}$			13,87	A
							$U(y) = 2 u_c(y)$			27,7	A
							y			321	A
							Expressed in % of 321 A			8,6	%

V_{Pk1} : is the voltage peak reading at the output of a current probe or across a current shunt. The error bound is obtained assuming that the scope has an 8-bit vertical resolution with interpolation capability (triangular probability density function).

Z_T : is the transfer impedance (or sensitivity) of the current shunt or probe. An estimated value of 0,001 Ω and an error bound of 5 % (rectangular probability density function) are assumed.

δR : quantifies the non-repeatability of the measurement setup, layout and instrumentation. This is a type A evaluation based on the formula of the experimental standard deviation. It is expressed in relative terms and an estimate of 0 % and an error bound of 3 % (1 standard deviation) are assumed.

δV : quantifies the amplitude measurement inaccuracy of the scope at DC. A 2 % error bound of a rectangular probability density function and an estimate of 0 are assumed.

β : is a coefficient which depends on the shape of both the impulse response of the measuring system and the standard impulse waveform in the neighborhood of the peak (see D.4.6). The interval (142 ± 16) kHz is representative of a wide class of systems, each having a different shape of the impulse response.

B: the bandwidth B of the measuring system can be experimentally obtained (direct measurement of the bandwidth) or calculated from the bandwidth B_i of each element of the measurement system (essentially a current probe or shunt, a cable and a scope) by using the following formula:

$$\frac{1}{B} = \sqrt{\left(\frac{1}{B_1}\right)^2 + \left(\frac{1}{B_2}\right)^2 + \dots}$$

An estimate of 20 MHz and a 500 kHz error bound of a rectangular probability density function are assumed for B .

NOTE The uncertainty of the peak the ring wave voltage is obtained by using a similar functional relationship where the reciprocal of the attenuation of the voltage probe is considered in place of Z_T and B is the bandwidth of the voltage measuring system (voltage probe, cable and oscilloscope).

D.4.4 Further MU contributions to time measurements

Time base error and jitter: the oscilloscope specifications may be taken as error bounds of rectangular probability density functions. Usually these contributions are negligible.

Vertical resolution: the contribution depends on the vertical amplitude resolution ΔA and on the slope of the trace dA/dt . The uncertainty is related to the half width of the resolution and is $(\Delta A/2)/(dA/dt)$. If trace interpolation is performed (see the oscilloscope manual) a triangular probability density function is used, otherwise a rectangular probability density function is used. This contribution is often negligible.

D.4.5 Rise time of the step response and bandwidth of the frequency response of the measuring system

Let T_{MS} be the rise time of the step response of the measuring system as defined by

$$T_{MS} = \sqrt{2\pi \int_0^{\infty} (t - T_s)^2 \cdot h_0(t) dt} \quad (D.1)$$

where $h_0(t)$ is the impulse response of the measuring system having a normalized area,

i.e. $\int_0^{\infty} h_0(t) dt = 1$, and T_s is the delay time given by

$$T_s = \int_0^{\infty} t \cdot h_0(t) dt \quad (D.2)$$

Formula (D.1) is much more easy to handle, from the mathematical point of view, than the usual one based on the 10 % and 90 % threshold levels. Nonetheless, in the technical applications, the 10 % to 90 % rise time definition is usually adopted. Given the –3 dB bandwidth of the system the two definitions lead to comparable rise times. Indeed, if we define

$$\alpha = T_{MS} B \quad (D.3)$$

we find that the α values derived from the two definitions of rise time do not differ very much. The values of α , corresponding to different shapes of the impulse response $h(t)$, are given in

Table D.3. It is evident from Table D.3 that it is not possible to identify a unique value of α since α depends both on the adopted definition of the rise time (e.g. based on thresholds or on Formula (D.1)) and on the shape of the impulse response of the measuring system. A reasonable estimate of α can be obtained as the arithmetic mean between the minimum ($321 \cdot 10^{-3}$) and maximum ($399 \cdot 10^{-3}$) values that appear in Table D.3, that is $360 \cdot 10^{-3}$. Further, it can be assumed that, if no information is available about the measuring system apart from its bandwidth, any value of α between $321 \cdot 10^{-3}$ and $399 \cdot 10^{-3}$ is equally probable. Differently stated, α is assumed to be a random variable having a rectangular probability density function with lower and upper bounds $321 \cdot 10^{-3}$ and $399 \cdot 10^{-3}$, respectively. The standard uncertainty of α quantifies both:

- e) the indifference to the mathematical model adopted for the definition of the rise time, and
- f) the indifference to the shape of the impulse response of the system.

Table D.3 – α factor (Formula (D.3)) of different unidirectional impulse responses corresponding to the same bandwidth of the system B

Values of α are multiplied by 10^3	Gaussian	I order	II order (crit. damp.)	Rectangular	Triangular
α – using Formula (D.1)	332	399	363	321	326
α – 10 % to 90 %	339	350	344	354	353

D.4.6 Impulse peak and width distortion due to the limited bandwidth of the measuring system

The distorted impulse waveform $V_{\text{out}}(t)$ at the output of the measuring system is given by the convolution integral

$$V_{\text{out}}(t) = \int_0^t V_{\text{in}}(\tau) h(t - \tau) d\tau \quad (\text{D.4})$$

where $V_{\text{in}}(t)$ is the input impulse waveform and $h(t)$ is the impulse response of the measuring system. Note that $A \cdot h(t) = \delta(t)$, where A is the DC attenuation of the measuring system. The input waveform can be approximated by its Taylor series expansion about the time instant t_p when the input reaches its peak value V_p

$$V_{\text{in}}(t) = V_p + \frac{V_{\text{in}}''(t_p)}{2} (t - t_p)^2 + \frac{V_{\text{in}}'''(t_p)}{6} (t - t_p)^3 + \dots \quad (\text{D.5})$$

Note that the first order term is missing from Formula (D.5) since $V_{\text{in}}'(t_p) = 0$. Further $V_{\text{in}}''(t_p) < 0$ because the concavity points downwards (maximum), and $V_{\text{in}}'''(t_p) > 0$ because, for the standard waveforms of interest here, the rise-time is lower than the fall time. Substituting Formula (D.5) by Formula (D.4) and after simplifications, valid when the bandwidth of the measuring system is large with respect to the bandwidth of the input signal (so that the power series terms whose order is greater than two are negligible), we obtain

$$V_{\text{pd}} = \frac{V_p}{A} \left[1 - \left(\frac{\beta}{B} \right)^2 \right] \quad (\text{D.6})$$

where V_{pd} is the output impulse peak, A is the DC attenuation of the measuring system and

$$\beta = \alpha \sqrt{\frac{|V''_{in}(t_p)|}{4\pi V_p}} \quad (D.7)$$

Note that the parameter β depends on the second derivative of the standard input waveform and on the parameter α defined and derived in D.4.5. The mathematical expression for the standard ring waveform is given in 4.1 and the value is numerically calculated as $\beta = (142 \pm 16)$ kHz.

D.5 Application of uncertainties in the ring waveform compliance criterion

In order to provide evidence that the ring wave generated is compliant with the requirements of this document, the calibration results should be compared with the tolerances specified by this document. Tolerances shall not be reduced by MU.

Further guidance is given in IEC TR 61000-1-6:2012, Clause 6.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –**Part 4-12: Testing and measurement techniques –
Ring wave immunity test****FOREWORD**

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International Standard IEC 61000-4-12 has been prepared by subcommittee 77B: High frequency phenomena, of IEC technical Committee 77: Electromagnetic compatibility.

It forms Part 4-12 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107.

This third edition cancels and replaces the second edition published in 2006. This edition constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

- a) addition of a mathematical modelling of ring wave waveform;
- b) new Annex B on selection of generators and test levels;
- c) new Annex C on explanatory notes;
- d) new Annex D on measurement uncertainty;

- e) addition of high speed CDN;
- f) addition of a calibration procedure for CDN.

The text of this International Standard is based on the following documents:

CDV	Report on voting
77B/764/CDV	77B/774/RVC

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

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

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

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

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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INTRODUCTION

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

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

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

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

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

This part is an International Standard which gives immunity requirements and test procedures related to ring waves. It should be noted that edition 1 of IEC 61000-4-12, published in 1995, covered immunity tests against two phenomena, ring waves and damped oscillatory waves. This situation was changed in edition 2, published in 2006, where IEC 61000-4-12 covered the ring wave phenomena only and the damped oscillatory wave phenomenon was moved into a new standard IEC 61000-4-18.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-12: Testing and measurement techniques – Ring wave immunity test

1 Scope

This part of IEC 61000 relates to the immunity requirements and test methods for electrical and electronic equipment, under operational conditions, to ring waves occurring in low-voltage power, control and signal lines supplied by public and non-public networks.

The object of this document is to establish a common reference for evaluating the immunity of electrical and electronic equipment when subjected to ring waves. The test method documented in this part of IEC 61000 describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon.

NOTE As described in IEC Guide 107, this is a basic EMC publication for use by product committees of the IEC. As also stated in Guide 107, the IEC product committees are responsible for determining whether this immunity test standard is applied or not, and if applied, they are responsible for determining the appropriate test levels and performance criteria. TC 77 and its sub-committees are prepared to co-operate with product committees in the evaluation of the value of particular immunity test and test levels for their products.

This document defines:

- test voltage and current waveforms;
- a range of test levels;
- test equipment;
- test setups;
- test procedures.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050 (all parts), *International Electrotechnical Vocabulary (IEV)* (available at www.electropedia.org)

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050 (all parts) as well as the following apply.

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

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

3.1.1**calibration**

set of operations which establishes, by reference to standards, the relationship which exists under specified conditions, between an indication and a result of a measurement

Note 1 to entry: This term is based on the "uncertainty" approach.

Note 2 to entry: The relationship between the indications and the results of measurement can be expressed, in principle, by a calibration diagram.

[SOURCE: IEC 60050-311:2001, 311-01-09]

3.1.2**coupling**

interaction between circuits, transferring energy from one circuit to another

3.1.3**coupling network****CN**

electrical circuit for the purpose of transferring energy from one circuit to another

3.1.4**coupling/decoupling network****CDN**

combination of a coupling network and a decoupling network

3.1.5**decoupling network****DN**

electrical circuit for the purpose of preventing test voltages applied to the equipment under test (EUT) from affecting other devices, equipment, or systems which are not under test

3.1.6**immunity (to a disturbance)**

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

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

3.1.7**port**

particular interface of an equipment, which couples this equipment with the external electromagnetic environment (IEC 60050-161:1990, 161-01-01) and through which the equipment is influenced by the environment

[SOURCE: IEC 60050-161:1990, 161-01-27]

3.1.8**ring wave**

damped oscillation, whose damping time constant is of the order of one period

[SOURCE: IEC 60050-161:1990, 161-02-30]

3.1.9**rise time** **T_r**

interval of time between the instants at which the instantaneous value of an impulse first reaches 10 % value and then the 90 % value

[SOURCE: IEC 60050-161:1990, 161-02-05, modified – the content of the note has been included in the definition and “pulse” has been changed to “impulse”]

3.1.10

transient (adj and noun)

pertaining to or designating a phenomenon or a quantity which varies between two consecutive steady states during a time interval short compared with the time-scale of interest

[SOURCE: IEC 60050-161:1990, 161-02-01]

3.1.11

verification

set of operations which is used to check the test equipment system (e.g. the test generator and its interconnecting cables) to demonstrate that the test system is functioning

Note 1 to entry: The methods used for verification may be different from those used for calibration.

Note 2 to entry: For the purposes of this basic EMC standard this definition is different from the definition given in IEC 60050-311:2001, 311-01-13.

3.2 Abbreviated terms

AE	Auxiliary equipment
CD	Coupling device
CDN	Coupling/decoupling network
CLD	Clamping device
CN	Coupling network
DN	Decoupling network
EMC	Electromagnetic compatibility
EUT	Equipment under test
GDT	Gas discharge tube
MU	Measurement uncertainty
PDF	Probability density function
PE	Protective earth
RGP	Reference ground plane
RWG	Ring wave generator
SPD	Surge protective device

4 General

4.1 Description of the phenomenon

The ring wave (described in Figure 1) is an oscillatory transient, induced in low-voltage cables due to the switching of electrical networks and reactive loads, faults and insulation breakdown of power supply circuits or lightning. It is, in fact, the most diffused phenomenon occurring in power supply (high voltage, medium voltage, low voltage) networks, as well as in control and signal lines.

The ring wave is representative of a wide range of electromagnetic environments of residential, as well as industrial installations. It is suitable for checking the immunity of equipment in respect of the above-mentioned phenomena, which give rise to impulses characterized by sharp front-waves that, in the absence of filtering actions, are in the order of 10 ns to a fraction of μs . The duration of these impulses may range from 10 μs to 100 μs .

The rise time and duration of the impulse are dependent on the propagation characteristics of the media and the path.

The propagation of the wave in the lines (power and signal) is always subject to reflections, due to the mismatching impedance (the lines are terminated with loads or connected to protection devices, input line filters, etc.). These reflections produce oscillations, whose frequency is related to the propagation speed. The presence of parasitic parameters (e.g. stray capacitance of components like motors, transformer windings, etc.) are additional influencing factors.

The rise time can be increased by the low-pass characteristics of the line. This effect is more relevant for fast rise times (in the order of 10 ns), and less relevant for slow rise times (in the order of 1 µs).

Another cause of the ring wave is lightning, which itself is characterized by a unidirectional waveform (standard 1,2/50 µs impulse). Circuits subjected to the indirect effects of lightning (inductive coupling among lines) are influenced by the derivative of the primary impulse and the coupling mechanisms involved, which can cause oscillations. The characteristics of the resulting ring wave depend on the reactive parameters of the ground circuits, metal structures involved in the lightning current flow, and the propagation in the low-voltage transmission lines.

The phenomenon, which is created by the above mentioned effects at the equipment ports, is an oscillatory transient or a ring wave. Oscillatory transients are covered in IEC 61000-4-18. A ring wave with a defined 0,5 µs rise time and 100 kHz oscillation frequency has been determined to be typical and is widely used for testing products.

The formula of the ideal waveform of Figure 1, $w(t)$, is as follows:

$$w(t) = A \cdot K \cdot \frac{\left(\frac{t}{t_1}\right)^n}{1 + \left(\frac{t}{t_1}\right)^n} \cdot \exp\left(-\frac{t}{t_2}\right) \cdot \cos(\beta t)$$

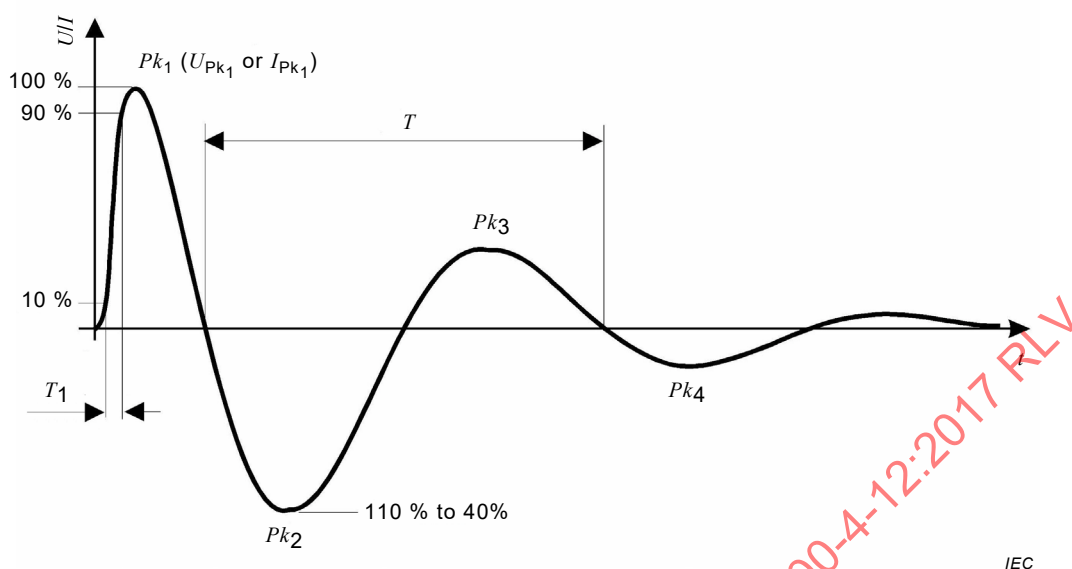
with

$$t_2 = \frac{T}{2} \cdot \frac{1}{\ln R} = 7,21 \mu\text{s} \text{ and } \beta = \frac{2\pi}{T} \text{ and } T = 10 \mu\text{s}$$

where the parameters for oscillation period $T = 10 \mu\text{s}$ are:

$$A = 1; K = 1,81; n = 1,83; t_1 = 0,507 \mu\text{s}$$

NOTE R is the ratio between Pk_2 and Pk_3 , Pk_3 and Pk_4 . The value of R ensures that the ratios Pk_2/Pk_3 , Pk_3/Pk_4 are in the range specified by this document. The value of R cannot be too small otherwise the ratio Pk_1/Pk_2 exceeds the specified tolerance. $R = 2$ has been selected. The parameters n and t_1 are adjusted to obtain $T_1 = 0,5 \mu\text{s}$.



Key

- T_1 Rise time
 T Oscillation period

NOTE Only Pk_1 is specified for the current waveform.

**Figure 1 – Waveform of the ring wave
(open-circuit voltage and short-circuit current)**

Other IEC standards, such as IEC 61000-4-5, refer to the 1,2/50 μ s standard lightning impulse, which may be considered to be complementary to the ring wave described in this document.

It is the responsibility of the product committees to define the most appropriate test, according to the phenomenon considered as relevant.

4.2 Relevant parameters

4.2.1 Repetition rate

The repetition rate of the transient is directly related to the frequency of occurrence of the primary phenomenon (lightning and switching). It is higher whenever the primary cause is the load switching in control lines, and less frequent in the case of faults and lightning. The occurrence may typically range from once per second down to once per year.

The repetition rate may be increased in order to reduce the duration of the test. It should be selected according to the characteristics of the protection device used for mitigation/suppression of transients.

4.2.2 Phase angle

Equipment failures related to the ring wave on power supply sources can depend on the phase angle of the AC mains at which the transient is applied. When a protection element operates during a ring wave test, follow current may occur depending on the phase angle at which the transient occurs. Follow current is the current from the connected power source that flows through a protective element, or from any arc in the EUT both during and following the transient.

For semiconductors, the phenomenon may be related to the conduction state of the device at the time the ring wave occurs. Semiconductor parameters that may be involved, include forward and reverse recovery characteristics and secondary breakdown performance.

Devices most likely to fail in a phase-related way are semiconductors involved in the power input circuitry. Other devices in different areas of the EUT can also exhibit such failure modes.

5 Test levels

The preferred test levels for the ring wave applicable to power, signal and control ports of the equipment, are given in Table 1. The test level is defined as the voltage of the first peak (maximum or minimum) in the test waveform (Pk_1 in Figure 1).

Different test levels may apply to power, signal and control ports.

Table 1 – Test levels

Level	Open-circuit test voltage	
	kV	
	Line-to-line	Line-to-ground ^b
1	0,25	0,5
2	0,5	1
3	1	2
4	2	4
X ^a	Special	Special
^a "X" can be any level, above, below or in between the others. This level shall be specified by product committees and/or equipment specification.		
^b For symmetrical interconnection lines the test can be applied to multiple lines simultaneously with respect to ground, i.e. "lines to ground".		

The test levels shall be selected according to the installation conditions; classes of installation are given in Annex C. Annex A gives information on test levels.

The test shall be applied at all test levels in Table 1 up to and including the specified test level (see 8.3).

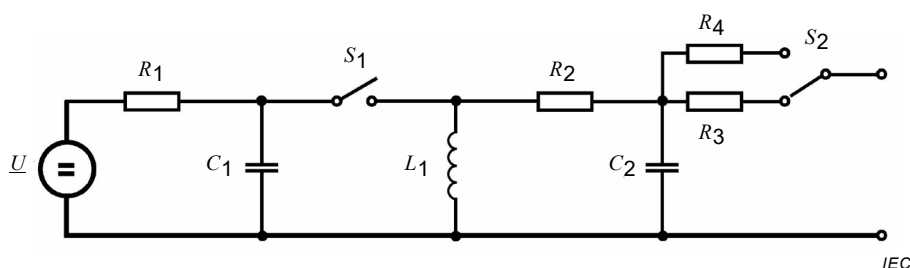
For selection of the test levels for the different interfaces, refer to Annex B.

6 Test instrumentation

6.1 Ring wave generator

6.1.1 Ring wave generator circuit

The generator output shall have the capability to operate under short-circuit conditions. A block diagram of a representative ring wave generator is shown in Figure 2.



Key

U :	high-voltage source	R_3 :	30 Ω resistor
C_1 :	energy storage capacitor	R_4 :	12 Ω resistor
C_2 :	filter capacitor	L_1 :	oscillating circuit coil
R_1 :	charging resistor	S_1 :	high-voltage switch
R_2 :	filter resistor	S_2 :	output impedance selector

Figure 2 – Example of schematic circuit of the ring wave generator

6.1.2 Impedance values

Two values of impedance (see R_3 and R_4 in Figure 2) have been selected as follows:

- 12 Ω when testing AC/DC power ports and shielded interconnection lines
- 30 Ω when testing unshielded interconnection lines

6.1.3 Performance characteristics of the ring wave generator

A generator with a floating output shall be used.

The generator is a single-shot ring wave generator with the following characteristics, measured at the output of the generator:

- voltage rise time (T_1 in Figure 1) 0,5 $\mu\text{s} \pm 30\%$ (open-circuit condition)
- current rise time (T_1 in Figure 1) 0,2 μs to 1,0 μs (short-circuit condition)
- voltage oscillation frequency ($1/T$ in Figure 1) 100 kHz $\pm 10\%$

NOTE 1 Oscillation frequency is defined as the reciprocal of the period between the first and third zero crossings after the initial peak.

- decay (voltage only; see Figure 1)
 - 0,4 $\leq$ ratio of Pk_2 to $Pk_1 \leq 1,1$
 - 0,4 $\leq$ ratio of Pk_3 to $Pk_2 \leq 0,8$
 - 0,4 $\leq$ ratio of Pk_4 to $Pk_3 \leq 0,8$
 - no requirements for Pk_5 onwards
- repetition rate 1/min or faster
- output impedance see Table 2

NOTE 2 The output impedance is calculated from the open-circuit voltage U_{Pk1} divided by the short-circuit current I_{Pk1}

- open-circuit voltage U_{Pk1} (see Figure 1) adjustable from 0,25 kV to the required test level
- short-circuit current I_{Pk1} (see Figure 1) see Table 2
- phase shifting in a range between 0° to 360° relative to the phase angle of the AC line voltage to the EUT with a tolerance of $\pm 10^\circ$

- polarity of Pk_1 (see Figure 1) positive and negative

Table 2 – Relationship between peak open-circuit voltage and peak short-circuit current

Open-circuit peak voltage $\pm 10\%$ at generator output	Short-circuit peak current $\pm 10\%$ at 12 Ω generator output	Short-circuit peak current $\pm 10\%$ at 30 Ω generator output
0,25 kV	20,8 A	8,3 A
0,5 kV	41,7 A	16,7 A
1,0 kV	83,3 A	33,3 A
2,0 kV	166,7 A	66,7 A
4,0 kV	333,3 A	133,3 A

6.1.4 Calibration of the ring wave generator

The test generator characteristics shall be calibrated in order to establish that they meet the requirements of this document. For this purpose the following procedure shall be undertaken.

The generator output shall be connected to a measurement system with a sufficient bandwidth (minimum 20 MHz), voltage and current capability to monitor the characteristics of the waveform.

The characteristics of the generator shall be measured both under open-circuit (load greater than or equal to 10 k Ω) and short-circuit conditions at the same set voltage.

All performance characteristics stated in 6.1.3, with the exception of phase shifting and repetition rate, shall be met at the output of the generator. Phase shifting performance shall be met at the output of the CDN at 0°, 90°, 180° and 270° at one polarity.

6.2 Coupling/decoupling networks

6.2.1 General

Each coupling/decoupling network (CDN) consists of a coupling network and a decoupling network as shown in the examples of Figure 4 through Figure 10.

NOTE The coupling capacitors can be part of the CDN or part of the generator or discrete external components.

The coupling network shall be provided with a coupling capacitor suitable for the selected impedance of the test generator, i.e. $\geq 3\ \mu\text{F}$.

On the AC or DC power lines, the decoupling network provides relatively high impedance to the ring wave transient but at the same time allows current to flow to the EUT. This impedance allows the voltage waveform to be developed at the output of the coupling/decoupling network and prevents the ring wave current from flowing back into the AC or DC power supply. High voltage capacitors are used as the coupling element, sized to allow the full waveform durations to be coupled to the EUT. The coupling/decoupling network for the AC or DC power supply shall be designed so that the open-circuit voltage waveform and short-circuit current waveform meet the requirements of Table 3.

For I/O and communication lines, the series impedance of the decoupling network limits the available bandwidth for data transmission. Coupling elements can be capacitors, in cases where the line tolerates the capacitive loading effects, clamping devices or arrestors. When coupling to interconnection lines, the waveforms may be distorted by the coupling mechanisms which are described in 6.2.3.

The coupling/decoupling network for the unshielded interconnection lines shall be designed so that the open-circuit voltage waveform and short-circuit current waveform meet the requirements of Table 5 and Table 7.

Each coupling/decoupling network shall satisfy the requirements of 6.2.2 or 6.2.3 and shall meet the calibration requirements in 6.3. Their use is made according to the flowchart in Figure 3:

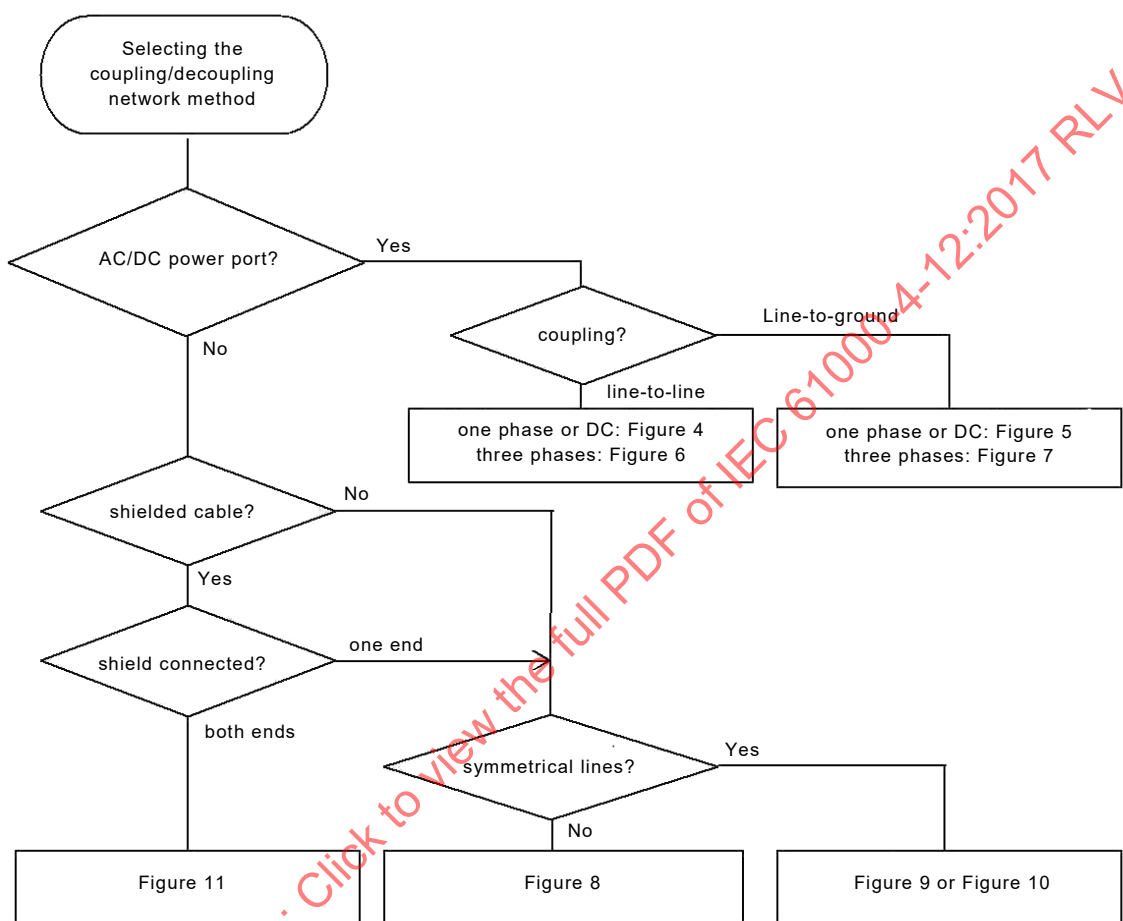


Figure 3 – Selection of coupling/decoupling method

6.2.2 Coupling/decoupling networks for AC/DC power port rated up to 63 A per line

The peak amplitude Pk_1 and rise time shall be verified for voltage under open-circuit conditions and for current under short-circuit conditions, at the EUT port as well as the oscillation period in addition to the voltage under open-circuit conditions. The waveform parameters measured at the EUT port of the CDN are dependent upon the generator source and as such are only valid for the particular generator/CDN combination tested. The CDN shall be connected to a measuring system with a sufficient bandwidth, voltage and current capability to monitor the characteristics of the waveforms.

NOTE The surge and ring wave originate from the same disturbance sources. The ring wave is the outcome of the involved cable layout and the surge protective device (SPD) between the disturbance source and the power outlet. For currents larger than 63 A the cable layout forms usually a part of the EUT and therefore the EUT is tested in accordance with IEC 61000-4-5.

The decoupling inductance shall be selected by the CDN manufacturer so that the voltage drop across the CDN shall not exceed 10 % of the CDN input voltage at the specified current rating, but should not exceed 1,5 mH.

To prevent unwanted voltage drops in the CDN, the value of the decoupling element shall be reduced for CDNs rated at > 16 A. As a consequence, the peak current can vary within the tolerances given in Table 3 below.

Table 3 – Ring wave specification at the EUT power port of the CDN

Ring wave parameter under short-circuit condition	Peak current
Peak current I_{pk1}	
Current rating ≤ 16 A	+10 –10 %
$16 \text{ A} < \text{current rating} \leq 32 \text{ A}$	+10 –10 %
$32 \text{ A} < \text{current rating} \leq 63 \text{ A}$	+10 –25 %
NOTE The current rating is the CDN rating.	

All performance characteristics stated in 6.1.3, with the exception of the repetition rate, shall be met at the output of the CDN. Phase shifting performance shall be met at 0° , 90° , 180° and 270° at one polarity.

The above mentioned characteristics are applicable for single-phase systems (line, neutral, protective earth) and three-phase systems (three-phase wires, neutral and protective earth).

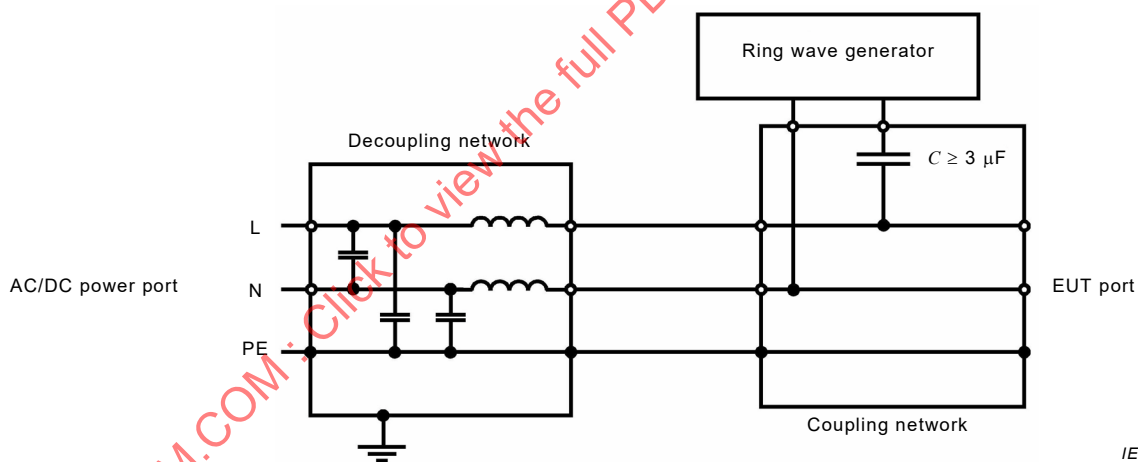
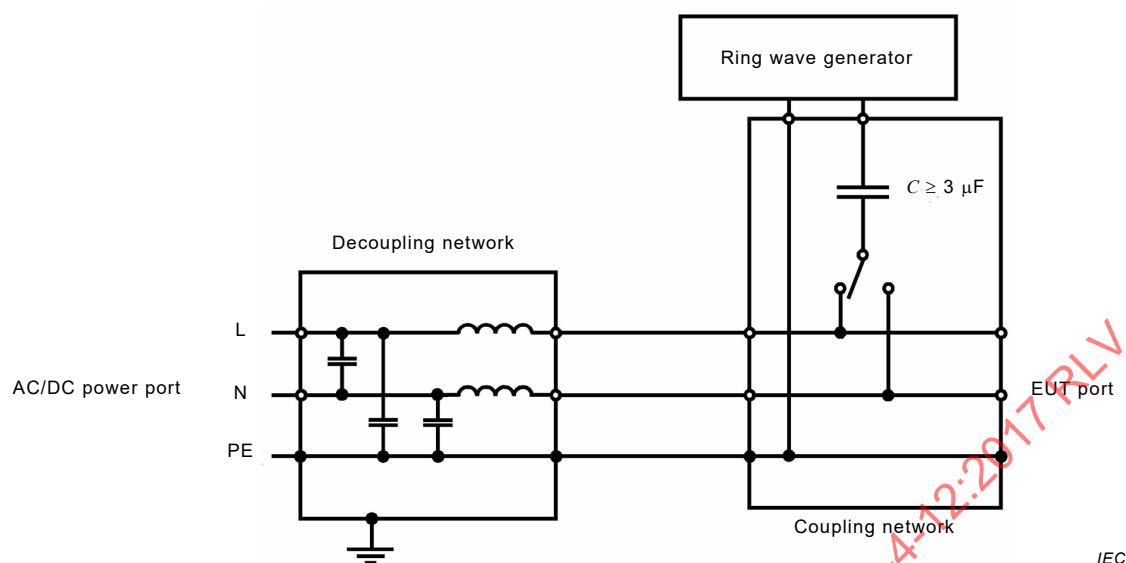
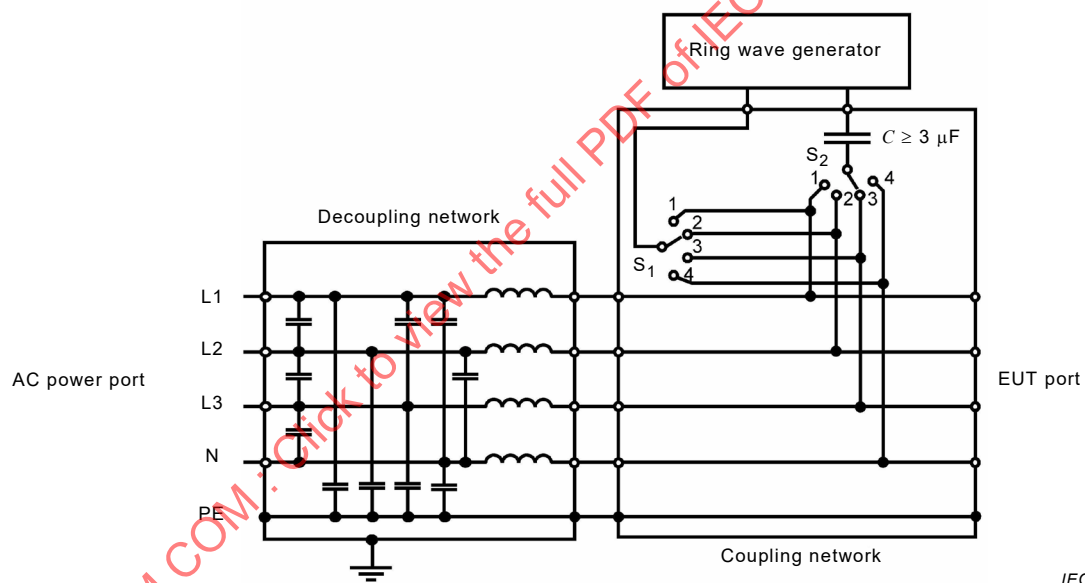


Figure 4 – Example of coupling network and decoupling network for capacitive coupling on AC/DC lines: line-to-line coupling



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Figure 5 – Example of coupling network and decoupling network for capacitive coupling on AC/DC lines: line-to-ground coupling

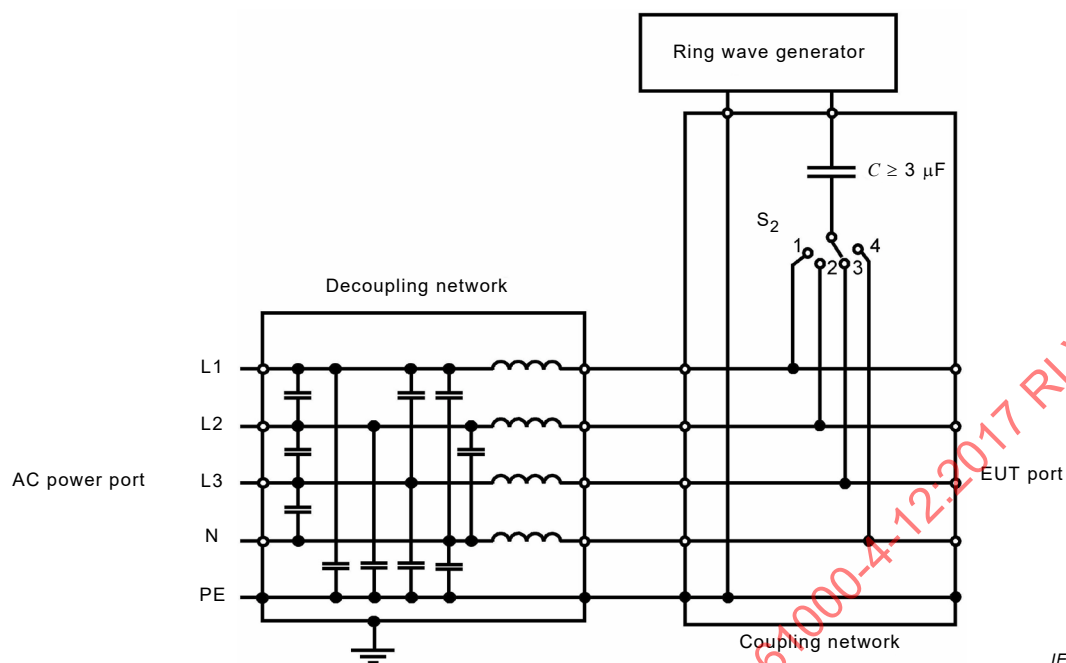


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Switches S_1 and S_2 are used to select individual lines for test.

During testing, the position of switch S_2 is different from the position of switch S_1 .

Figure 6 – Example of coupling network and decoupling network for capacitive coupling on AC lines (three phases): line L3-to-line L2 coupling



Switch S₂ is used to select individual lines for test.

Figure 7 – Example of coupling network and decoupling network for capacitive coupling on AC lines (three phases): line L3-to-ground coupling

6.2.3 Coupling/decoupling networks for interconnection lines

6.2.3.1 General

The coupling method shall be selected as a function of interconnection cable types, the circuits, and the operational conditions supported by the product specification/standard.

Coupling to unshielded lines requires coupling devices (CDs) that ensure sufficient insulation between the interconnection lines and the ring wave generator, but allow efficient transfer of the ring wave impulse.

Any CDs, such as capacitors or gas discharge tubes (GDTs) capable of meeting the coupling and insulation functions may be used.

Coupling using capacitors maintains waveform integrity, but may have filtering effects on fast data transfer.

Avalanche devices like GDTs have a low parasitic capacitance and allow connection to most types of interconnection lines. The breakdown voltage of the coupling device shall be selected to be as low as possible, but higher than the maximum working voltage of the lines to be tested.

All CDNs shall meet the calibration requirements in 6.3.

Current compensated inductors shall be used in the decoupling network if the signal lines are symmetrical.

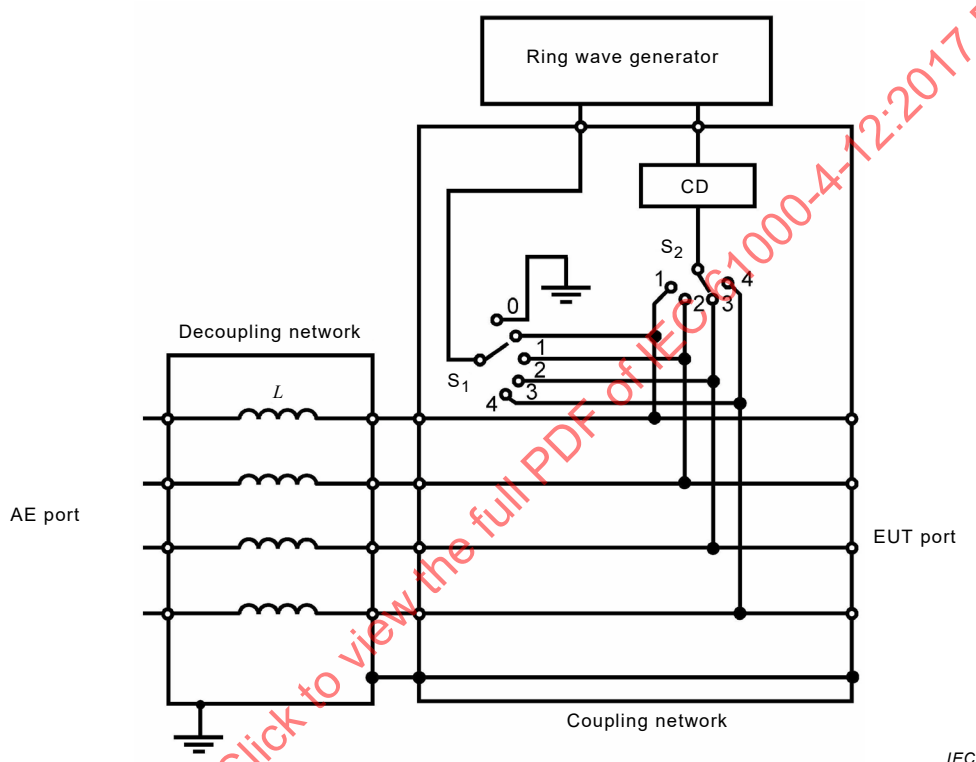
The required decoupling performance on the AE side depends on the application specification and determines the value of the decoupling elements (inductors, resistors, capacitors, GDTs, clamping devices, etc.) to be used. In order to ensure the best possible decoupling

performance and AE protection, a case specific analysis is required for the choice of the decoupling elements.

6.2.3.2 Coupling/decoupling of ring waves to unshielded unsymmetrical interconnection lines

Coupling to unshielded unsymmetrical interconnection lines can be to both line-to-line and line-to-ground. Decoupling is provided with one decoupling choke per line.

An example of a coupling/decoupling network for unshielded unsymmetrical interconnection lines is shown in Figure 8.



- 1) Switch S_1
 - line-to-ground: position 0
 - line-to-line: positions 1 to 4
- 2) Switch S_2 : Positions 1 to 4
 - during testing, the position of switch S_2 is different from the position of switch S_1

NOTE For details of CD: see Table 5.

Figure 8 – Example of coupling network and decoupling network for unshielded unsymmetrical interconnection lines: line-to-line and line-to-ground coupling

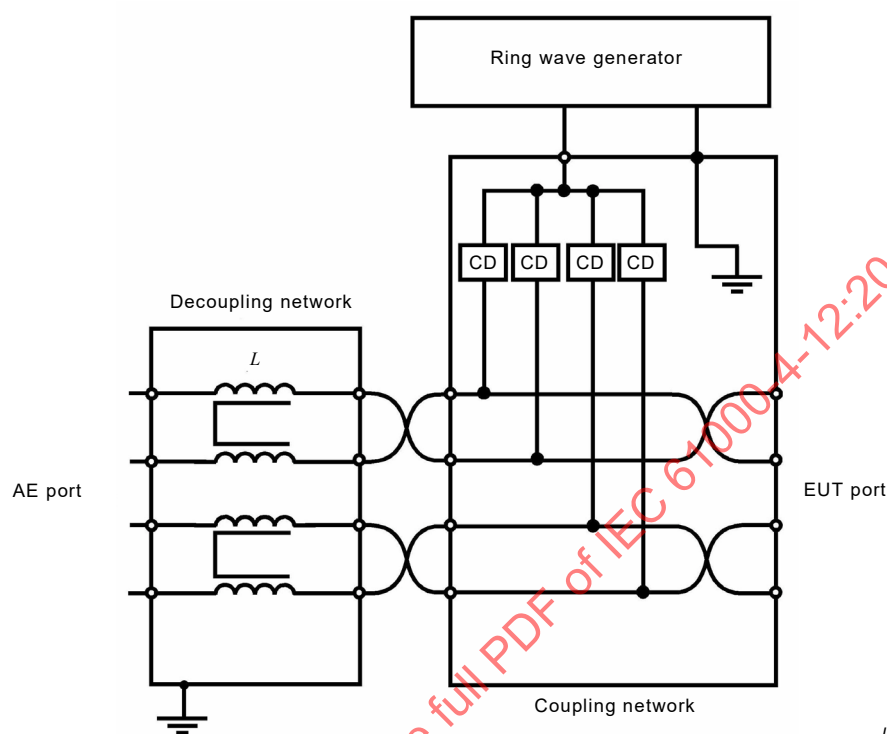
6.2.3.3 Coupling/decoupling of ring waves to unshielded symmetrical interconnection lines

Due to the characteristic nature of unshielded wiring, coupling to symmetrical interconnection lines (twisted pairs) is always in common mode, i.e. coupling between all lines to ground.

The energy transfer from the ring wave generator to the EUT is considered to be a constant which is independent from the number of lines in the cable. The CDN shall be selected to match the number of lines/pairs existing in the cable; however, for cables with more than eight lines/four pairs the pairs shall be split and linked through several eight-line/four-pair CDNs.

Common mode chokes are used for decoupling, allowing fast data transfer and ensuring efficient common mode decoupling.

One example of a coupling/decoupling network for unshielded symmetrical interconnection lines is shown in Figure 9.



L with current compensation may include all four coils or only pairs (as shown in Figure 9) to be effective.

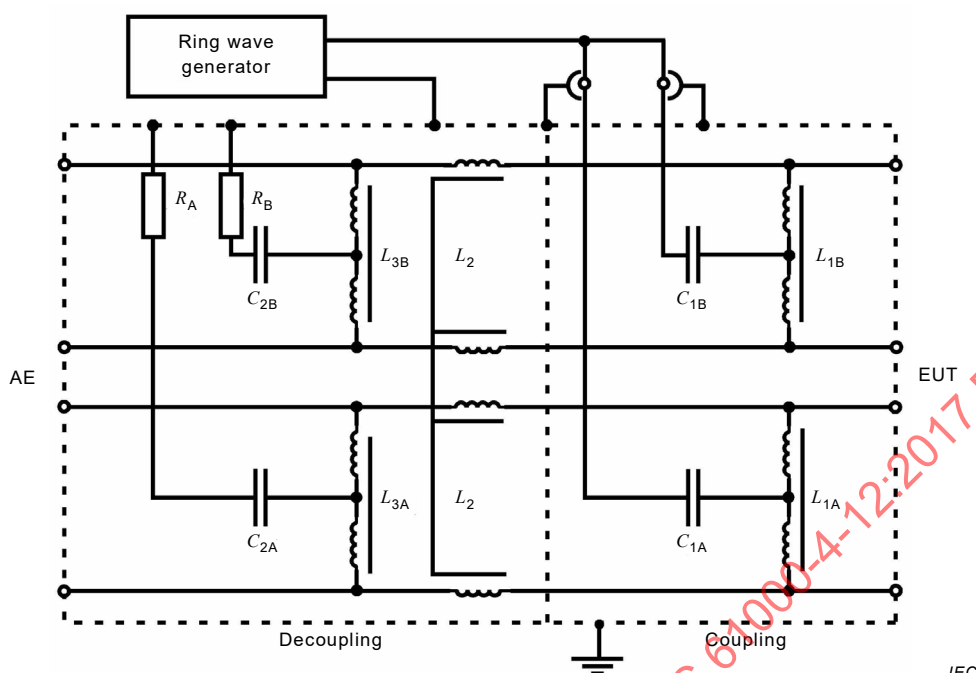
NOTE For details of CD: see Table 7.

Figure 9 – Example of coupling and decoupling network for unshielded symmetrical interconnection lines: lines-to-ground coupling

For high-speed interconnection lines, the examples given in Figure 9 and Figure 10 can be used.

In order to avoid the coupling and decoupling capacitors having a filtering effect on the data transfer, a balanced high frequency design associating the coupling capacitors with coupling chokes is required.

Figure 10 shows an example of a coupling and decoupling network for a two-pair symmetrical interconnection lines. A similar design with four-pair symmetrical interconnection lines allows tests with an interconnection speed up to 1 Gbit/s (Ethernet).



R_A , R_B , C_1 , C_2 , L_1 , L_2 , L_3 : All components are selected so that the specified impulse parameters are met.

NOTE The generator impedance is 30 Ω for two pairs as shown or multiple pairs.

Figure 10 – Example of coupling and decoupling network for unshielded symmetrical interconnection lines: lines-to-ground coupling via capacitors

Where normal functioning cannot be achieved because of the impact of the CDN on the EUT, product committees should specify appropriate operation or that no ring wave test is required.

6.3 Calibration of coupling/decoupling networks

6.3.1 General

In order to compare the test results from different CDNs, the CDN shall be calibrated periodically. For this purpose, the following procedure is necessary to measure the most essential characteristics of the CDN. The waveform parameters measured at the EUT port of the CDN are dependent upon the generator source and as such are only valid for the particular generator/CDN combination tested.

The measuring equipment used for the calibration of the CDN shall satisfy the same requirements applicable to the calibration of the generator (see 6.1.4).

6.3.2 Calibration of CDNs for AC/DC power port rated up to 63 A per line

The characteristics of the CDN shall be measured under open-circuit conditions (load greater than or equal to 10 k Ω) and under short-circuit conditions (less than 0,1 Ω) at the same set voltage.

The residual ring wave voltage measured between coupled lines and ground on the AC/DC power port of the decoupling network with EUT and mains supply not connected shall not exceed 15 % of the maximum applied test voltage or twice the rated peak voltage of the CDN, whichever is higher.

The unwanted ring wave voltage measured between non-coupled lines and ground with EUT and mains supply not connected shall not exceed 15 % of the maximum applied test voltage (open-circuit).

NOTE Due to the structure of the coupling/decoupling network a significant part of the test voltage can appear as a line-to-line voltage during line-to-ground coupling. This voltage can be higher than the corresponding line-to-line test level in the case of a high impedance EUT (see 7.3. for further information).

All performance characteristics stated in 6.2.2, Table 3, shall be met at the EUT port of the CDN with the AC/DC power port left in an open-circuit condition.

6.3.3 Calibration of CDNs for interconnection lines

6.3.3.1 General

It is recommended and sufficient to calibrate the CDNs for interconnection lines in the same configuration (same coupling and decoupling elements fitted) that will be used for testing.

The residual ring wave voltage measured between the coupled lines and ground on the AE side of the CDN, with the EUT and AE equipment disconnected, shall be measured and recorded so that users of the CDN may determine if the protection is sufficient for use with a particular AE.

6.3.3.2 Calibration of CDNs for unsymmetrical interconnection lines

The measurements shall be performed with the impulse applied to one coupling path at a time.

The peak voltage, the rise time, the oscillation period and the ratio between peaks shall be measured for the CDN rated impulse voltage at the EUT port according to Table 4.

The peak current and the rise time shall be measured for the CDN rated impulse voltage at the EUT port according to Table 4.

The inputs of the DN at the AE side shall be short-circuited to PE for the impulse voltage and impulse current measurement at the EUT port.

The residual voltage value depends on the protection requirements of the AE. Therefore no limits are given in this document.

**Table 4 – Summary of calibration process for CDNs
for unsymmetrical interconnection lines**

	Coupling	Measuring	AE side	EUT side
Ring wave voltage at EUT side	Single line to PE	Single line Peak voltage, rise time, voltage oscillation period, ratio between peaks	All lines shorted to PE	Open-circuit
Ring wave current at EUT side	Single line to PE	Single line Peak current, rise time	All lines shorted to PE	Short-circuit
Ring wave voltage at EUT side	Single line-to-line	Single line Peak voltage, rise time, voltage oscillation period, ratio between peaks	All lines shorted to PE	Open-circuit
Ring wave current at EUT side	Single line-to-line	Single line Peak current, rise time	All lines shorted to PE	Short-circuit
Residual voltage on AE side (with protection elements)	Single line to PE	Line to PE at a time Peak voltage	Open-circuit	Open-circuit

The intention of this calibration process is to check the proper function of the components, the saturation of decoupling chokes, the decoupling effect of the DN part, the current capability and the coupling effect of the CN part. The coupling method described in the above paragraphs has an influence on the voltage and current wave forms. The parameters for the calibration are defined in Table 5.

Table 5 – Ring wave waveform specifications at the EUT port of the CDN for unsymmetrical interconnection lines

Coupling method	RWG output voltage ^{a,b,c}	U_{pk1} at CDN EUT port $\pm 10 \%$	Voltage rise time T_1 $\pm 30 \%$	Voltage oscillation period T $\pm 10 \%$	I_{pk1} at CDN EUT port $\pm 10 \%$	Current rise time T_1
Line to PE CD $\geq 3 \mu\text{F}$	4 kV	4 kV	0,5 μs	10 μs	133,3 A	0,2 μs to 1,0 μs
Line to PE CD = GDT	4 kV	4 kV	0,5 μs	10 μs	133,3 A	0,2 μs to 1,0 μs
Line-to-line CD $\geq 3 \mu\text{F}$	4 kV	4 kV	0,5 μs	10 μs	133,3 A	0,2 μs to 1,0 μs
Line-to-line CD = GDT	4 kV	4 kV	0,5 μs	10 μs	133,3 A	0,2 μs to 1,0 μs
^a It is recommended to calibrate the CDN at the highest rated impulse voltage, as this will minimise the effects of the switching noise generated by CLDs and GDTs. The value shown in the table is for a generator setting of 4 kV and 30 Ω. In case the CDN is rated for another maximum impulse voltage, the calibration shall be done at this maximum rated impulse voltage. The short-circuit peak current specification shall be adapted accordingly. For example, if the maximum voltage is 1 kV the short-circuit current value shown in this table shall be multiplied by 1/4. ^b Coupling via gas arrestors, clamping or avalanche devices will show some switching noise on the impulse waveform. Working with the highest possible impulse voltage will minimise their impact on measurements; it is recommended to neglect the switching noise for the front times and duration values measurements. ^c The values shown in this table are for a ring wave generator with ideal values. In case the ring wave generator generates parameter values close to the tolerances, the additional tolerances of the CDN may generate values out of the tolerances for the ring wave generator-CDN combination.						

6.3.3.3 Calibration of CDNs for symmetrical interconnection lines

The measurements shall be performed as indicated in Table 6 at the CDN rated impulse voltage. The peak voltage and current, the rise time and the oscillation period shall be measured at the EUT port according to Table 6.

The inputs of the DN at the auxiliary equipment (AE) shall be short-circuited to PE for the voltage and current measurements at the EUT port.

The residual voltage value depends on the protection requirements of the AE. Therefore no limits are given in this document.

NOTE The open-circuit voltage between wires of different pairs can also be measured. A differential voltage between pairs can produce false failures in EUTs that are designed to operate in highly balanced networks. No limit has been proposed for this value as the tolerance is dependent upon the design of the EUT.

**Table 6 – Summary of calibration process for CDNs
for symmetrical interconnection lines**

	Coupling	Measuring	AE side	EUT side
Ring wave voltage at EUT side	Common mode – all lines to PE	All lines shorted together Peak voltage, rise time, voltage oscillation period, ratio between peaks	All lines shorted to PE	Open-circuit – all lines connect together
Ring wave current at EUT side	Common mode – all lines to PE	All lines shorted together Peak current, rise time	All lines shorted to PE	All lines shorted to PE
Residual voltage on AE side (with protection elements)	Common mode – all lines to PE	Each line to PE in turn Peak voltage	Open-circuit	Open-circuit

The intention of this calibration process is to check the proper function of the components, the saturation of decoupling chokes, the decoupling effect of the DN part, the current capability and the coupling effect of the CN part. The coupling method described in the above paragraphs has an influence on the voltage and current wave forms. The parameters for the calibration are defined in Table 7.

**Table 7 – Ring wave waveform specifications at the EUT port
of the CDN for symmetrical interconnection lines**

Coupling method	RWG output voltage ^{a, b, c}	U_{pk1} at CDN EUT port $\pm 10 \%$	Voltage rise time T_1 $\pm 30 \%$	Voltage oscillation period T $\pm 10 \%$	I_{pk1} at CDN EUT port $\pm 10 \%$	Current rise time T_1
Common mode CD ^d	2 kV	2 kV	0,5 μ s	10 μ s	66,7 A	0,2 μ s to 1,0 μ s

^a It is recommended to calibrate the CDN at the highest rated impulse voltage, as this will minimise the effects of the switching noise generated by CLDs and GDTs. The value shown in the table is for a generator setting of 2 kV and 30 Ω . In case the CDN is rated for another maximum impulse voltage, the calibration shall be done at this maximum rated impulse voltage. The short-circuit peak current specification shall be adapted accordingly. For example, if the maximum voltage is 4 kV, the short-circuit current value shall be multiplied by 2.

^b Coupling via gas arrestors, clamping or avalanche devices will show some switching noise on the impulse wave. Working with the highest possible impulse voltage will minimise their impact on measurements, however, it is recommended to neglect the switching noise for the peak values measurements.

^c The values shown in this table are for a ring wave 30 Ω generator with ideal values. In case the ring wave generator generates parameter values close to the tolerances, the additional tolerances of the CDN may generate values out of the tolerances for the ring wave generator-CDN combination.

^d The CD can be based upon capacitors, gas arrestors, clamping devices, avalanche devices or any method that allows the wanted data of the EUT to function correctly and at the same time meet the impulse waveform parameters of this table.

7 Test setup

7.1 Test equipment

The following equipment is part of the test setup:

- equipment under test;
- auxiliary equipment when required;

- cables (of specified type and length);
- coupling/decoupling networks;
- ring wave generator;
- reference ground plane for tests to shielded lines as described in 7.6 and Figure 11.

7.2 Verification of the test instrumentation

The purpose of verification is to ensure that the test setup is operating correctly. The test setup includes:

- the ring wave generator;
- the CDN;
- the interconnection cables of the test equipment.

To verify that the system is functioning correctly, the following signal should be checked:

- ring wave present at the output terminal of the CDN.

It is sufficient to verify that the ring wave is present at any level by using suitable measuring equipment (e.g. oscilloscope) without an EUT connected to the system.

NOTE Test laboratories can define an internal control reference value assigned to this verification procedure.

7.3 Test setup for ring waves applied to EUT power ports

The ring wave shall be applied to the EUT power supply terminals via the capacitive coupling network (see Figure 4, Figure 5, Figure 6 and Figure 7). Decoupling networks are required in order to avoid possible adverse effects on equipment not under test that may be powered by the same lines and to provide sufficient decoupling impedance to the ring wave wave so that the specified wave may be applied on the lines under test.

The selection of the CDN specification from Table 3 shall be made to match the current rating of the EUT (for example: an EUT rated at 5 A shall be tested using a CDN fulfilling the specifications of a 16 A rated CDN). Any higher current rated CDN can be used if it meets the specification requirements in Table 3 for the relevant lower current rating of the EUT (for example: a CDN rated 63 A can be used for testing an EUT rated at 5 A, if it meets the specification requirements of a 16 A rated CDN).

If not otherwise specified the power cord between the EUT and the coupling network shall not exceed 2 m in length.

For the purpose of generating the specifications within this document, power ports have been considered to be those ports directly connected to either an AC mains supply or a DC mains supply (distribution network).

Product committees may decide that power ports not connected to distribution networks require testing according to this document using a CDN defined in 6.3.3.

DC mains supply ring wave testing is applied between the lines (e.g. 0 V to -48 V) and between each line in turn and ground (e.g. 0 V to ground and -48 V to ground).

No line-to-ground ring waves are applied for double-insulated products (i.e. products without any dedicated earth terminal).

Product committees may decide if line-to-ground ring wave testing is applicable to double-insulated products with earthed connections other than PE.

7.4 Test setup for ring waves applied to unshielded unsymmetrical interconnection lines

The CDN shall not influence the specified functional conditions of the circuits to be tested.

An example of a coupling network is given in Figure 8.

If not otherwise specified, the interconnection line between the EUT and the coupling network shall not exceed 2 m in length.

No line-to-ground ring waves are applied for double-insulated products (i.e. products without any dedicated earth terminal).

7.5 Test setup for ring waves applied to unshielded symmetrical interconnection lines

Examples of coupling networks for symmetrical interconnection lines are given in Figure 9 and Figure 10.

NOTE If coupling arrestors are used, test levels below the ignition point of the coupling arrestor (the ignition point is about 300 V for a gas arrestor with a rated voltage of 90 V) cannot be specified.

If not otherwise specified the interconnection line between the EUT and the coupling network shall not exceed 2 m in length.

For ring wave testing to high speed interconnection lines, no ring wave test shall be applied when normal functioning cannot be achieved because of the impact of the CDN on the EUT.

No line-to-ground ring waves are applied for double-insulated products (i.e. products without any dedicated earth terminal).

7.6 Test setup for ring waves applied to shielded lines

The EUT is isolated from ground and the ring wave is applied to its metallic enclosure; the termination (or auxiliary equipment) at the port(s) under test is grounded. This test applies to equipment with one or more shielded cables (see Figure 11).

NOTE 1 The reference ground plane mentioned in Figure 11 represents a low impedance reference. A dedicated cable or a metal plate can be used.

All connections to the EUT other than the port(s) under test shall be isolated from ground by suitable means such as safety isolating transformers or a suitable decoupling network.

No line-to-ground ring waves are applied for double-insulated products (i.e. products without any dedicated earth terminal).

The length of the cable between the port(s) under test and the device attached to the other end of the cable (AE in Figure 11) shall be:

- 20 m (preferred length), or
- the shortest length over 10 m, where the manufacturer provides pre-assembled cables used in actual installations.

No test shall be required for cables which according to the manufacturer's specification are ≤ 10 m.

The cable between the EUT and the AE shall be non-inductively bundled or wound as a bifilar coil and shall be placed on an insulated support.

8 Test procedure

8.1 General

The test procedure includes:

- the verification of the test instrumentation according to 7.2;
- the establishment of the laboratory reference conditions;
- the confirmation of the correct operation of the EUT;
- the execution of the test;
- the evaluation of the test results (see Clause 9).

8.2 Laboratory reference conditions

8.2.1 Climatic conditions

Unless otherwise specified by the committee responsible for the generic or product standard, the climatic conditions in the laboratory shall be within any limits specified for the operation of the EUT and the test equipment by their respective manufacturers.

Tests shall not be performed if the relative humidity is so high as to cause condensation on the EUT or the test equipment.

8.2.2 Electromagnetic conditions

The electromagnetic conditions of the laboratory shall be such as to guarantee the correct operation of the EUT so as not to influence the test results.

8.3 Execution of the test

Verification shall be performed. It is preferable to perform the verification prior to the test (see 7.2).

The test shall be performed according to a test plan which shall specify the test setup, including:

- test level;
- number of impulses (for each coupling path):
number of ring wave impulses unless otherwise specified by the relevant standard:
 - for DC power ports and interconnection lines five positive and five negative ring wave impulses;
 - for AC power ports five positive and five negative impulses each at 0°, 90°, 180° and at 270°;
- time between successive impulses: 1 min or less;
- representative operating conditions of the EUT;
- EUT ports to be tested;
- test generator and the internal impedance selected for each test;
- applied test levels.

Power ports (AC or DC) can be input ports or output ports.

Ring waves to output ports are recommended in applications where ring waves are likely to enter the EUT via those output ports (e.g. switching of loads with large power consumption).

When testing three-phase systems, the synchronization of phase angles shall be taken from the same line under test, for example when applying ring wave impulses between L2 and L3, the phase angle synchronization shall be the voltage between L2 and L3.

No synchronization is applied in case of absence of mains supply voltage between the coupled lines, for example between N and PE in TN-S power distribution systems. In this case, five positive impulses and five negative impulses shall be applied.

Ring waves to low voltage DC input/output ports (≤ 60 V) are not applied when secondary circuits (isolated from the AC mains) are not subject to transient overvoltages (i.e. reliably-grounded, capacitively-filtered DC secondary circuits where the peak-to-peak ripple is less than 10 % of the DC component).

NOTE 1 In the case of several identical circuits, representative tests on a selected number of circuits can be sufficient.

If testing done at rates faster than one per minute causes failures and tests done at one per minute do not, the test done at one per minute prevails.

NOTE 2 Product committees can select different phase angles and either increase or reduce the number of ring waves per phase if appropriate for their products.

NOTE 3 Most protectors in common use have limited average power capabilities even though their peak power or peak energy handling capabilities can deal with high currents. Therefore, the time between two ring waves depends on the built-in protection devices of the EUT.

NOTE 4 Further information on the application of the tests is given in Clause C.2.

When testing line-to-ground, the lines are tested individually in sequence, if there is no other specification.

The test procedure shall also consider the non-linear current-voltage characteristics of the equipment under test. Therefore all lower test levels (see Table 1) including the selected test level shall be tested.

9 Evaluation of test results

The test results shall be classified in terms of the loss of function or degradation of performance of the equipment under test, relative to a performance level defined by its manufacturer or the requestor of the test, or agreed between the manufacturer and the purchaser of the product. The recommended classification is as follows:

- a) normal performance within limits specified by the manufacturer, requestor or purchaser;
- b) temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention;
- c) temporary loss of function or degradation of performance, the correction of which requires operator intervention;
- d) loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.

The manufacturer's specification may define effects on the EUT which may be considered insignificant, and therefore acceptable.

This classification may be used as a guide in formulating performance criteria, by committees responsible for generic, product and product-family standards, or as a framework for the agreement on performance criteria between the manufacturer and the purchaser, for example where no suitable generic, product or product-family standard exists.

10 Test report

The test report shall contain all the information necessary to reproduce the test. In particular, the following shall be recorded:

- the items specified in the test plan required in Clause 8 of this document;
- identification of the EUT and any associated equipment, for example brand name, product type, serial number;
- identification of the test equipment, for example brand name, product type, serial number;
- any special environmental conditions in which the test was performed, for example shielded enclosure;
- any specific conditions necessary to enable the test to be performed;
- performance level defined by the manufacturer, requestor or purchaser;
- performance criterion specified in the generic, product or product-family standard;
- any effects on the EUT observed during or after the application of the test disturbance, and the duration for which these effects persist;
- the rationale for the pass/fail decision (based on the performance criterion specified in the generic, product or product-family standard, or agreed between the manufacturer and the purchaser);
- any specific conditions of use, for example cable length or type, shielding or grounding, or EUT operating conditions, which are required to achieve compliance;
- test configuration (hardware) including the coupling method used;
- test configuration (software).

Annex A (informative)

Information on electromagnetic environments, installation classes and test levels

The relevance of the ring wave phenomena for immunity testing depends on the electromagnetic environment where equipment is intended to be operated. Based on common installation practices which are representative for the electromagnetic environment concerned, a guide for the selection of levels for ring waves testing may be based on the following classification. According to the description of the ring wave phenomenon (see 4.1), effects of switching and of lightning are considered.

- Class 0** Well-protected electrical environment, often within a special room. All incoming cables are provided with overvoltage (primary and secondary) protection. The units of the electronic equipment are interconnected by a well-designed grounding system, which is not significantly influenced by the power installation or lightning. The electronic equipment has a dedicated power supply (see Table B.1).
- Class 1** Switching: the power supply port of the EUT is connected to protected local power source (for example uninterruptible power system, power converter). The cables of EUT input/output ports run in parallel with power cables of this class.
- Lightning: power supply, input/output ports of equipment are installed in partly protected areas (for example in a control room).
- The requirements of this class are covered by test level 1 as defined in Table 1.
- Class 2** Switching: the power supply port of the EUT is directly connected to the public mains distribution systems of the residential area or is decoupled from a private mains power distribution system through isolation transformers, protection devices, etc. The cables of EUT input/output ports run in parallel with power cables of this class.
- Lightning: power supply, input/output ports are connected to shielded cables.
- The requirements of this class are covered by test level 2 as defined in Table 1.
- Class 3** Switching: the power supply port of the EUT is connected to dedicated power distribution systems in electrical and industrial plants. The cables of EUT input/output ports run in parallel with power cables of this class.
- Lightning: the power supply port is connected to unshielded cables; power supply, input/output ports connected to outdoor cables are provided with mitigation measures (for example, metallic cable trays).
- The requirements of this class are covered by test level 3 as defined in Table 1.
- Class 4** Switching: the power supply port of the EUT is connected to power sources characterized by switching of heavy inductive loads in electrical and industrial plants. The cables of EUT input/output ports run in parallel with power cables of this class.
- Lightning: power supply, input/output ports are connected to outdoor cables without shielding provisions.
- The requirements of this class are covered by test level 4 as defined in Table 1.
- Class 5** Switching: electronic equipment connected to telecommunication cables and overhead power lines in a non-densely populated area.
- Lightning: All these cables and lines are provided with overvoltage (primary) protection. Outside the electronic equipment there is no widespread grounding system (exposed plant). The interference voltages due to lightning (currents up to 100 kA) can be extremely high.
- The requirements of this class are covered by test level 4 as defined in Table 1.

Class X The minor or major electromagnetic separation of interference sources from equipment circuits, cables, lines etc., and the quality of the installations may require the use of a higher or lower test level than those described above. This may need a case-by-case assessment.

It should be noted that the lines of equipment (e.g. cabling, bus bars, overhead lines) associated to electromagnetic environments with higher test levels can penetrate into locations being assigned to an environment with lower test levels. In such cases a re-assessment of the latter location with respect to the suitable test levels should be carried out.

A manufacturer should test its equipment on the basis of the specified test levels to confirm the equipment level immunity, for example with secondary protection at the ports of the EUT for a level of 0,5 kV. The users of the plant or those responsible for the installation should then apply measures (e.g. shielding, bonding, grounding protection) necessary to ensure that the interference voltage caused by, for example, switching does not exceed the chosen immunity level.

The above selection of test levels in terms of electromagnetic environments should be used as a guide only. There might be cases where a location might be assigned to one of the above types of electromagnetic environments but due to the features of the equipment concerned or other circumstances a different test level than that associated to that type of electromagnetic environment might be more appropriate. Corresponding assessment should be done by the parties involved (e.g. product committees).

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Annex B (informative)

Selection of generators and test levels

B.1 General

The selection of the test levels should be based on the installation conditions and may be specified in product or product family standards. Where there are no defined levels, Table B.1 and Table B.2 should be used, together with the information given in Annex A. These values are included for illustration only and do not form a recommendation or requirement. The values have been chosen only for explanatory purposes and are not put forward as some recommended practice.

B.2 The classification of environments

The classification of environments is listed as follows:

Class 0: Well-protected electrical environment, often within a special room

Class 1: Partly protected electrical environment

Class 2: Electrical environment where the cables are well-separated, even at short runs

Class 3: Electrical environment where cables run in parallel

Class 4: Electrical environment where the interconnections run as outdoor cables along with power cables, and cables are used for both electronic and electric circuits

Class 5: Electrical environment for electronic equipment connected to communication cables and overhead power lines in a non-densely populated area

Class x: Special conditions specified in the product specification

To demonstrate the system level immunity, additional measures relevant to the actual installation conditions, for example primary protection, should be taken. Additional information is given in Annex C.

B.3 The definition of port types

The following ports are defined:

Intra-system port:

- The port is connected to ports within the same system.

Internal port:

- Only connected to cables within the same building.
- The port is not intended to provide a service that can be directly connected to an outdoor connection.
- The port will not have a conductive connection to a cable which leaves the building via other equipment (e.g., via a splitter).

External port:

- The port is intended to connect directly to lines which exit a building.
- The port has a conductive connection to a cable which leaves the building via other equipment (e.g., via a splitter).

B.4 Selection of the test levels

Examples of the selection of test levels are given in Table B.1 and Table B.2.

**Table B.1 – Power ports: Selection of the test levels
(depending on the installation class)**

Installation class	Test levels (kV)							
	AC power supply and AC I/O external ports ^a		AC power supply and AC I/O internal ports ^{a d}		DC power supply and DC I/O external ports ^a		DC power supply and DC I/O internal ports ^{a d}	
	Coupling mode		Coupling mode		Coupling mode		Coupling mode	
	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground
0	NA	NA	NA	NA	NA	NA	NA	NA
1	NA	0,5	NA	NA	NA	NA	NA	NA
2	0,5	1,0	NA	NA	NA	Nan	NA	NA
3	1,0	2,0	1,0	2,0	NA	NA	NA	NA
4	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b
5	c, b	c, b	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b

^a No test is advised if the cable length is shorter than or equal to 10 m.

^b Where the port is always intended to be used with specified primary protection, testing is performed with the primary protection in place to ensure coordination with the protection elements. If primary protection is required to protect the interface but not provided, testing is also performed at the maximum let through level of the specified primary protection and with a typical primary protector.

^c Depends on the class of the local power supply system.

^d The testing of intra-system ports is generally not required.

**Table B.2 – Circuits/lines: Selection of the test levels
(depending on the installation class)**

Installation class	Test levels (kV)											
	Unsymmetrical operated circuits/lines ^{a, c, e}				Symmetrical operated circuits/lines ^{a, c, e}				Shielded circuits/lines ^{a, d, e}			
	External port		Internal port		External port		Internal port		External port		Internal port	
	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground
0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	NA	NA	NA	0,5	NA	NA	NA	0,5	NA	NA	NA	NA
2	NA	NA	0,5	1,0	NA	NA	NA	1,0	NA	NA	NA	1,0
3	NA	NA	1,0	2,0	NA	NA	NA	2,0	NA	NA	NA	2,0
4	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b
5	2,0 ^b	4,0 ^b	2,0 ^b	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b	NA	4,0 ^b
^a No test is advised for data connections intended for cables shorter than 10 m. ^b Where the port is always intended to be used with specified primary protection, testing is performed with the primary protection in place to ensure coordination with the protection elements. If primary protection is required to protect the interface but not provided, testing is also performed at the maximum let through level of the specified primary protection and with a typical primary protector. ^c Line-to-line transients (transverse) may occur in networks where SPDs (surge protective devices) with connection to ground are used for protection. Such ring waves are outside the scope of this document. This phenomenon can however be simulated by applying common mode ring waves through the defined primary protection elements. ^d The testing of ports connecting to antennas is outside the scope of this document. ^e The testing of intra-system ports is generally not required.												

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Annex C (informative)

Explanatory notes

C.1 Different source impedance

The selection of the source impedance of the generator depends on the kind of cable/conductor/line, i.e. AC power supply, DC power supply, shielded interconnection or unshielded interconnection lines, etc. and on the expected impedance of the power supply network depending on the proximity to the power supply source (e.g. generator, transformer) (see 6.1.2).

C.2 Application of the tests

C.2.1 Equipment level immunity

The test is intended to be carried out in the laboratory on a single EUT. The immunity of the EUT thus tested refers to equipment level immunity.

Preferential ranges of test levels are given in Table B.1 and Table B.2. The ring wave test is applicable to external connections only (i.e. connections outside of the cabinet/housing).

It is highly recommended that the test voltage does not exceed the specified capability of the EUT's insulation to withstand high-voltage stress.

If it is possible to test at the system level (see C.2.2), it is not necessary to test at the equipment level, especially in cases where the shield of the interconnection cable is part of the protection measure.

C.2.2 System level immunity

A test carried out in the laboratory refers to an EUT, but immunity at the EUT level does not necessarily assure the immunity of a system which contains that EUT. In order to ensure system level immunity, a test at the system level is recommended to simulate the real installation as closely as possible. This simulated installation should be comprised of individual EUTs and should also include protective devices (surge protective devices (SPDs)) if they are requested by the system application manual or stipulated by the system/network operator. The real length and type of interconnection lines should be used, all of which could affect the overall system protection level.

Annex D (informative)

Measurement uncertainty (MU) considerations

D.1 General

The reproducibility of EMC tests relies on many factors, or influences, that affect the test results. These influences may be categorized as random or systematic effects. The compliance of the realized disturbance quantity with the disturbance quantity specified by this document is usually confirmed through a set of measurements (e.g. measurement of the rise time of an impulse with an oscilloscope by using a voltage or current probe). The result of each measurement includes a certain amount of measurement uncertainty (MU) due to the imperfection of the measuring instrumentation as well as to the lack of repeatability of the measurand itself.

In order to evaluate MU it is necessary to:

- a) identify the sources of uncertainty, related both to the measuring instrumentation and to the measurand,
- b) identify the functional relationship (measurement model) between the influence (input) quantities and the measured (output) quantity,
- c) obtain an estimate and standard uncertainty of the input quantities,
- d) obtain an estimate of the interval containing, with a high level of confidence, the true value of the measurand.

In immunity tests estimates and uncertainties are evaluated for the parameters of the disturbance quantity (e.g. rise time, peak and oscillation period). As such, they describe the degree of agreement of the disturbance quantity with the relevant specifications of this basic standard.

These estimates and uncertainties, derived for a particular disturbance quantity, do not describe the degree of agreement between the simulated electromagnetic phenomenon, as defined in the basic standard, and the real electromagnetic phenomenon in the world outside the laboratory.

Since the effect of the parameters of the disturbance quantity on the EUT is a priori unknown and in most cases the EUT shows a nonlinear behaviour, a single estimate and uncertainty numbers cannot be defined for the disturbance quantity. Therefore each of the parameters of the disturbance quantity will be accompanied by the corresponding estimate and uncertainty. This yields to more than one uncertainty budget.

D.2 Legend for ring wave parameters

- | | |
|--------|--|
| T_1 | rise time of the ring wave (voltage or current, 10 % to 90 %) |
| T | period of the ring wave (voltage, time interval between the first and third zero crossings after the initial peak) |
| Pk_1 | first peak of the ring wave (voltage or current) |
| Pk_2 | second peak of the ring wave (voltage) |
| Pk_3 | third peak of the ring wave (voltage) |
| Pk_4 | fourth peak of the ring wave (voltage) |

NOTE The meaning and the relations among the symbols $u(x_i)$, c_i , $u_i(y)$, $u_c(y)$, $U(y)$ and y are explained in IEC TR 61000-1-6.

D.3 Uncertainty contributors to the ring wave measurement uncertainty

The following list shows the contributors used to assess both the measuring instrumentation and test setup influences:

- reading of peak value
- bandwidth of the measuring system
- shape of the impulse response of the measuring system
- oscilloscope vertical axis measurement error
- measurement system, measurand and setup repeatability (type A)
- calibration of oscilloscope
- calibration of voltage and current probes

D.4 Uncertainty of the generator output voltage and current measurement

D.4.1 General

In the case of the ring wave immunity test, the disturbance quantities are the impulse voltage and current generated by the test generator plus CDN combination and applied to the EUT. As discussed in Clause D.1, an uncertainty budget for each measured parameter of the disturbance quantity is required. The parameters of these disturbance quantities are the rise time T_1 of the (open-circuit) voltage and (short-circuit) current waveforms, the amplitude of the first peak Pk_1 of the voltage and current waveforms, the voltage waveform frequency $1/T$, decaying of voltage waveform (ratio between Pk_2 and Pk_1 , Pk_3 and Pk_2 , Pk_4 and Pk_3) and waveform repetition frequency. The evaluation of the measurement uncertainty of the voltage waveform frequency, the decaying of the voltage waveform and the waveform repetition frequency, although required, are less demanding. Therefore attention is focused here on the waveform rise time and peak (both voltage and current).

The approach adopted here to evaluate the impulse MU is described in D.4.5 and D.4.6. Table D.1 and Table D.2 give examples of uncertainty budgets for the amplitude of the first peak and the rise time parameters, respectively. Tables 1 and 2 include the input quantities that are considered most significant for this example, the details (numerical values, type of probability density function, etc.) of each contributor to MU and the results of the calculations required for determining the uncertainty budget.

D.4.2 Rise time of the ring wave

The measurand is the ring wave open-circuit voltage and short-circuit current rise time calculated by using the functional relationship

$$T_1 = \sqrt{(T_{90\%} - T_{10\%} + \delta R)^2 - T_{MS}^2}$$

where

$$T_{MS} = \frac{\alpha}{B}$$

and:

$T_{10\%}$ time at 10 % of the first peak amplitude

$T_{90\%}$ time at 90 % of the first peak amplitude

δR correction for non-repeatability

T_{MS} rise time of the step response of the measuring system (10 % to 90 %)

B –3 dB bandwidth of the measuring system

α coefficient whose value is 360 ± 40 (B in kHz and T_{MS} in μs)

Table D.1 – Example of uncertainty budget for ring wave rise time (T_1)

Symbol	Estimate	Unit	Error bound	Unit	Probability density function (PDF)	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
$T_{10\%}$	0,07	μs	0,005 0	μs	triangular	2,45	0,002 0	–1,001	1	0,002 0	μs
$T_{90\%}$	0,64	μs	0,005 0	μs	triangular	2,45	0,002 0	1,001	1	0,002 0	μs
δR	0	μs	0,025	μs	normal ($k=1$)	1,00	0,025	1,001	1	0,025	μs
α	360	$\mu s \cdot kHz$	40	$\mu s \cdot kHz$	rectangular	1,73	23,1	$-1,58 \cdot 10^{-6}$	1/kHz	0,000 04	μs
B	20 000	kHz	500	kHz	rectangular	1,73	288,7	$2,84 \cdot 10^{-8}$	$\mu s/kHz$	0,000 01	μs
$u_c(y) = \sqrt{\sum u_i(y)^2}$										0,025 2	μs
$U(y) = 2 u_c(y)$										0,05	μs
y										0,57	μs

$T_{10\%}, T_{90\%}$: is the time reading at 10 % or 90 % of the first peak amplitude. The error bound is obtained assuming a sampling frequency of 100 MS/s and trace interpolation capability of the scope (triangular probability density function). Were this not the case, a rectangular probability density function should be assumed. Only the contributor to MU due to the sampling rate is considered here, for additional contributors see D.4.5. The readings are assumed to be $T_{10\%} = 0,07 \mu s$ and $T_{90\%} = 0,64 \mu s$.

T_{MS} : is the calculated rise time of the step response of the measuring system. The coefficient α depends on the shape of the impulse response of the measuring system. The range 360 ± 40 is representative of a wide class of systems, each having a different shape of the impulse response (see D.4.5 and Table D.3). The bandwidth B of the measuring system can be experimentally obtained (direct measurement of the bandwidth) or calculated from the bandwidth B_i of each element of the measurement system (essentially a voltage and current probe, a cable and a scope) by using the following formula:

$$\frac{1}{B} = \sqrt{\left(\frac{1}{B_1}\right)^2 + \left(\frac{1}{B_2}\right)^2 + \dots}$$

An estimate of 20 MHz and a 500 kHz error bound of a rectangular probability density function are assumed for B .

δR : is the 10 % to 90 % rise time non-repeatability. It quantifies the lack of repeatability in the measurement of $T_{90\%} - T_{10\%}$ due to the measuring instrumentation, the layout of the measurement setup and the ring wave generator itself. It is determined experimentally. This is a type A evaluation based on the formula of the experimental standard deviation $s(q_k)$ of a sample of n repeated measurements q_j and given by

$$s(q_k) = \sqrt{\frac{1}{n-1} \sum_{j=1}^n (q_j - \bar{q})^2}$$

where $\bar{q}$ is the arithmetic mean of the q_j values. An error bound $s(q_k) = 25$ ns (1 standard deviation of a normal probability density function) and an estimate of 0 ns are assumed.

NOTE For the open-circuit voltage and short-circuit current the uncertainty budgets are similarly obtained. In the case of the voltage waveform T_{MS} includes the bandwidth of the voltage probe, while it includes the bandwidth of the current probe in the case of the current waveform. The functional relationship is the same in both cases.

D.4.3 Peak of the ring wave

The measurand is the first peak of the short-circuit current of the ring wave obtained by using the functional relationship

$$Pk_1 = \frac{V_{Pk1}}{Z_T} \cdot \frac{1 + \delta R + \delta V}{1 - \left(\frac{\beta}{B}\right)^2}$$

where

V_{Pk1} impulse voltage peak reading

Z_T transfer impedance (or sensitivity) of the current probe or shunt

δR correction for non-repeatability

δV DC vertical accuracy of the scope

B – 3 dB bandwidth of the current measuring system

β coefficient whose value is (142 ± 16) kHz

Table D.2 – Example of uncertainty budget for the peak of the short-circuit current of the ring wave (I_{Pk1})

Symbol	Estimate	Unit	Error bound	Unit	Probability density function (PDF)	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
V_{Pk1}	0,321	V	0,000 6	V	triangular	2,45	0,000 26	1 000	1/Ω	0,256	A
Z_T	0,001	Ω	0,000 05	Ω	rectangular	1,73	0,000 03	$3,21 \cdot 10^5$	A/Ω	9,267	A
δR	0	1	0,03	1	normal ($k=1$)	1,00	0,030	321,0	A	9,630	A
δV	0	1	0,02	1	rectangular	1,73	0,011 6	321,0	A	3,707	A
β	142	kHz	16	kHz	rectangular	1,73	9,238	$2,3 \cdot 10^{-4}$	A/kHz	0,002 11	A
B	20 000	kHz	500	kHz	rectangular	1,73	288,7	$-1,6 \cdot 10^{-6}$	A/kHz	0,000 47	A
							$u_c(y) = \sqrt{\sum u_i(y)^2}$			13,87	A
							$U(y) = 2 u_c(y)$			27,7	A
							y			321	A
							Expressed in % of 321 A			8,6	%

V_{Pk1} : is the voltage peak reading at the output of a current probe or across a current shunt. The error bound is obtained assuming that the scope has an 8-bit vertical resolution with interpolation capability (triangular probability density function).

Z_T : is the transfer impedance (or sensitivity) of the current shunt or probe. An estimated value of 0,001 Ω and an error bound of 5 % (rectangular probability density function) are assumed.

δR : quantifies the non-repeatability of the measurement setup, layout and instrumentation. This is a type A evaluation based on the formula of the experimental standard deviation. It is expressed in relative terms and an estimate of 0 % and an error bound of 3 % (1 standard deviation) are assumed.

δV : quantifies the amplitude measurement inaccuracy of the scope at DC. A 2 % error bound of a rectangular probability density function and an estimate of 0 are assumed.

β : is a coefficient which depends on the shape of both the impulse response of the measuring system and the standard impulse waveform in the neighborhood of the peak (see D.4.6). The interval (142 ± 16) kHz is representative of a wide class of systems, each having a different shape of the impulse response.

B: the bandwidth B of the measuring system can be experimentally obtained (direct measurement of the bandwidth) or calculated from the bandwidth B_i of each element of the measurement system (essentially a current probe or shunt, a cable and a scope) by using the following formula:

$$\frac{1}{B} = \sqrt{\left(\frac{1}{B_1}\right)^2 + \left(\frac{1}{B_2}\right)^2 + \dots}$$

An estimate of 20 MHz and a 500 kHz error bound of a rectangular probability density function are assumed for B .

NOTE The uncertainty of the peak the ring wave voltage is obtained by using a similar functional relationship where the reciprocal of the attenuation of the voltage probe is considered in place of Z_T and B is the bandwidth of the voltage measuring system (voltage probe, cable and oscilloscope).

D.4.4 Further MU contributions to time measurements

Time base error and jitter: the oscilloscope specifications may be taken as error bounds of rectangular probability density functions. Usually these contributions are negligible.

Vertical resolution: the contribution depends on the vertical amplitude resolution ΔA and on the slope of the trace dA/dt . The uncertainty is related to the half width of the resolution and is $(\Delta A/2)/(dA/dt)$. If trace interpolation is performed (see the oscilloscope manual) a triangular probability density function is used, otherwise a rectangular probability density function is used. This contribution is often negligible.

D.4.5 Rise time of the step response and bandwidth of the frequency response of the measuring system

Let T_{MS} be the rise time of the step response of the measuring system as defined by

$$T_{MS} = \sqrt{2\pi \int_0^{\infty} (t - T_s)^2 \cdot h_0(t) dt} \quad (D.1)$$

where $h_0(t)$ is the impulse response of the measuring system having a normalized area, i.e. $\int_0^{\infty} h_0(t) dt = 1$, and T_s is the delay time given by

$$T_s = \int_0^{\infty} t \cdot h_0(t) dt \quad (D.2)$$

Formula (D.1) is much more easy to handle, from the mathematical point of view, than the usual one based on the 10 % and 90 % threshold levels. Nonetheless, in the technical applications, the 10 % to 90 % rise time definition is usually adopted. Given the –3 dB bandwidth of the system the two definitions lead to comparable rise times. Indeed, if we define

$$\alpha = T_{MS} B \quad (D.3)$$

we find that the α values derived from the two definitions of rise time do not differ very much. The values of α , corresponding to different shapes of the impulse response $h(t)$, are given in

Table D.3. It is evident from Table D.3 that it is not possible to identify a unique value of α since α depends both on the adopted definition of the rise time (e.g. based on thresholds or on Formula (D.1)) and on the shape of the impulse response of the measuring system. A reasonable estimate of α can be obtained as the arithmetic mean between the minimum ($321 \cdot 10^{-3}$) and maximum ($399 \cdot 10^{-3}$) values that appear in Table D.3, that is $360 \cdot 10^{-3}$. Further, it can be assumed that, if no information is available about the measuring system apart from its bandwidth, any value of α between $321 \cdot 10^{-3}$ and $399 \cdot 10^{-3}$ is equally probable. Differently stated, α is assumed to be a random variable having a rectangular probability density function with lower and upper bounds $321 \cdot 10^{-3}$ and $399 \cdot 10^{-3}$, respectively. The standard uncertainty of α quantifies both:

- e) the indifference to the mathematical model adopted for the definition of the rise time, and
- f) the indifference to the shape of the impulse response of the system.

Table D.3 – α factor (Formula (D.3)) of different unidirectional impulse responses corresponding to the same bandwidth of the system B

Values of α are multiplied by 10^3	Gaussian	I order	II order (crit. damp.)	Rectangular	Triangular
α – using Formula (D.1)	332	399	363	321	326
α – 10 % to 90 %	339	350	344	354	353

D.4.6 Impulse peak and width distortion due to the limited bandwidth of the measuring system

The distorted impulse waveform $V_{\text{out}}(t)$ at the output of the measuring system is given by the convolution integral

$$V_{\text{out}}(t) = \int_0^t V_{\text{in}}(\tau) h(t - \tau) d\tau \quad (\text{D.4})$$

where $V_{\text{in}}(t)$ is the input impulse waveform and $h(t)$ is the impulse response of the measuring system. Note that $A \cdot h(t) = \delta(t)$, where A is the DC attenuation of the measuring system. The input waveform can be approximated by its Taylor series expansion about the time instant t_p when the input reaches its peak value V_p

$$V_{\text{in}}(t) = V_p + \frac{V_{\text{in}}''(t_p)}{2} (t - t_p)^2 + \frac{V_{\text{in}}'''(t_p)}{6} (t - t_p)^3 + \dots \quad (\text{D.5})$$

Note that the first order term is missing from Formula (D.5) since $V_{\text{in}}'(t_p) = 0$. Further $V_{\text{in}}''(t_p) < 0$ because the concavity points downwards (maximum), and $V_{\text{in}}'''(t_p) > 0$ because, for the standard waveforms of interest here, the rise-time is lower than the fall time. Substituting Formula (D.5) by Formula (D.4) and after simplifications, valid when the bandwidth of the measuring system is large with respect to the bandwidth of the input signal (so that the power series terms whose order is greater than two are negligible), we obtain

$$V_{\text{pd}} = \frac{V_p}{A} \left[1 - \left(\frac{\beta}{B} \right)^2 \right] \quad (\text{D.6})$$

where V_{pd} is the output impulse peak, A is the DC attenuation of the measuring system and

$$\beta = \alpha \sqrt{\frac{|V_{in}''(t_p)|}{4\pi V_p}} \quad (D.7)$$

Note that the parameter β depends on the second derivative of the standard input waveform and on the parameter α defined and derived in D.4.5. The mathematical expression for the standard ring waveform is given in 4.1 and the value is numerically calculated as $\beta = (142 \pm 16)$ kHz.

D.5 Application of uncertainties in the ring waveform compliance criterion

In order to provide evidence that the ring wave generated is compliant with the requirements of this document, the calibration results should be compared with the tolerances specified by this document. Tolerances shall not be reduced by MU.

Further guidance is given in IEC TR 61000-1-6:2012, Clause 6.

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

COMPATIBILITÉ ÉLECTROMAGNÉTIQUE (CEM) –

**Partie 4-12: Techniques d'essai et de mesure –
Essai d'immunité à l'onde sinusoïdale fortement amortie**

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La Norme internationale IEC 61000-4-12 a été établie par le sous-comité 77B: Phénomènes haute fréquence, du comité d'études 77 de l'IEC: Compatibilité électromagnétique.

Elle constitue la partie 4-12 de l'IEC 61000. Elle a le statut de publication fondamentale en CEM en accord avec le Guide 107 de l'IEC.

Cette troisième édition annule et remplace la deuxième édition parue en 2006. Cette édition constitue une révision technique. Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

- a) ajout d'une modélisation mathématique de forme d'onde sinusoïdale fortement amortie;

- b) ajout d'une nouvelle Annexe B relative à la sélection des générateurs et des niveaux d'essai;
- c) ajout d'une nouvelle Annexe C relative aux notes explicatives;
- d) ajout d'une nouvelle Annexe D relative à l'incertitude de mesure;
- e) ajout d'un RCD à grande vitesse;
- f) ajout d'une procédure d'étalonnage pour le RCD.

Le texte de cette Norme internationale est issu des documents suivants:

CDV	Rapport de vote
77B/764/CDV	77B/774/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette norme.

Cette publication a été rédigée selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 61000, publiées sous le titre général *Compatibilité électromagnétique (CEM)*, peut être consultée sur le site web de l'IEC.

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INTRODUCTION

L'IEC 61000 est publiée sous forme de plusieurs parties conformément à la structure suivante:

Partie 1: Généralités

Considérations générales (introduction, principes fondamentaux)

Définitions, terminologie

Partie 2: Environnement

Description de l'environnement

Classification de l'environnement

Niveaux de compatibilité

Partie 3: Limites

Limites d'émission

Limites d'immunité (dans la mesure où elles ne relèvent pas des comités de produits)

Partie 4: Techniques d'essai et de mesure

Techniques de mesure

Techniques d'essai

Partie 5: Guides d'installation et d'atténuation

Guides d'installation

Méthodes et dispositifs d'atténuation

Partie 6: Normes génériques

Partie 9: Divers

Chaque partie est à son tour subdivisée en plusieurs parties, publiées soit comme normes internationales soit comme spécifications techniques ou rapports techniques, dont certaines ont déjà été publiées comme sections. D'autres seront publiées avec le numéro de partie, suivi d'un tiret et complété d'un second numéro identifiant la subdivision (exemple: IEC 61000 6-1).

La présente partie est une Norme internationale qui donne les exigences d'immunité et les procédures d'essai relatives aux ondes sinusoïdales fortement amorties. Il convient de noter que l'édition 1 de l'IEC 61000-4-12, parue en 1995, couvrait deux phénomènes en relation avec les essais d'immunité: les ondes sinusoïdales fortement amorties et les ondes oscillatoires amorties. Cette situation a changé avec la parution, en 2006, de l'édition 2 de l'IEC 61000-4-12, qui traitait uniquement des ondes sinusoïdales fortement amorties, les ondes oscillatoires amorties étant traitées dans une nouvelle norme, l'IEC 61000-4-18.

COMPATIBILITÉ ÉLECTROMAGNÉTIQUE (CEM) –

Partie 4-12: Techniques d'essai et de mesure – Essai d'immunité à l'onde sinusoïdale fortement amortie

1 Domaine d'application

La présente partie de l'IEC 61000 traite des méthodes d'essai des matériels électriques et électroniques dans leurs conditions d'exploitation et des exigences d'immunité aux ondes sinusoïdales fortement amorties se manifestant sur les alimentations basse tension ainsi que sur les lignes de commande et de signal raccordées aux réseaux publics ou privés.

Le présent document a pour objet d'établir une référence commune dans le but d'évaluer l'immunité des matériels électriques et électroniques soumis à des ondes sinusoïdales fortement amorties. La méthode d'essai documentée dans la présente partie de l'IEC 61000 décrit une méthode cohérente en vue d'évaluer l'immunité d'un matériel ou d'un système vis-à-vis d'un phénomène défini.

NOTE Comme décrit dans le Guide 107 de l'IEC, il s'agit d'une publication fondamentale en CEM pour utilisation par les comités de produits de l'IEC. Comme indiqué également dans le Guide 107, il incombe aux comités de produits de l'IEC la responsabilité de déterminer si la présente norme d'essai d'immunité est appliquée ou non et, si c'est le cas, il incombe aux comités de produits de définir les critères de performances correspondants et de choisir les niveaux d'essai d'immunité appropriés. Le comité d'études 77 et ses sous-comités sont prêts à coopérer avec les comités de produits à l'évaluation de la valeur de l'essai d'immunité et des niveaux d'essai d'immunité particuliers pour leurs produits.

Le présent document définit:

- la tension d'essai et les formes d'ondes de courant;
- une plage de niveaux d'essai;
- le matériel d'essai;
- les montages d'essai;
- les procédures d'essai.

2 Références normatives

Les documents ci-après, dans leur intégralité ou non, sont des références normatives indispensables à l'application du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60050 (toutes les parties), *Vocabulaire Électrotechnique International (IEV)* (disponible à l'adresse www.electropedia.org)

3 Termes, définitions et termes abrégés

3.1 Termes et définitions

Pour les besoins du présent document, les termes et définitions donnés dans l'IEC 60050 (toutes les parties), ainsi que les suivants, s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse <http://www.electropedia.org/>
- ISO Online browsing platform: disponible à l'adresse <http://www.iso.org/obp>

3.1.1

étalonnage

ensemble des opérations établissant, en référence à des étalons, la relation qui existe, dans les conditions spécifiées, entre une indication et un résultat de mesure

Note 1 à l'article: Cette définition est conçue dans l'approche « incertitude ».

Note 2 à l'article: La relation entre les indications et les résultats de mesures peut être donnée, en principe, dans un diagramme d'étalonnage.

[SOURCE: IEC 60050-311:2001, 311-01-09]

3.1.2

couplage

interaction entre circuits avec transfert d'énergie d'un circuit dans un autre

3.1.3

réseau de couplage

RC

circuit électrique destiné à transférer de l'énergie d'un circuit à un autre

3.1.4

réseau de couplage/découplage

RCD

combinaison d'un réseau de couplage et d'un réseau de découplage

3.1.5

réseau de découplage

RD

circuit électrique destiné à empêcher la tension d'essai appliquée à l'équipement en essai (EST) de brouiller les dispositifs, matériels ou systèmes non soumis à des essais

3.1.6

immunité (à une perturbation)

aptitude d'un dispositif, d'un appareil ou d'un système à fonctionner sans dégradation en présence d'une perturbation électromagnétique

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

3.1.7

accès

interface particulière d'un matériel qui assure son couplage avec l'environnement électromagnétique (IEC 60050-161:1990, 161-01-01) extérieur et à travers laquelle il est influencé par cet environnement

[SOURCE: IEC 60050-161:1990, 161-01-27]

3.1.8

onde sinusoïdale fortement amortie

oscillation amortie dont la constante de temps d'amortissement est de l'ordre d'une période

[SOURCE: IEC 60050-161:1990, 161-02-30]

3.1.9

temps de montée

T_r

durée de l'intervalle de temps entre les instants auxquels la valeur instantanée d'une impulsion atteint pour la première fois 10 %, puis 90 % de sa hauteur

[SOURCE: IEC 60050-161:1990, 161-02-05, modifiée – le contenu de la note a été compris dans la définition]

3.1.10

transitoire (adj et nom)

se dit d'un phénomène ou d'une grandeur qui varie entre deux régimes établis consécutifs dans un intervalle de temps relativement court à l'échelle des temps considérée

[SOURCE: IEC 60050-161:1990, 161-02-01]

3.1.11

vérification

ensemble des opérations utilisées pour vérifier le système d'essai (par exemple, le générateur d'essai et ses câbles d'interconnexion) pour démontrer que le système d'essai fonctionne

Note 1 à l'article: Les méthodes utilisées pour la vérification peuvent être différentes de celles utilisées pour l'étalonnage.

Note 2 à l'article: Pour les besoins de la présente norme fondamentale en CEM, cette définition est différente de celle donnée dans l'IEC 60050-311:2001, 311-01-13.

3.2 Termes abrégés

EA	Équipement auxiliaire
CD	Coupling device (dispositif de couplage)
RCD	Réseau de couplage/découplage
CLD	Clamping device (dispositif de clampage)
RC	Réseau de couplage
RD	Réseau de découplage
CEM	Compatibilité électromagnétique
EST	Équipement en essai
GDT	Gas discharge tube (tube à décharge)
MU	Measurement uncertainty (incertitude de mesure)
PDF	Probability density function (fonction de densité de probabilité)
PE	Protective earth (terre de protection)
RGP	Reference ground plane (plan de masse de référence)
RWG	Ring wave generator (générateur d'ondes sinusoïdales fortement amorties)
SPD	Surge protective device (dispositif de protection contre les surtensions)

4 Généralités

4.1 Description du phénomène

L'onde sinusoïdale fortement amortie (représentée à la Figure 1) est un phénomène de transitoire oscillatoire survenant dans les câbles basse tension dû à des commutations de réseaux électriques et de charges réactives, des défauts ou des claquages de circuits d'alimentation électrique, ou des coups de foudre. De fait, il s'agit du phénomène le plus

répandu rencontré dans les réseaux d'alimentation (haute tension, moyenne tension, basse tension) ainsi que dans les lignes de commande et de signal.

Représentative d'une large plage d'environnements électromagnétiques résidentiels comme industriels, l'onde sinusoïdale fortement amortie permet de vérifier l'immunité des matériels relevant de ces environnements vis-à-vis des phénomènes susmentionnés. Ces manifestations produisent des impulsions caractérisées par des ondes à front raide de l'ordre de 10 ns à une fraction de μs , en l'absence de tout filtrage. La durée de ces impulsions peut varier entre 10 μs et 100 μs .

Le temps de montée et la durée des impulsions dépendent des caractéristiques de propagation des milieux et du trajet.

La propagation de l'onde dans les lignes (puissance et signal) donne toujours lieu à des réflexions dues à la non-adaptation des impédances (les lignes sont raccordées à des charges ou à des dispositifs de protection, des filtres d'entrée, etc.). Ces réflexions produisent des oscillations dont la fréquence dépend de la vitesse de propagation. La présence éventuelle de phénomènes parasites (par exemple, capacité parasite de composants tels que les moteurs, les enroulements de transformateurs, etc.) ajoute des facteurs d'influence.

Le temps de montée peut être augmenté par les caractéristiques passe-bas du circuit. Cet effet est plus marqué lorsque le temps de montée est rapide (de l'ordre de 10 ns) et tend à devenir négligeable lorsque le temps de montée est lent (de l'ordre de 1 μs).

Des ondes sinusoïdales fortement amorties peuvent également être produites par des coups de foudre, phénomène caractérisé par sa forme d'onde unidirectionnelle (impulsion normalisée 1,2/50 μs). Les circuits indirectement affectés par la foudre (couplage inductif entre lignes) sont influencés par la dérivée de l'impulsion initiale et les mécanismes de couplage impliqués, ce qui peut provoquer des oscillations. Les caractéristiques de l'onde sinusoïdale fortement amortie résultante dépendent des paramètres réactifs des circuits de terre, des structures métalliques traversées par le courant de foudre, ainsi que de la propagation dans les lignes de transmission à basse tension.

Par suite des effets susmentionnés, un transitoire oscillatoire ou une onde sinusoïdale fortement amortie se produit aux accès de l'équipement. Les transitoires oscillatoires sont traités dans l'IEC 61000-4-18. Une onde sinusoïdale fortement amortie avec un temps de montée défini de 0,5 μs et une fréquence d'oscillation de 100 kHz a été déterminée comme étant une onde sinusoïdale fortement amortie type et est largement utilisée pour soumettre les produits à l'essai.

La formule correspondant à la forme d'onde idéale de la Figure 1, $w(t)$, est la suivante:

$$w(t) = A \cdot K \cdot \frac{\left(\frac{t}{t_1}\right)^n}{1 + \left(\frac{t}{t_1}\right)^n} \cdot \exp\left(-\frac{t}{t_2}\right) \cdot \cos(\beta t)$$

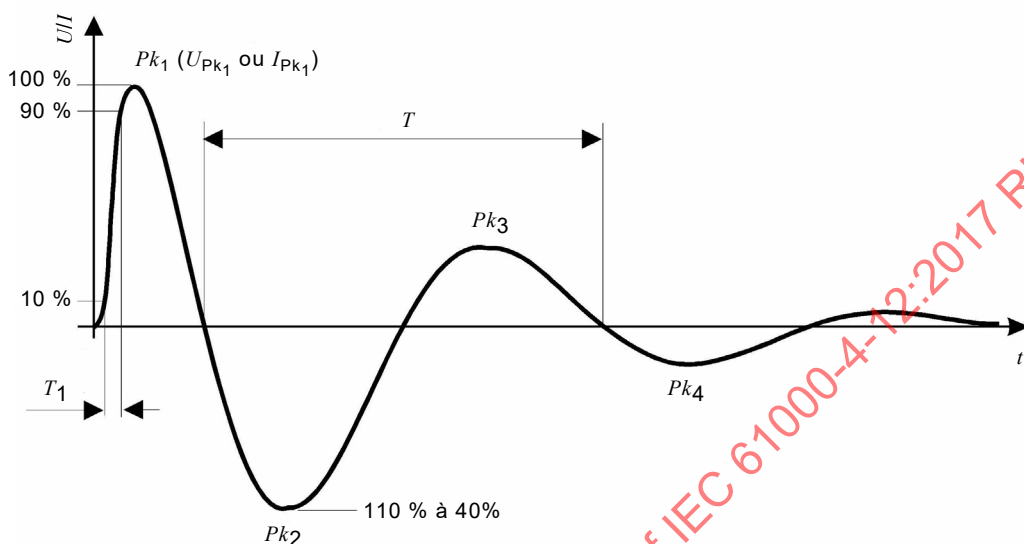
avec

$$t_2 = \frac{T}{2} \cdot \frac{1}{\ln R} = 7,21 \mu\text{s} \text{ et } \beta = \frac{2\pi}{T} \text{ et } T = 10 \mu\text{s}$$

où les paramètres de la période d'oscillation $T = 10 \mu\text{s}$ sont:

$$A = 1; K = 1,81; n = 1,83; t_1 = 0,507 \mu s$$

NOTE R est le rapport entre Pk_2 et Pk_3 , Pk_3 et Pk_4 . La valeur de R garantit que les rapports Pk_2/Pk_3 , Pk_3/Pk_4 sont compris dans la plage spécifiée dans le présent document. La valeur de R ne peut pas descendre en dessous d'un certain seuil car le rapport Pk_1/Pk_2 dépasserait les tolérances spécifiées. $R = 2$ a été sélectionné. Les paramètres n et t_1 sont ajustés afin d'obtenir $T_1 = 0,5 \mu s$.



IEC

Légende

T_1 temps de montée

T période d'oscillation

NOTE Seul Pk_1 est déterminé pour la forme d'onde de courant.

**Figure 1 – Forme d'onde de l'onde sinusoïdale fortement amortie
(tension en circuit ouvert et courant de court-circuit)**

D'autres normes IEC, comme l'IEC 61000-4-5, font référence à l'impulsion de foudre normalisée 1,2/50 μs , qui peut être considérée comme complémentaire à l'onde sinusoïdale fortement amortie décrite dans le présent document.

C'est aux comités de produits qu'il incombe de définir l'essai le plus approprié en fonction du phénomène considéré comme pertinent.

4.2 Paramètres pertinents

4.2.1 Fréquence de répétition

La fréquence de répétition d'un transitoire est directement liée à la fréquence d'occurrence du phénomène originel (foudre et commutation). La fréquence de répétition est plus importante lorsque la cause principale est une commutation de charges sur des lignes de commande, et moins importante lorsque la cause principale est un défaut et un coup de foudre. Cette fréquence peut généralement varier d'une fois par seconde à une fois par an.

La fréquence de répétition peut être augmentée afin de réduire la durée de l'essai. Il convient toutefois de la choisir en fonction des caractéristiques du dispositif de protection utilisé pour atténuer/supprimer les transitoires.

4.2.2 Angle de phase

Les défaillances de matériel liées à l'onde sinusoïdale fortement amortie sur les sources d'alimentation électrique peuvent dépendre de l'angle de phase du réseau d'alimentation en courant alternatif auquel le transitoire est appliqué. Quand un élément de protection fonctionne pendant un essai à l'onde sinusoïdale fortement amortie, cela peut s'accompagner d'un phénomène de courant de suite selon l'angle de phase auquel le transitoire se produit. Le courant de suite est un courant provenant de la source raccordée et s'écoulant à travers un élément de protection, ou tout autre arc dans l'EST pendant et après le transitoire.

Dans le cas des semi-conducteurs, le phénomène peut être lié au seuil de conduction du dispositif au moment où l'onde sinusoïdale fortement amortie se produit. Les paramètres de semi-conducteurs pouvant entrer en ligne de compte sont les caractéristiques de récupération directe et inverse, ainsi que les conditions de tenue au claquage secondaire.

Les dispositifs les plus exposés à une défaillance liée au déphasage sont les semi-conducteurs implantés dans les circuits d'entrée de puissance. D'autres dispositifs situés dans différentes parties de l'EST peuvent aussi présenter de tels modes de défaillance.

5 Niveaux d'essai

Les niveaux d'essai préférentiels pour l'onde sinusoïdale fortement amortie applicables aux accès d'alimentation, de signal et de commande du matériel pris en considération sont donnés dans le Tableau 1. Le niveau d'essai est défini comme la tension de la première crête (maximum ou minimum) dans la forme d'onde d'essai (Pk_1 à la Figure 1).

Les niveaux d'essai applicables aux accès d'alimentation, de signal et de commande peuvent être différents.

Tableau 1 – Niveaux d'essai

Niveau	Tension d'essai en circuit ouvert	
	kV	
	Entre phases	Entre phase et terre ^b
1	0,25	0,5
2	0,5	1
3	1	2
4	2	4
X ^a	Spécial	Spécial
^a « X » peut correspondre à un niveau quelconque, supérieur, inférieur ou intermédiaire. Ce niveau doit être spécifié par les comités de produits et/ou la spécification du matériel.		
^b Pour les lignes d'interconnexion symétriques, l'essai peut être appliqué à différentes lignes de manière simultanée par rapport à la terre, c'est-à-dire « entre phases et terre ».		

Les niveaux d'essai doivent être choisis selon les conditions d'installation; les classes d'installation sont données à l'Annexe C. L'Annexe A donne des informations relatives aux niveaux d'essai.

L'essai doit être appliqué à tous les niveaux d'essai du Tableau 1 jusqu'au niveau d'essai spécifié inclus (voir 8.3).

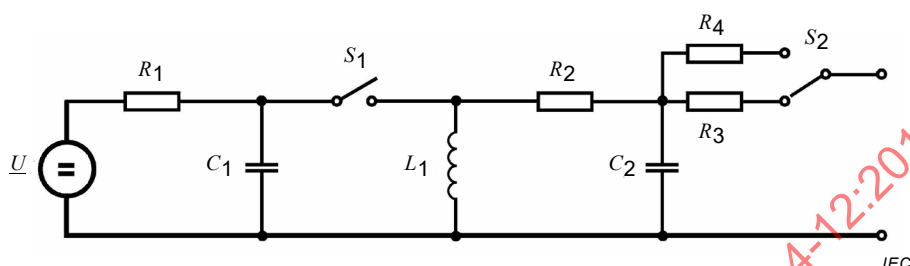
Pour de plus amples informations sur la sélection des niveaux d'essai pour les différentes interfaces, voir l'Annexe B.

6 Instrumentation d'essai

6.1 Générateur d'ondes sinusoïdales fortement amorties

6.1.1 Circuit du générateur d'ondes sinusoïdales fortement amorties

La sortie du générateur doit être en mesure de fonctionner en conditions de court-circuit. Le diagramme d'un générateur d'ondes sinusoïdales fortement amorties représentatif est présenté en Figure 2.



Légende

U :	source haute tension	R_3 :	résistance 30 Ω
C_1 :	condensateur de stockage d'énergie	R_4 :	résistance 12 Ω
C_2 :	condensateur de filtrage	L_1 :	bobine de circuit oscillant
R_1 :	résistance de charge	S_1 :	commutateur haute tension
R_2 :	résistance de filtrage	S_2 :	sélecteur d'impédance de sortie

Figure 2 – Exemple de schéma du circuit du générateur d'ondes sinusoïdales fortement amorties

6.1.2 Valeurs d'impédance

Deux valeurs d'impédance (voir R_3 et R_4 de la Figure 2) ont été sélectionnées comme suit:

- 12 Ω lorsque les accès d'alimentation en courant alternatif/courant continu et les lignes d'interconnexion blindées sont soumis à l'essai
- 30 Ω lorsque les lignes d'interconnexion non blindées sont soumises à l'essai

6.1.3 Caractéristiques des performances du générateur d'ondes sinusoïdales fortement amorties

Un générateur à sortie flottante doit être utilisé.

Il s'agit d'un générateur d'ondes sinusoïdales fortement amorties unique présentant les caractéristiques suivantes, mesurées à la sortie du générateur:

- temps de montée de la tension (T_1 à la Figure 1) 0,5 $\mu\text{s} \pm 30 \%$ (en circuit ouvert)
- temps de montée du courant (T_1 à la Figure 1) 0,2 μs à 1,0 μs (en court-circuit)
- fréquence d'oscillation ($1/T$ à la Figure 1) 100 kHz $\pm 10 \%$

NOTE 1 La fréquence d'oscillation est définie comme l'inverse de la période entre le 1^{er} et le 3^e passage à zéro après la crête initiale.

- décroissance (tension seulement, voir Figure 1)
 - 0,4 $\leq$ rapport de Pk_2 à $Pk_1 \leq 1,1$
 - 0,4 $\leq$ rapport de Pk_3 à $Pk_2 \leq 0,8$
 - 0,4 $\leq$ rapport de Pk_4 à $Pk_3 \leq 0,8$
 - pas d'exigence pour Pk_5

- fréquence de répétition 1 ou plus par minute
- impédance de sortie voir Tableau 2

NOTE L'impédance de sortie est calculée comme le rapport entre la tension en circuit ouvert U_{Pk1} et le courant de court-circuit I_{Pk1} .

- tension en circuit ouvert U_{Pk1} (voir Figure 1) réglable de 0,25 kV au niveau d'essai exigé
- courant de court-circuit I_{Pk1} (voir Figure 1) voir Tableau 2
- déphasage dans une plage comprise entre 0° et 360° relativement à l'angle de phase de la tension alternative d'alimentation de l'EST, avec une tolérance de $\pm 10^\circ$
- polarité de Pk_1 (voir Figure 1) positive et négative

Tableau 2 – Relation entre la tension de crête en circuit ouvert et le courant de crête en court-circuit

Tension de crête en circuit ouvert $\pm 10\%$ à la sortie du générateur	Courant de crête en court-circuit $\pm 10\%$ à la sortie du générateur 12 Ω	Courant de crête en court-circuit $\pm 10\%$ à la sortie du générateur 30 Ω
0,25 kV	20,8 A	8,3 A
0,5 kV	41,7 A	16,7 A
1,0 kV	83,3 A	33,3 A
2,0 kV	166,7 A	66,7 A
4,0 kV	333,3 A	133,3 A

6.1.4 Étalonnage du générateur d'ondes sinusoïdales fortement amorties

Les caractéristiques du générateur d'essai doivent être étalonnées de façon à s'assurer qu'elles satisfont aux exigences du présent document. À cet effet, la procédure suivante doit être appliquée.

La sortie du générateur doit être raccordée à un système de mesure avec une largeur de bande (20 MHz au minimum), une tension et un courant suffisants pour surveiller les caractéristiques de la forme d'onde.

Les caractéristiques du générateur doivent être mesurées en conditions de circuit ouvert (charge supérieure ou égale à 10 k Ω) et de court-circuit à la même tension définie.

Toutes les caractéristiques de performances indiquées en 6.1.3, à l'exception du déphasage et de la fréquence de répétition, doivent être satisfaites à la sortie du générateur. Les performances de déphasage doivent être satisfaites à la sortie du RCD à 0°, 90°, 180° et 270° pour une polarité.

6.2 Réseaux de couplage/découplage

6.2.1 Généralités

Chaque réseau de couplage/découplage (RCD) comporte un réseau de couplage et un réseau de découplage, comme représenté dans les exemples de la Figure 4 à la Figure 10.

NOTE Les condensateurs de couplage peuvent faire partie du RCD ou du générateur ou être des composants externes discrets.

Le réseau de couplage doit être équipé d'un condensateur de couplage adapté à l'impédance choisie pour le générateur d'essai, c'est-à-dire $\geq 3 \mu\text{F}$.

Sur les circuits d'alimentation en courant alternatif ou en courant continu, le réseau de découplage fournit une impédance relativement élevée au transitoire de l'onde sinusoïdale fortement amortie mais il permet en même temps au courant d'alimentation de circuler vers l'EST. Cette impédance permet à la forme d'onde de tension de se développer à la sortie du réseau de couplage/découplage, et empêche le courant de l'onde sinusoïdale fortement amortie de circuler vers la source alternative ou continue. Des condensateurs à haute tension sont utilisés comme éléments de couplage. Leurs dimensions permettent à la totalité des durées de forme d'onde de se coupler à l'EST. Le réseau de couplage/découplage pour l'alimentation en courant alternatif ou en courant continu doit être conçu de sorte que la forme d'onde de tension en circuit ouvert et la forme d'onde de courant de court-circuit satisfassent aux exigences du Tableau 3.

Pour les entrées/sorties et les lignes de communication, l'impédance série du réseau de découplage limite la largeur de bande disponible pour la transmission de données. Les éléments de couplage peuvent être des condensateurs, dans les cas où la ligne tolère les effets de charge capacitive, des dispositifs de clamping ou des parafoudres. Quand elles se couplent aux lignes d'interconnexion, les formes d'onde peuvent être déformées par les mécanismes de couplage tels qu'ils sont décrits en 6.2.3.

Le réseau de couplage/découplage pour les lignes d'interconnexion non blindées doit être conçu de sorte que la forme d'onde de tension en circuit ouvert et la forme d'onde du courant de court-circuit satisfassent aux exigences du Tableau 5 et du Tableau 7.

Chaque réseau de couplage/découplage doit satisfaire aux exigences de 6.2.2 ou 6.2.3 et doit satisfaire aux exigences d'étalonnage de 6.3. Leur utilisation s'effectue selon le diagramme à la Figure 3:

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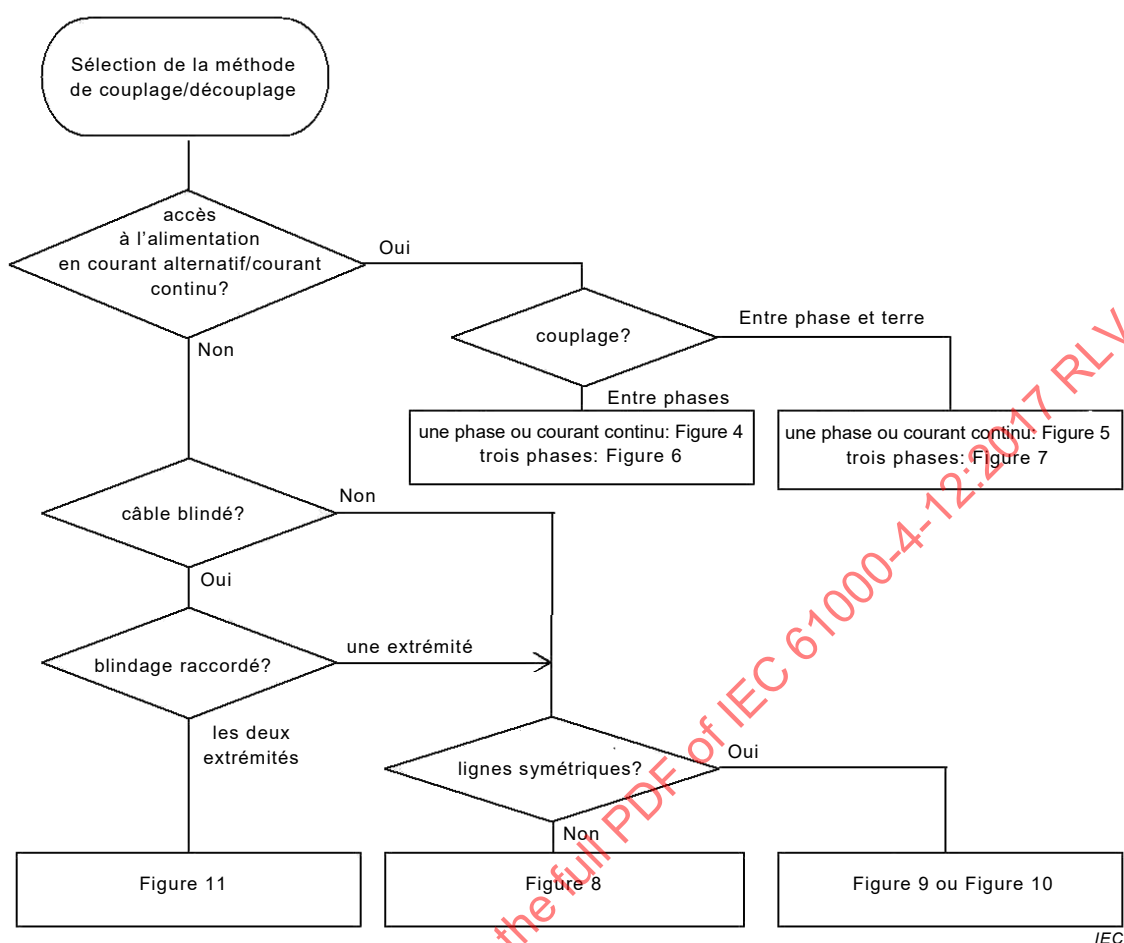


Figure 3 – Sélection de la méthode de couplage/découplage

6.2.2 Réseaux de couplage/découplage pour un accès d'alimentation en courant alternatif/courant continu assigné jusqu'à 63 A par ligne

L'amplitude de crête Pk_1 et le temps de montée doivent être vérifiés pour la tension en circuit ouvert et pour le courant en court-circuit à l'accès de sortie EST ainsi que la période d'oscillation qui doit également être vérifiée pour la tension en circuit ouvert. Les paramètres de forme d'onde mesurés à l'accès l'EST du RCD dépendent de la source du générateur et sont donc valides uniquement pour la combinaison générateur/RCD soumise à l'essai. Le RCD doit être raccordé à un système de mesure avec une largeur de bande, une tension et un courant suffisants pour surveiller les caractéristiques des formes d'onde.

NOTE. L'onde de choc et l'onde sinusoïdale fortement amortie tiennent leur origine des mêmes sources de perturbations. L'onde sinusoïdale fortement amortie résulte de la disposition des câbles impliquée et du dispositif de protection contre les surtensions (SPD) entre la source de perturbation et la prise de courant. Pour les courants supérieurs à 63 A, la disposition des câbles fait généralement partie de l'EST et, par conséquent, l'EST est soumis à l'essai conformément à l'IEC 61000-4-5.

L'inductance de découplage doit être choisie par le constructeur du RCD de sorte qu'au niveau du RCD, la chute de tension doit être inférieure à 10 % de la tension d'entrée du RCD à la valeur assignée du courant spécifié. Toutefois, il convient qu'elle ne dépasse pas 1,5 mH.

Afin d'éviter les chutes de tension non désirées dans le RCD, la valeur de l'élément de découplage doit être réduite pour les RCD de courant assigné > 16 A. Par conséquent, le courant de crête peut varier dans les tolérances indiquées dans le Tableau 3 ci-dessous.

Tableau 3 – Spécification d'onde sinusoïdale fortement amortie aux accès d'alimentation de l'EST du RCD

Paramètre d'onde sinusoïdale fortement amortie en condition de circuit ouvert	Courant de crête
Courant de crête I_{PK1} Courant assigné ≤ 16 A	+10 % –10 %
16 A < courant assigné ≤ 32 A	+10 % –10 %
32 A < courant assigné ≤ 63 A	+10 % –25 %
NOTE Le courant assigné est le courant assigné du RCD.	

Toutes les caractéristiques de performances indiquées en 6.1.3, à l'exception de la fréquence de répétition, doivent être satisfaites à la sortie du RCD. Les performances de déphasage doivent être satisfaites à 0°, 90°, 180° et 270° pour une polarité.

Les caractéristiques susmentionnées s'appliquent aux systèmes monophasés (phase, neutre, terre de protection) et aux systèmes triphasés (fils triphasés, neutre et terre de protection).

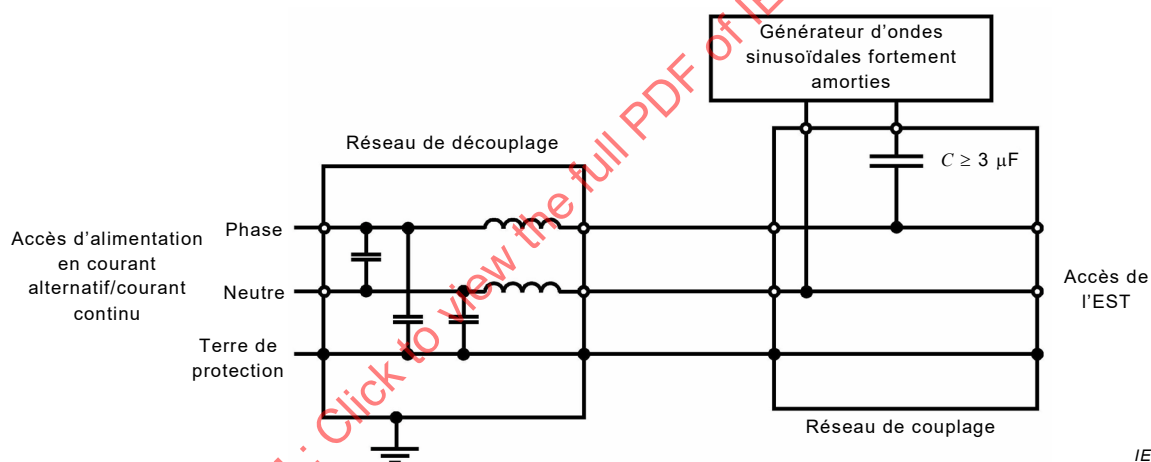


Figure 4 – Exemple de réseau de couplage et de réseau de découplage pour couplage capacitif sur lignes de courant alternatif/courant continu: couplage entre phases

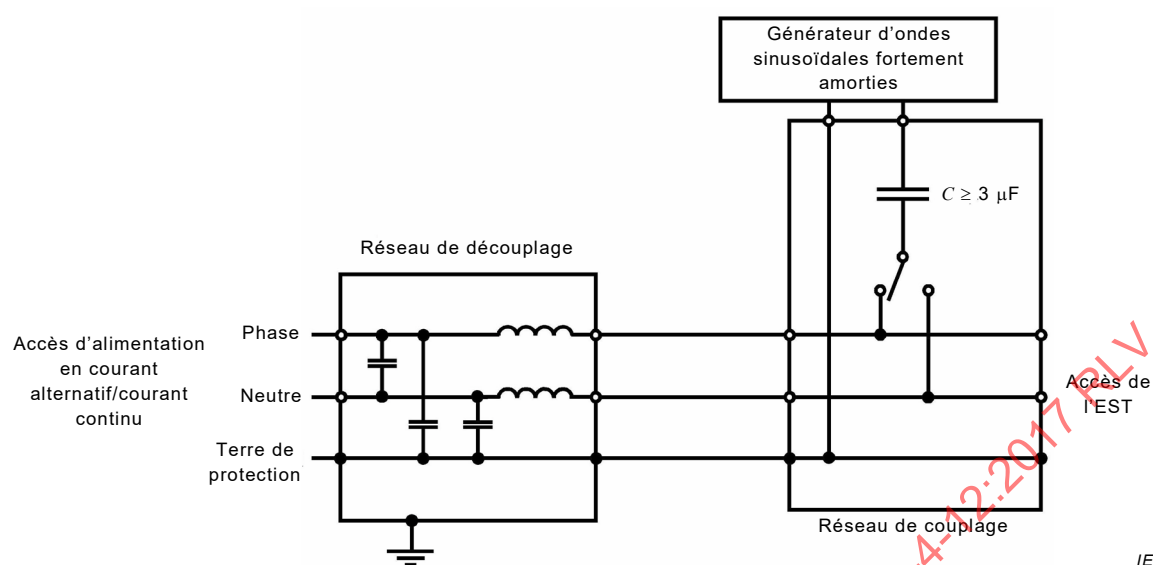
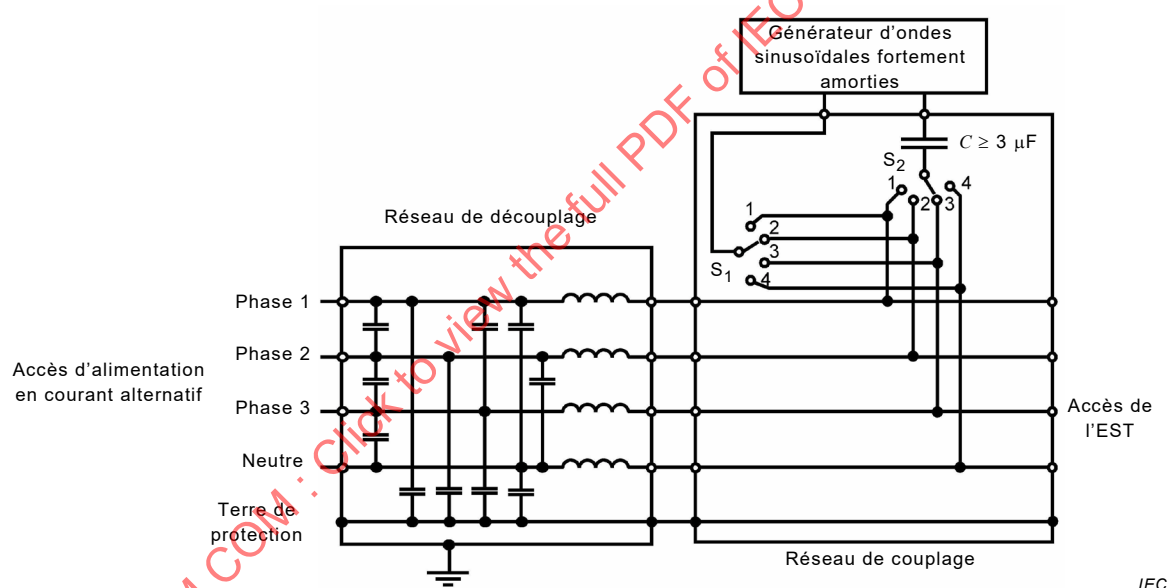


Figure 5 – Exemple de réseau de couplage et de réseau de découplage pour couplage capacitif sur lignes de courant alternatif/courant continu: couplage phase-terre



Les commutateurs S_1 et S_2 sont utilisés pour sélectionner les lignes individuelles pour l'essai.

Au cours de l'essai, la position du commutateur S_2 diffère de la position du commutateur S_1 .

Figure 6 – Exemple de réseau de couplage et de réseau de découplage pour couplage capacitif sur lignes de courant alternatif (triphasé): couplage entre la phase L3 et la phase L2