

INTERNATIONAL STANDARD

IEC 61000-4-5

Second edition
2005-11

BASIC EMC PUBLICATION

Electromagnetic compatibility (EMC) –

**Part 4-5:
Testing and measurement techniques –
Surge immunity test**

*This **English-language** version is derived from the original **bilingual** publication by leaving out all French-language pages. Missing page numbers correspond to the French-language pages.*



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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

ELECTROMAGNETIC COMPATIBILITY (EMC) –**Part 4-5 : Testing and measurement techniques –
Surge immunity test**

FOREWORD

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International Standard IEC 61000-4-5 has been prepared by subcommittee 77B: High frequency phenomena, of IEC technical Committee 77: Electromagnetic compatibility.

It forms Part 4-5 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107, *Electromagnetic compatibility – Guide to the drafting of electromagnetic compatibility publications*.

This second edition cancels and replaces the first edition published in 1995 and its amendment 1 (2000), and constitutes a technical revision. Particularly, the clauses dedicated to coupling/decoupling networks and to test setups are more detailed.

The text of this standard is based on the following documents:

FDIS	Report on voting
77B/467/FDIS	77B/486/RVD

Full information on the voting for the approval of this 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.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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- withdrawn;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.

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: 61000-6-1).

This part is an International Standard which gives immunity requirements and test procedures related to surge voltages and surge currents.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-5 : Testing and measurement techniques – Surge immunity test

1 Scope and object

This part of IEC 61000 relates to the immunity requirements, test methods, and range of recommended test levels for equipment to unidirectional surges caused by overvoltages from switching and lightning transients. Several test levels are defined which relate to different environment and installation conditions. These requirements are developed for and are applicable to electrical and electronic equipment.

The object of this standard is to establish a common reference for evaluating the immunity of electrical and electronic equipment when subjected to surges. 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 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 tests for their products.

This standard defines:

- a range of test levels;
- test equipment;
- test setups;
- test procedures.

The task of the described laboratory test is to find the reaction of the EUT under specified operational conditions, to surge voltages caused by switching and lightning effects at certain threat levels.

It is not intended to test the capability of the EUT's insulation to withstand high-voltage stress. Direct injections of lightning currents, i.e, direct lightning strikes, are not considered in this standard.

2 Normative references

The following referenced documents are indispensable for the application 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 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60469-1, *Pulse techniques and apparatus – Part 1: Pulse terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions in IEC 60050(161) and the following apply.

3.1

avalanche device

diode, gas tube arrestor, or other component that is designed to break down and conduct at a specified voltage

3.2

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

[IEV 311-01-09]

NOTE 1 This term is based on the "uncertainty" approach.

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

3.3

clamping device

diode, varistor or other component that is designed to prevent an applied voltage from exceeding a specified value

3.4

combination wave generator

generator with 1,2/50 μs or 10/700 μs open-circuit voltage waveform and respectively 8/20 μs or 5/320 μs short-circuit current waveform

3.5

coupling network

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

3.6

decoupling network

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

3.7

duration

absolute value of the interval during which a specified waveform or feature exists or continues

[IEC 60469-1]

3.8**effective output impedance** (of a surge generator)

ratio of the peak open-circuit voltage to the peak short-circuit current

3.9**electrical installation**

assembly of associated electrical equipment having co-ordinated characteristics to fulfil purposes

[IEV 826-10-01]

3.10**EUT**

equipment under test

3.11**front time****surge voltage**

the front time T_1 of a surge voltage is a virtual parameter defined as 1,67 times the interval T between the instants when the impulse is 30 % and 90 % of the peak value (see Figures 2 and 5)

surge current

the front time T_1 of a surge current is a virtual parameter defined as 1,25 times the interval T between the instants when the impulse is 10 % and 90 % of the peak value (see Figures 3 and 6)

[IEC 60060-1, 24.3 modified]

3.12**ground (reference)**

part of the Earth considered as conductive, the electrical potential of which is conventionally taken as zero, being outside the zone of influence of any earthing (grounding) arrangement

[IEV 195-01-01]

3.13**high-speed communication lines**

input/output lines which operate at transmission frequencies above 100 kHz

3.14**immunity**

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

[IEV 161-01 -20]

3.15**interconnection lines**

I/O lines (input/output lines) and communication lines

3.16**primary protection**

means by which the majority of stressful energy is prevented from propagating beyond a designated interface

3.17**rise time**

interval of time between the instants at which the instantaneous value of a pulse first reaches the specified lower and upper limits.

[IEV 161-02-05]

NOTE Unless otherwise specified, the lower and upper values are fixed at 10 % and 90 % of the pulse magnitude.

3.18**secondary protection**

means by which the let-through energy from primary protection is suppressed. It may be a special device or an inherent characteristic of the EUT

3.19**surge**

transient wave of electrical current, voltage, or power propagating along a line or a circuit and characterized by a rapid increase followed by a slower decrease

[IEV 161-08-11 modified]

3.20**symmetrical lines**

pair of symmetrically driven conductors with a conversion loss from differential to common mode of greater than 20 dB

3.21**system**

set of interdependent elements constituted to achieve a given objective by performing a specified function

[IEV 351-11-01 modified]

NOTE The system is considered to be separated from the environment and other external systems by an imaginary surface which cuts the links between them and the considered system. Through these links, the system is affected by the environment, is acted upon by the external systems, or acts itself on the environment or the external systems.

3.22**time to half-value** **T_2**

interval of time between the instant of virtual origin O_1 and the instant when the voltage or current has decreased to half the peak value

[IEC 60060-1, 18.1.6 modified]

NOTE The time to half-value T_2 of a surge is a virtual parameter.

3.23**transient**

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

[IEV 161-02-01]

3.24**verification**

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

NOTE 1 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 to ensure the correct operation of the test generator, and other items making up the test setup so that the intended waveform is delivered to the EUT.

NOTE 3 For the purposes of this basic EMC standard this definition is different of the definition given in IEC 311-01-13.

3.25

virtual Origin

O_1

for the surge voltage waveform, it is the instant at which a straight line drawn through the 30 % and 90 % amplitude values crosses the time axis. For the surge current waveform, it is the instant at which a straight line drawn through the 10 % and 90 % amplitude values crosses the time axis

4 General

4.1 Power system switching transients

Power system switching transients can be separated into transients associated with

- a) major power system switching disturbances, such as capacitor bank switching;
- b) minor local switching activity or load changes in the power distribution system;
- c) resonating circuits associated with switching devices, such as thyristors;
- d) various system faults, such as short circuits and arcing faults to the grounding system of the installation.

4.2 Lightning transients

The major mechanisms by which lightning produces surge voltages are the following:

- a) direct lightning stroke to an external (outdoor) circuit injecting high currents producing voltages by either flowing through ground resistance or flowing through the impedance of the external circuit;
- b) an indirect lightning stroke (i.e. a stroke between or within clouds or to nearby objects which produces electromagnetic fields) that induces voltages/currents on the conductors outside and/or inside a building;
- c) lightning ground current flow resulting from nearby direct-to-earth discharges coupling into the common ground paths of the grounding system of the installation.

The rapid change of voltage and flow of current which can occur as a result of the operation of a lightning protection device can induce electromagnetic disturbances into adjacent equipment.

4.3 Simulation of the transients

The characteristics of the test generator are such that it simulates the above-mentioned phenomena as closely as possible.

If the source of interference is in the same circuit, for example in the power supply network (direct coupling), the generator may simulate a low impedance source at the ports of the equipment under test.

If the source of interference is not in the same circuit as the victim equipment (indirect coupling), then the generator may simulate a higher impedance source.

5 Test levels

The preferred range of test levels is given in Table 1.

Table 1 – Test levels

Level	Open-circuit test voltage $\pm 10\%$
	kV
1	0,5
2	1,0
3	2,0
4	4,0
X	Special
NOTE X can be any level, above, below or in between the other levels. This level can be specified in the product standard.	

The test levels shall be selected according to the installation conditions; classes of installation are given in Clause B.3.

All voltages of the lower test levels shall be satisfied (see 8.2).

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

6 Test instrumentation

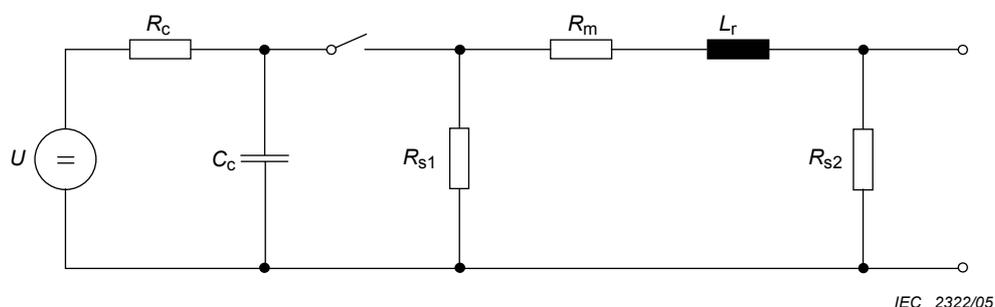
Two types of combination wave generator are specified. Each has its own particular applications, depending on the type of port to be tested (see Clause 7). The 10/700 μs combination wave generator is used to test ports intended for connection to symmetrical communication lines. The 1,2/50 μs combination wave generator is used in all other cases, and in particular, for testing ports intended for power lines and short-distance signal connections.

6.1 1,2/50 μs combination wave generator

It is the intention of this standard that the output waveforms meet specifications at the point where they are to be applied to the EUT. Waveforms are specified as open-circuit voltage and short-circuit current and therefore are measured without the EUT connected. In the case of an a.c. or d.c. powered product where the surge is applied to the a.c. or d.c. supply lines, the output must be as specified in Tables 6 and 7. In the case where the surge is to be applied directly from the generator output terminals, the waveforms shall be as specified in Table 2. It is not intended that the waveforms meet specifications both at the generator output and at the output of coupling/decoupling networks simultaneously, but only as applied to the EUT. The waveform specifications are to be met without an EUT connected.

This generator is intended to generate a surge having: an open-circuit voltage front time of 1,2 μs ; an open-circuit voltage time to half value of 50 μs ; a short-circuit current front time of 8 μs ; and a short-circuit current time to half value of 20 μs .

A simplified circuit diagram of the generator is given in Figure 1. The values for the different components R_{S1} , R_{S2} , R_m , L_r , and C_c are selected so that the generator delivers a 1,2/50 μs voltage surge (at open-circuit conditions) and a 8/20 μs current surge into a short circuit.



U	High-voltage source
R_C	Charging resistor
C_C	Energy storage capacitor
R_S	Pulse duration shaping resistors
R_m	Impedance matching resistor
L_r	Rise time shaping inductor

Figure 1 – Simplified circuit diagram of the combination wave generator (1,2/50 μs – 8/20 μs)

For convenience, the ratio of peak open-circuit output voltage to peak short-circuit current of a combination wave generator may be considered the effective output impedance. For this generator, the ratio defines an effective output impedance of 2 Ω .

NOTE The waveform of the voltage and current is a function of the EUT input impedance. This impedance may change during surges to equipment due either to proper operation of the installed protection devices, or to flash over or component breakdown if the protection devices are absent or inoperative. Therefore, the 1,2/50 μs voltage and the 8/20 μs current waves have to be available from the same generator output as required by the load.

6.1.1 Characteristics and performance of the generator

Polarity	positive and negative
Phase shifting	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 $\pm 10^\circ$
Repetition rate	1 per minute or faster
Open-circuit peak output voltage	adjustable from 0,5 kV to the required test level
Waveform of the surge voltage	see Table 2 and Figure 2
Output voltage setting tolerance	see Table 3
Short-circuit peak output current	depends on peak voltage setting (see Tables 2 and 3)
Waveform of the surge current	see Table 2 and Figure 3
Short-circuit output current tolerance	see Table 3
Effective output impedance	2 $\Omega \pm 10\%$

Table 2 – Definitions of the waveform parameters 1,2/50 μ s – 8/20 μ s

Definitions	In accordance with IEC 60060-1		In accordance with IEC 60469-1	
	Front time μ s	Time to half value μ s	Rise time (10 % – 90 %) μ s	Duration time (50 % – 50 %) μ s
Open-circuit voltage	1,2 \pm 30 %	50 \pm 20 %	1 \pm 30 %	50 \pm 20 %
Short-circuit current	8 \pm 20 %	20 \pm 20 %	6,4 \pm 20 %	16 \pm 20 %

NOTE In existing IEC publications, the waveforms 1,2/50 μ s and 8/20 μ s are generally defined according to IEC 60060-1 as shown in Figures 2 and 3. Other IEC recommendations are based on waveform definitions according to IEC 60469-1 as shown in Table 2.

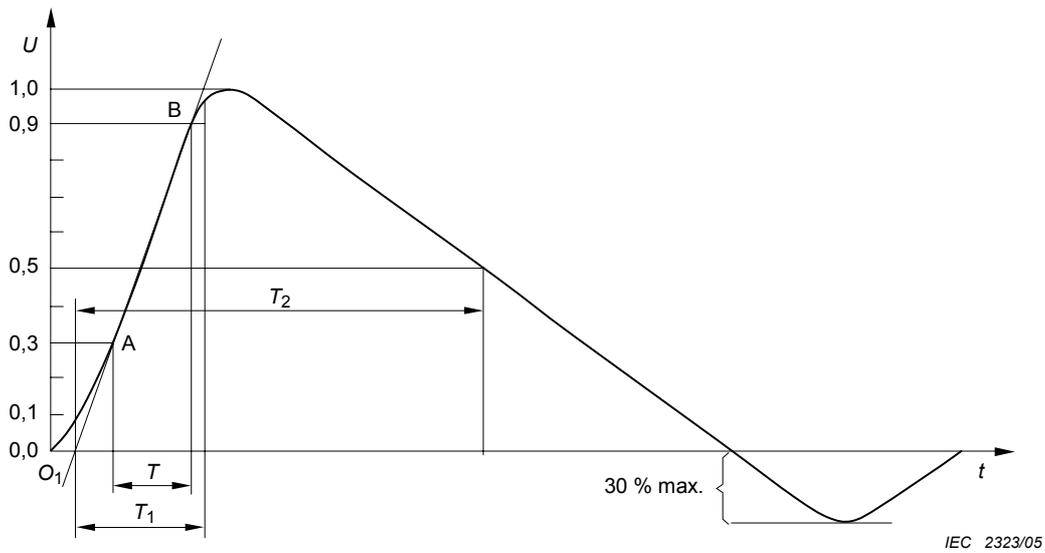
Both definitions are valid for this part of IEC 61000 and describe just one single generator.

Table 3 – Relationship between peak open-circuit voltage and peak short-circuit current

Open-circuit peak voltage \pm 10 %	Short-circuit peak current \pm 10 %
0,5 kV	0,25 kA
1,0 kV	0,5 kA
2,0 kV	1,0 kA
4,0 kV	2,0 kA

The peak short-circuit current shall be as shown in Table 3 when the peak open circuit voltage is as specified.

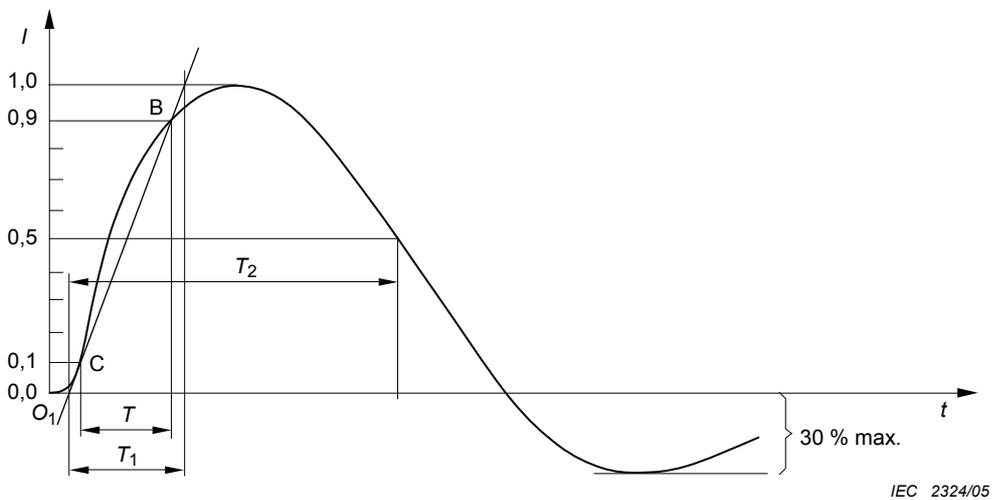
A generator with floating output shall be used.



Front time: $T_1 = 1,67 \times T = 1,2 \mu\text{s} \pm 30 \%$
 Time to half-value: $T_2 = 50 \mu\text{s} \pm 20 \%$.

NOTE The open circuit voltage waveform at the output of the coupling/decoupling network may have a considerable undershoot, in principle as the curve shown in Figure 3.

Figure 2 – Waveform of open-circuit voltage (1,2/50 μs) at the output of the generator with no CDN connected (waveform definition according to IEC 60060-1)



Front time: $T_1 = 1,25 \times T = 8 \mu\text{s} \pm 20 \%$
 Time to half-value: $T_2 = 20 \mu\text{s} \pm 20 \%$

NOTE The 30 % undershoot specification applies only at the generator output. At the output of the coupling/decoupling network there is no limitation on undershoot or overshoot.

Figure 3 – Waveform of short-circuit current (8/20 μs) at the output of the generator with no CDN connected (waveform definition according to IEC 60060-1)

6.1.2 Calibration of the generator

In order to compare the test results from different generators, the generator shall be calibrated periodically. For this purpose, the following procedure is necessary to measure the most essential characteristics of the generator.

The generator output shall be connected to a measuring system with a sufficient bandwidth and voltage capability to monitor the characteristics of the waveforms.

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

All waveform definitions as well as the performance parameters stated in 6.1.1 and 6.1.2 respectively shall be met at the output of the generator.

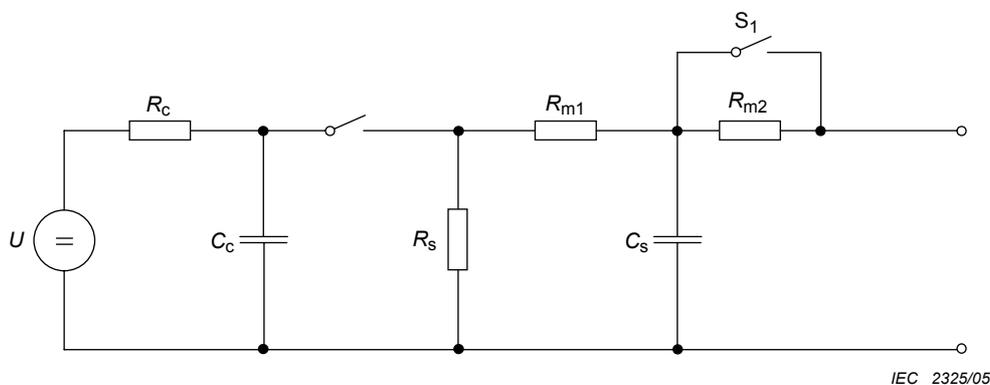
NOTE 1 When an additional internal or external resistor is added to the generator output to increase the effective source impedance from 2 Ω to e.g. 42 Ω according to the requirements of the test setup, the front time and the time to half value of test pulses at the output of the coupling network may be significantly changed.

NOTE 2 The characteristics of the combination wave generator in this clause can be used for verification.

6.2 10/700 μ s combination wave generator

This generator is intended to generate a surge having: an open-circuit voltage front time of 10 μ s; and an open-circuit voltage time to half value of 700 μ s.

The simplified circuit diagram of the generator is given in Figure 4. The values for the different components are selected so that the generator delivers a 10/700 μ s surge.



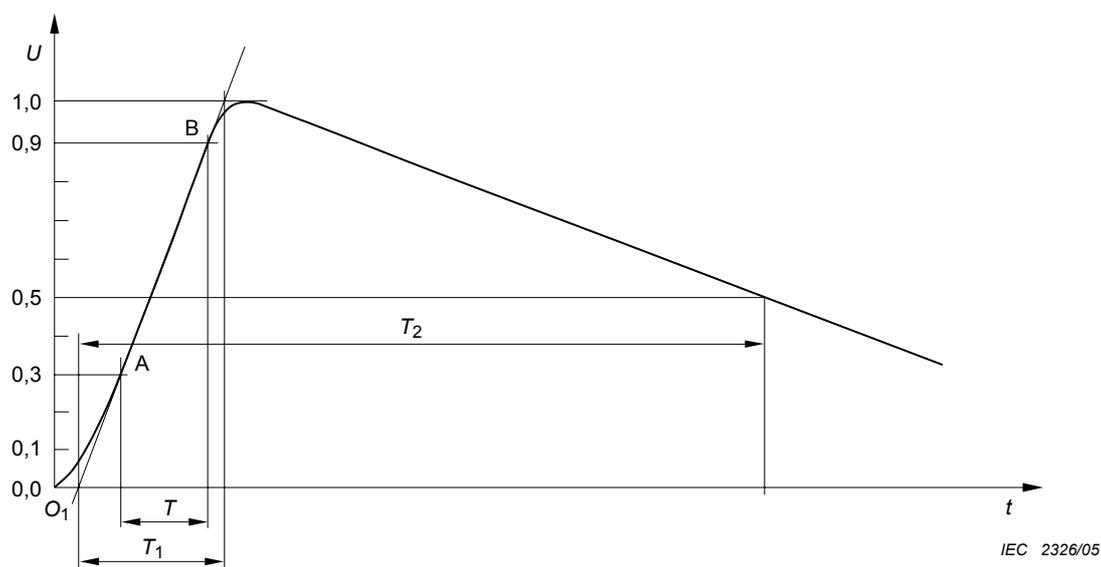
U	High-voltage source
R_C	Charging resistor
C_C	Energy storage capacitor
R_S	Pulse duration shaping resistor
R_M	Impedance matching resistors
C_S	Rise time shaping capacitor
S_1	Switch closed when using external matching resistors

Figure 4 – Simplified circuit diagram of the combination wave generator (10/700 μ s – 5/320 μ s) according to ITU K series standards

6.2.1 Characteristics and performances of the generator

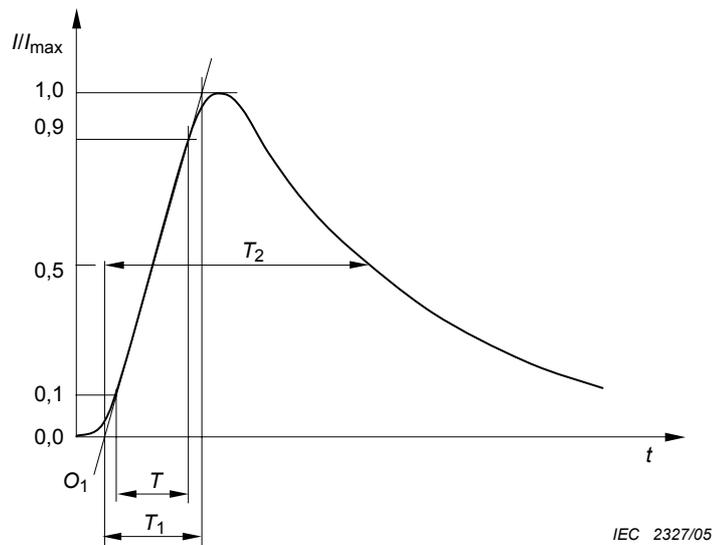
Polarity	positive and negative
Repetition rate	1 per minute or faster
Open-circuit peak output voltage	adjustable from 0,5 kV to the required test level
Waveform of the surge voltage	see Table 4 and Figure 5
Output voltage setting tolerance	see Table 5
Short-circuit peak output current	depends on peak voltage setting (see Tables 4 and 5)
Short-circuit output current tolerance	see Table 5
Effective output impedance	40 $\Omega \pm 10\%$ for generator output only.

NOTE The effective output impedance typically consists of internal 15 Ω (Rm1) and 25 Ω (Rm2) resistors. The Rm2 resistors may be bypassed, paralleled or shorted and replaced with external coupling resistors when used for multiple coupling – see Figure 14.



Front time: $T_1 = 1,67 \times T = 10 \mu\text{s} \pm 30\%$
 Time to half-value: $T_2 = 700 \mu\text{s} \pm 20\%$.

**Figure 5 – Waveform of open-circuit voltage (10/700 μs)
 (waveform definition according to IEC 60060-1)**



Front time: $T_1 = 1,25 \times T = 5 \mu\text{s} \pm 20 \%$
 Time to half-value: $T_2 = 320 \mu\text{s} \pm 20 \%$.

NOTE In IEC 60060-1 the specification of the waveform is defined as 5/320 μs , while in IEC 60469-1 it is defined as 4/300 μs . Moreover this waveform is measured with the switch S1 in Figure 4 opened.

Figure 6 – Waveform of the 5/320 μs short-circuit current waveform (definition according to IEC 60060-1)

Table 4 – Definitions of the waveform parameters 10/700 μs – 5/320 μs

Definitions	In accordance with ITU-T K series and IEC 60060-1		In accordance with IEC 60469-1	
	Front time	Time to half-value	Rise time (10 % – 90 %)	Duration time (50 % – 50 %)
	μs	μs	μs	μs
Open-circuit voltage	10 \pm 30 %	700 \pm 20 %	6,5 \pm 30 %	700 \pm 20 %
Short-circuit current	5 \pm 20 %	320 \pm 20 %	4 \pm 20 %	300 \pm 20 %

NOTE In existing IEC and ITU-T publications, the waveform 10/700 μs is generally defined according to IEC 60060-1 as shown in Figures 5 and 6. Other IEC recommendations are based on waveform definitions according to IEC 60469-1 as shown in Table 4.
 Both definitions are valid for this section of IEC 61000-4 and describe just one single generator.

Table 5 – Relationship between peak open-circuit voltage and peak short-circuit current

Open-circuit peak voltage $\pm 10 \%$	Short-circuit peak current $\pm 10 \%$
0,5 kV	12,5 A
1,0 kV	25 A
2,0 kV	50 A
4,0 kV	100 A

NOTE The short-circuit peak current is measured with switch S1 of Figure 4 open.

The peak short-circuit current shall be as shown in Table 5 when the peak open-circuit voltage is as specified.

6.2.2 Calibration of the generator

In order to compare the test results from different generators, the generator shall be calibrated periodically. For this purpose, the following procedure is necessary to measure the most essential characteristics of the generator.

The generator output shall be connected to a measuring system with a sufficient bandwidth and voltage capability to monitor the characteristics of the waveforms.

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

All waveform definitions as well as the performance parameters stated in 6.2.1 and 6.2.2 respectively shall be met at the output of the generator.

NOTE The characteristics of the combination wave generator in this clause can be used for verification.

6.3 Coupling/decoupling networks

Each coupling/decoupling network (CDN) consists of a decoupling network and a coupling element as shown in the examples of Figures 7 through 15.

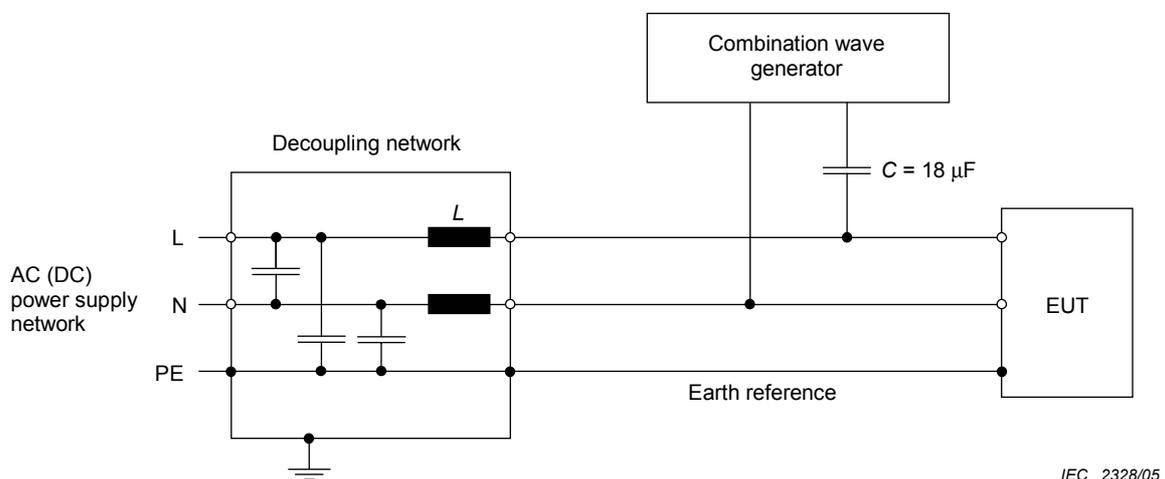


Figure 7 – Example of test setup for capacitive coupling on a.c./d.c. lines; line-to-line coupling (according to 7.2)

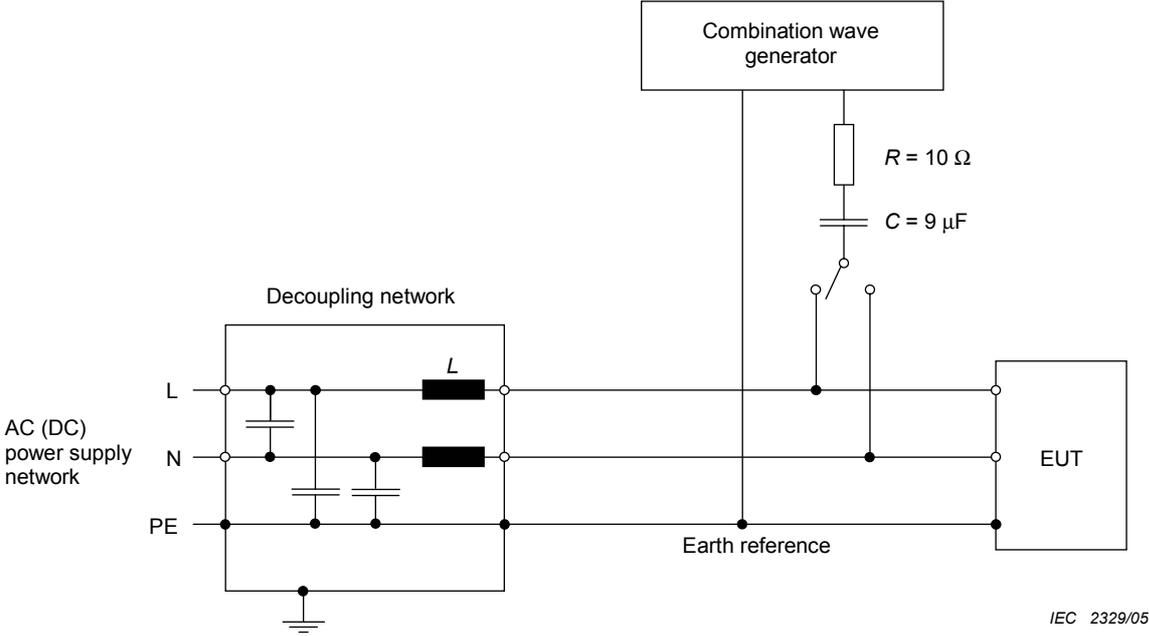
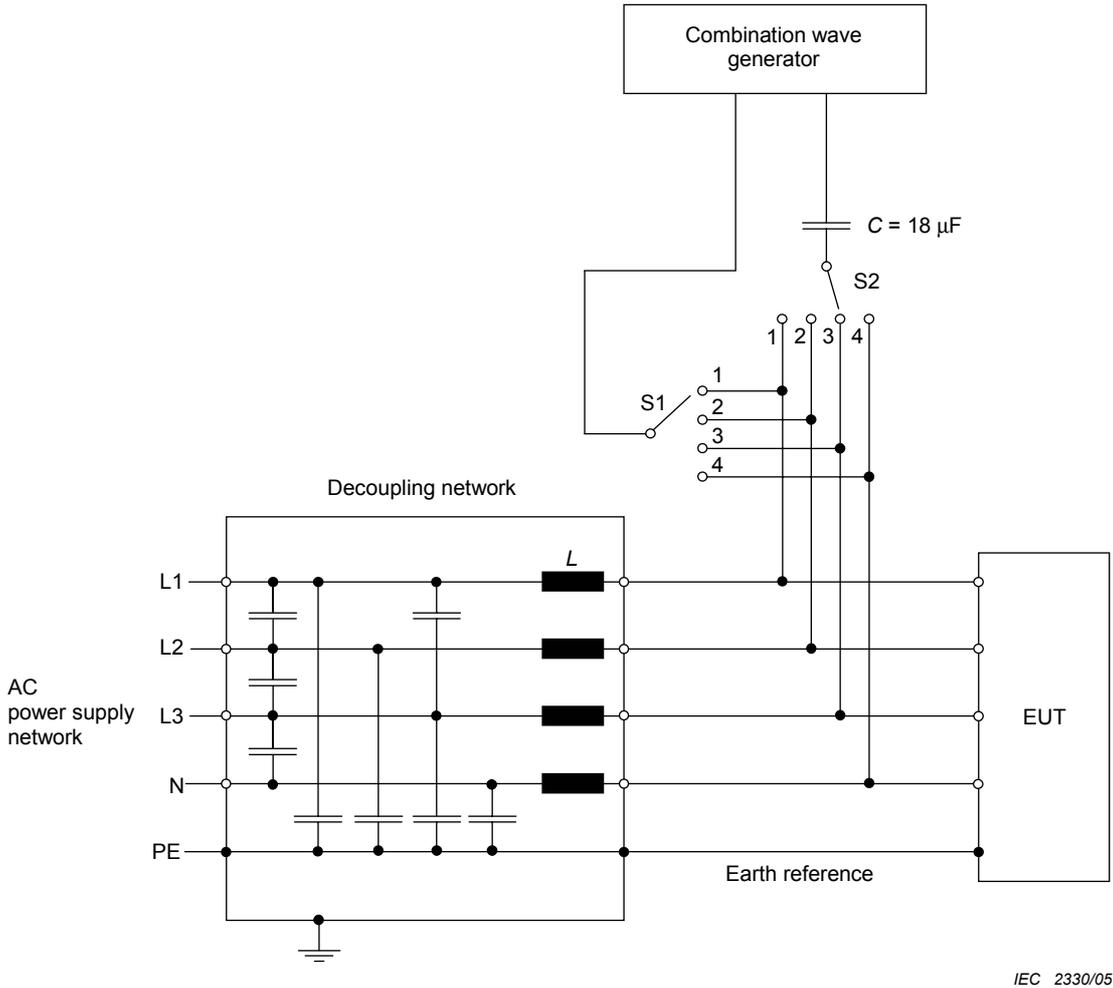
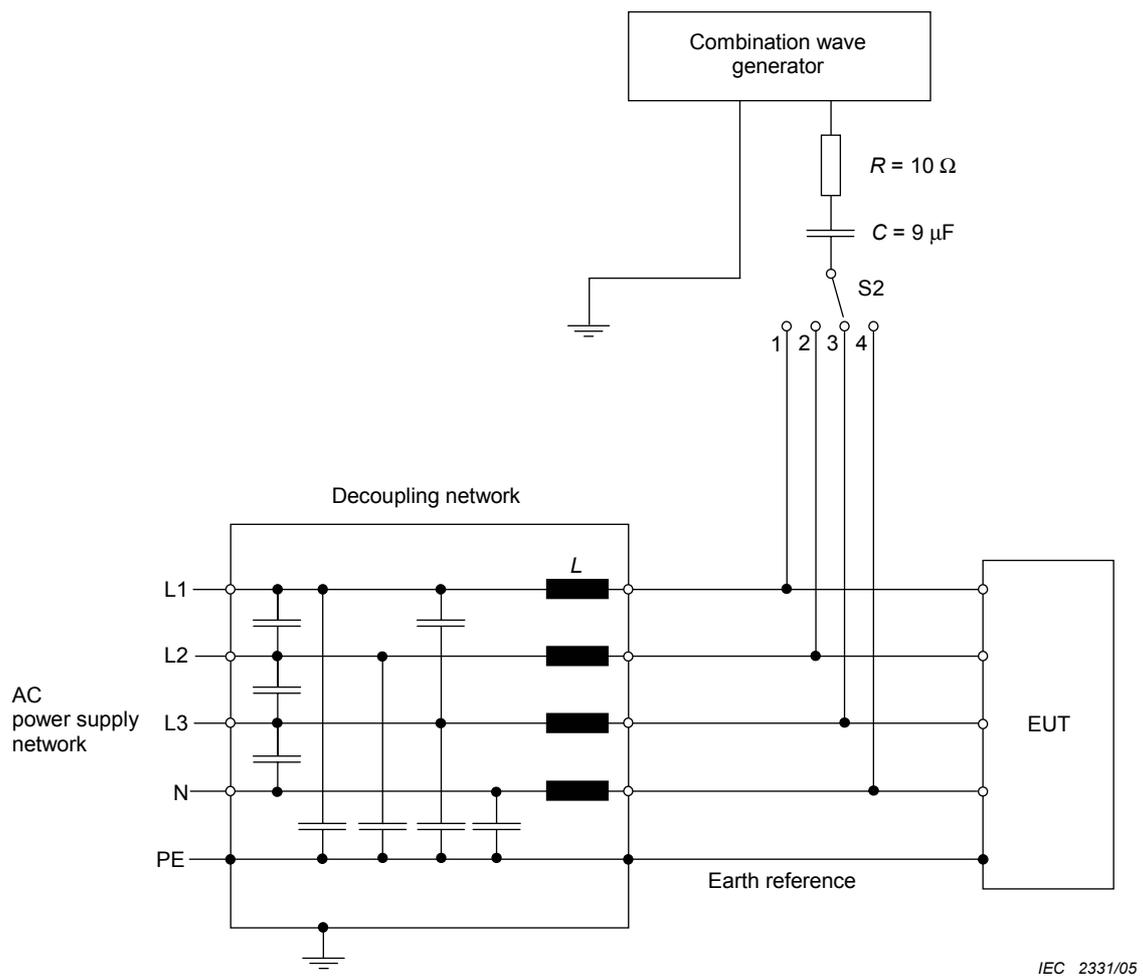


Figure 8 – Example of test setup for capacitive coupling on a.c./d.c. lines; line-to-ground coupling (according to 7.2)



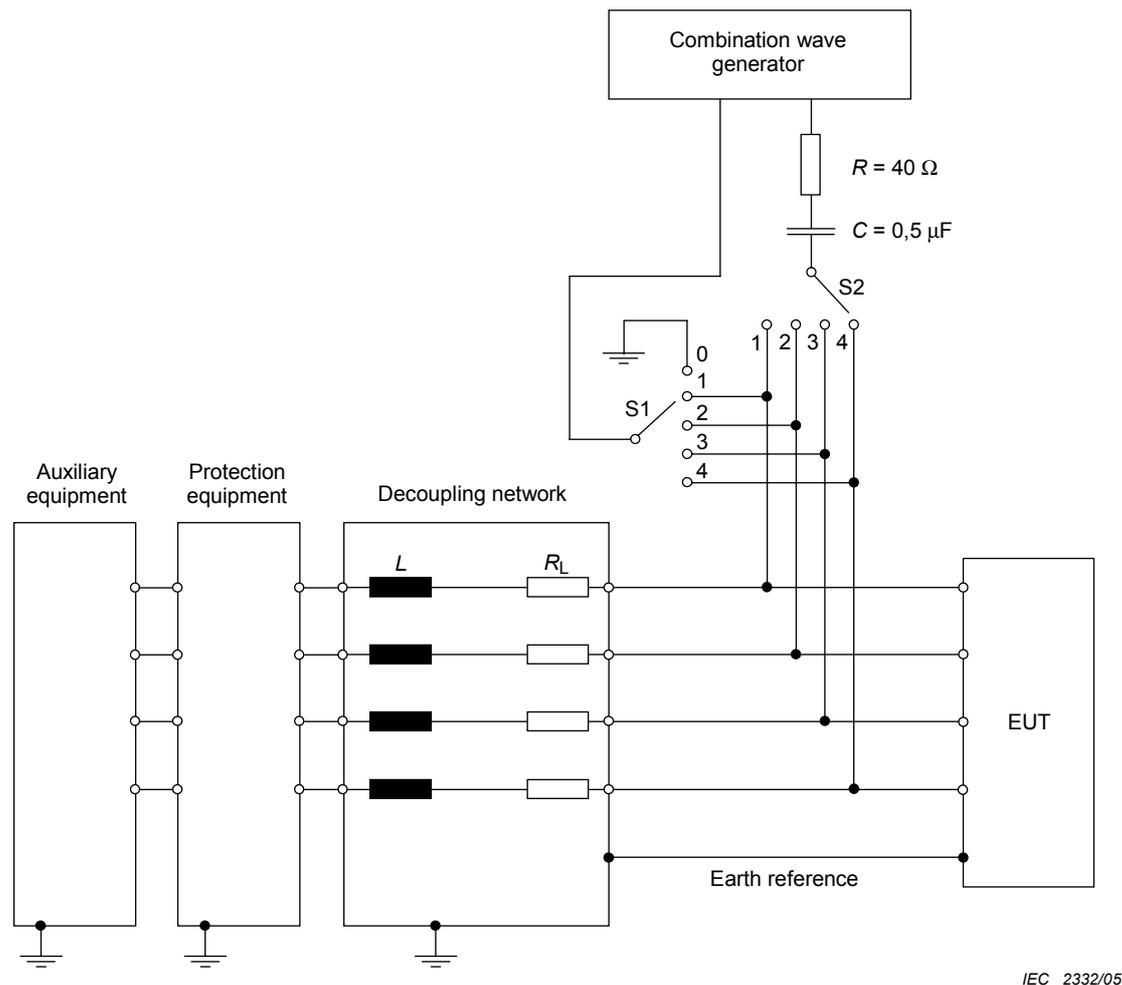
IEC 2330/05

Figure 9 – Example of test setup for capacitive coupling on a.c. lines (3 phases); line L3 to line L1 coupling (according to 7.2)



Switch S2 is used to select individual lines for test.

Figure 10 – Example of test setup for capacitive coupling on a.c. lines (3 phases); line L3 to ground coupling (according to 7.2)



IEC 2332/05

1) Switch S1

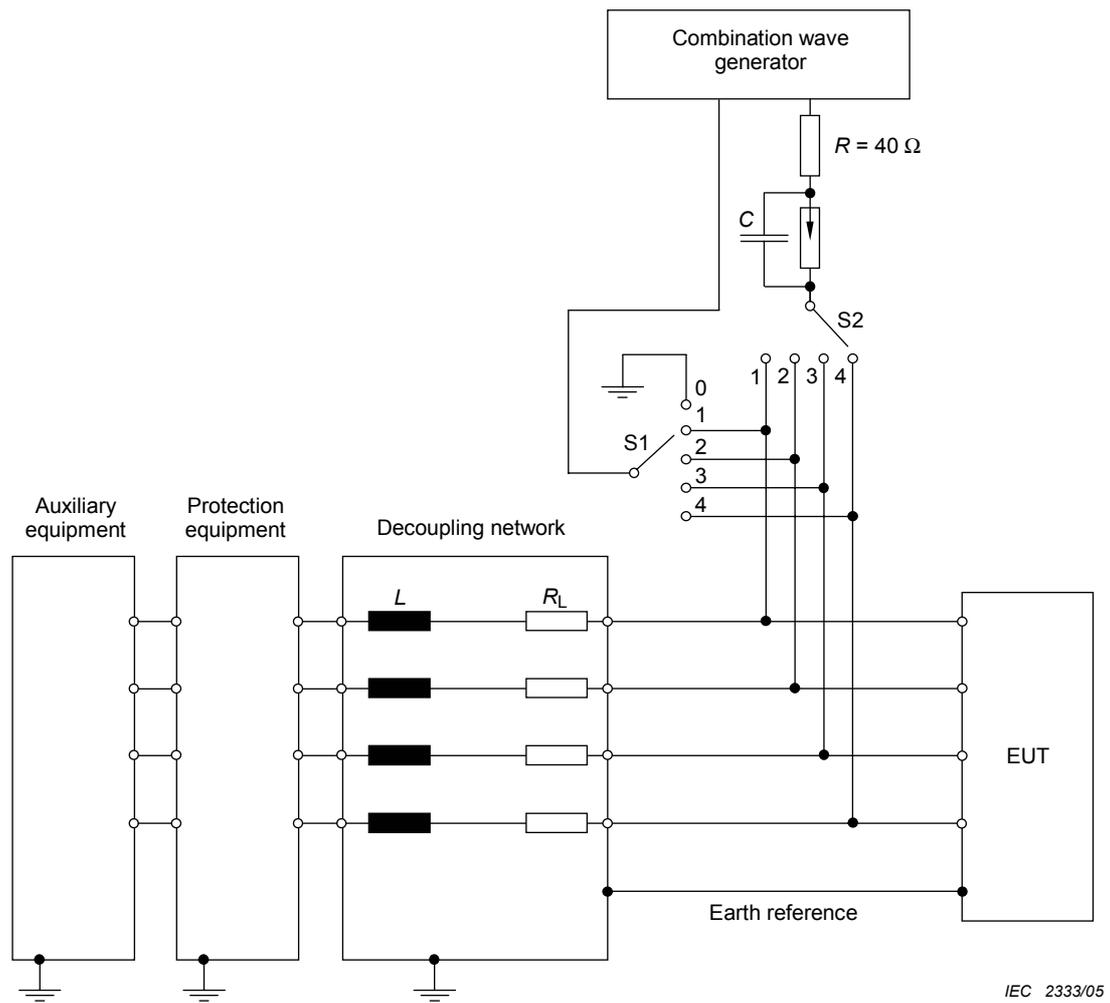
- line to ground: position 0
- line to line: positions 1 to 4

2) Switch S2

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

3) $L = 20 \text{ mH}$, R_L represents the resistive part of L

Figure 11 – Example of test set up for unshielded unsymmetrical interconnection lines; line-to-line and line-to-ground coupling (according to 7.3), coupling via capacitors



1) Switch S1

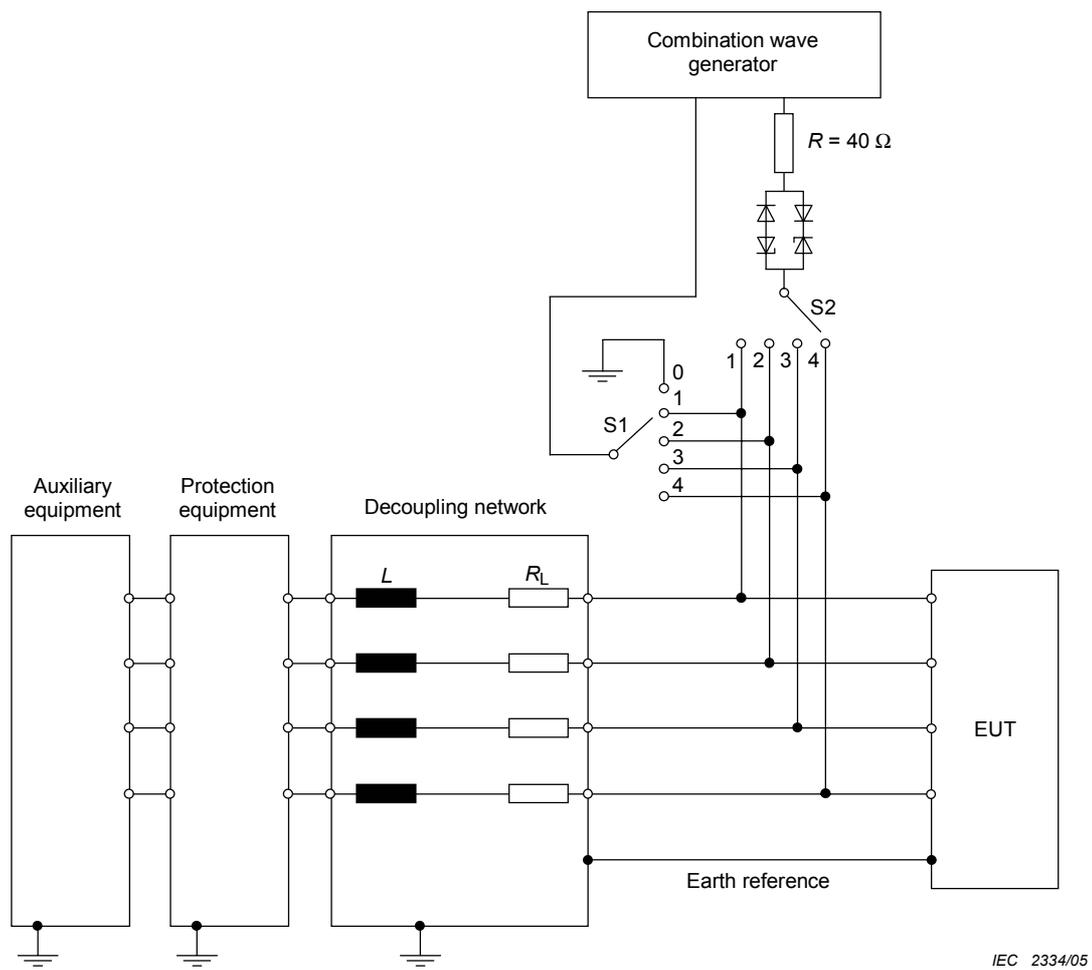
- line to ground: position 0
- line to line: positions 1 to 4

2) Switch S2

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

3) $L = 20 \text{ mH}$, R_L represents the resistive part of L

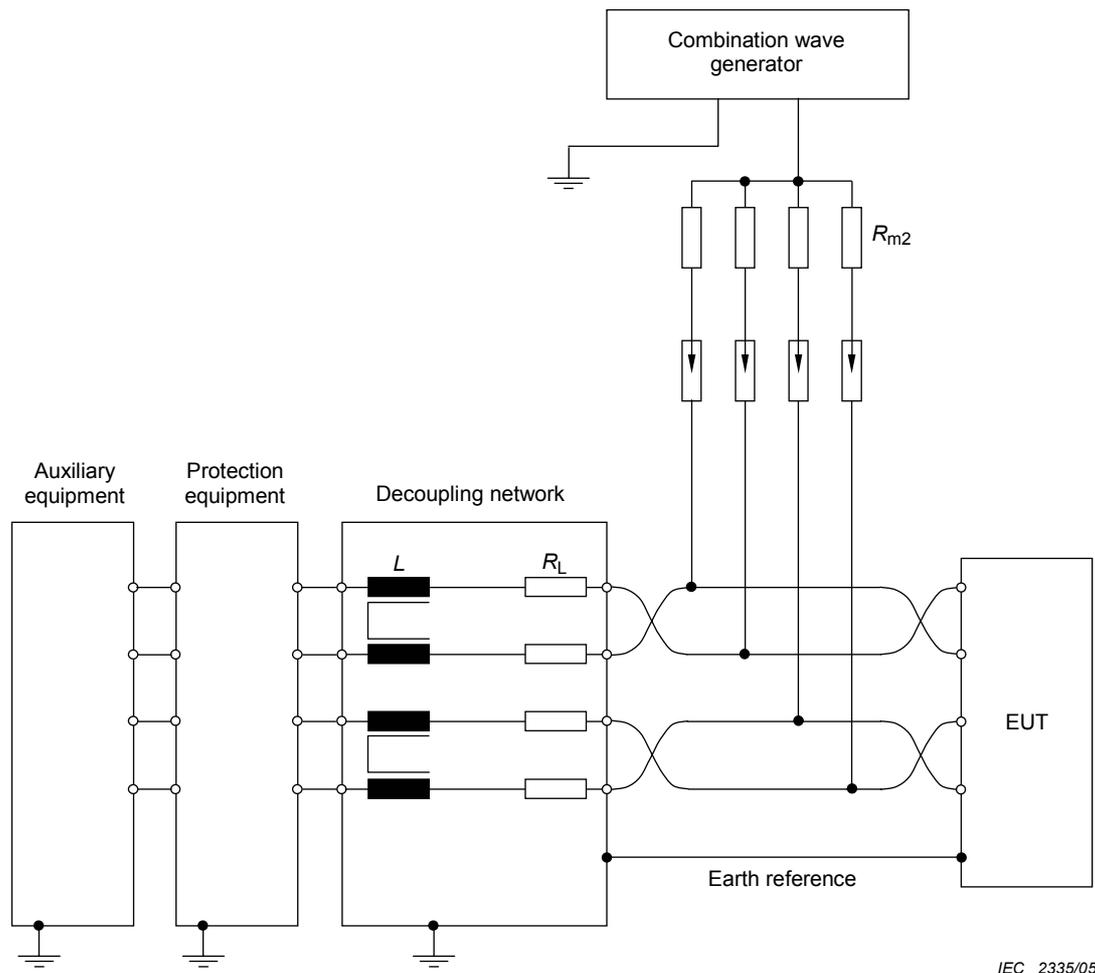
Figure 12 – Example of test setup for unshielded unsymmetrical interconnection lines; line-to-line and line-to-ground coupling (according to 7.3), coupling via arrestors



IEC 2334/05

- 1) Switch S_1
 - line to ground: position 0
 - line to line: positions 1 to 4
- 2) Switch S_2
 - during the test positions 1 to 4, but not in the same position with switch S_1
- 3) $L = 20 \text{ mH}$, R_L represents the resistive part of L

Figure 13 – Example of test setup for unshielded unsymmetrical interconnection lines; line-to-line and line-to-ground coupling (according to 7.3), coupling via a clamping circuit



Calculation of R_{m2} when using CWG (1,2/50 μ s generator)

Example for $n = 4$:

$$R_{m2} = 4 \times 40 \Omega = 160, \text{ max. } 250 \Omega$$

Calculation of R_{m2} when using CWG (10/700 μ s generator)

The internal matching resistor R_{m2} (25 Ω) is replaced by external $R_{m2} = n \times 25 \Omega$ per conductor (for n conductors with n equal or greater than 2).

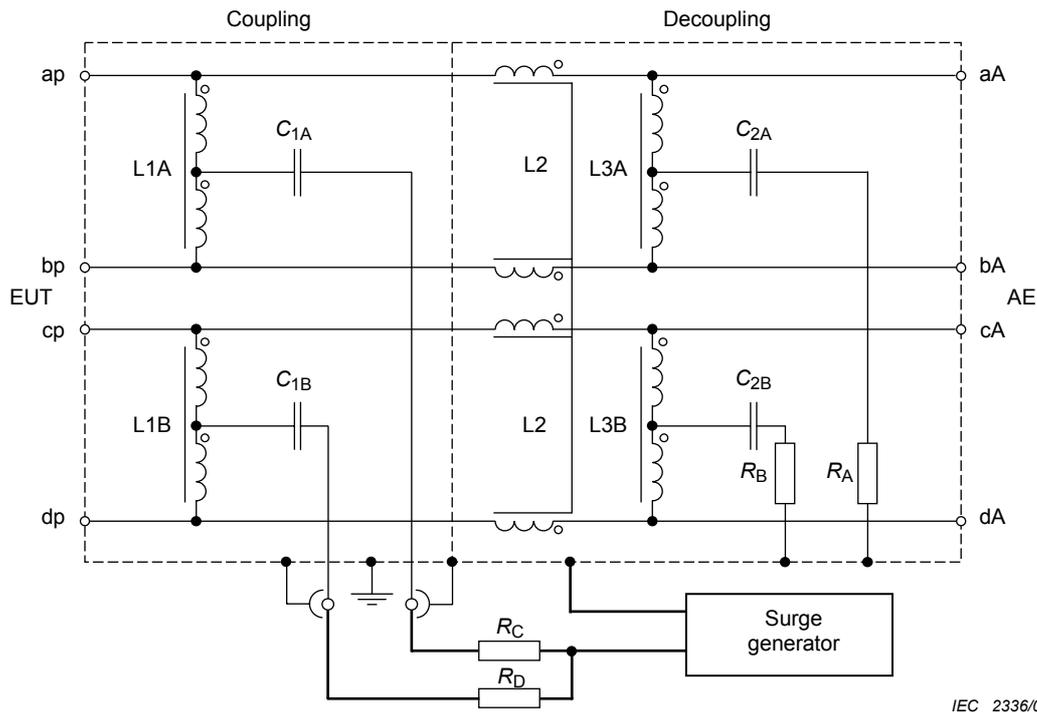
Example for $n = 4$:

$$R_{m2} = 4 \times 25 \Omega = 100 \Omega, R_{m2} \text{ shall not exceed } 250 \Omega.$$

$L = 20$ mH, current compensation may include all 4 coils or only pairs as shown in the figure to be effective.
 R_L : value depending on negligible attenuation of the transmission signal

NOTE The gas arrestors shown can be replaced by a clamping circuit such as that shown in Figure 13.

Figure 14 – Example of test setup for unshielded symmetrical interconnection lines (communication lines); lines-to-ground coupling (according to 7.4), coupling via arrestors



The socket-like symbols in the figure mean connection points.

NOTE 1 L2 shall be a 4-coil current compensated choke to avoid saturation of coil due to phantom power feeding. Further L2 shall have a low resistive impedance; i.e. $\ll 1 \Omega$. resistors connected parallel to L2 may lower the total resistance.

NOTE 2 R_A and R_B should have a value as low as possible to prevent oscillation or ringing.

NOTE 3 R_C and R_D are meant to be isolation resistors of 80Ω .

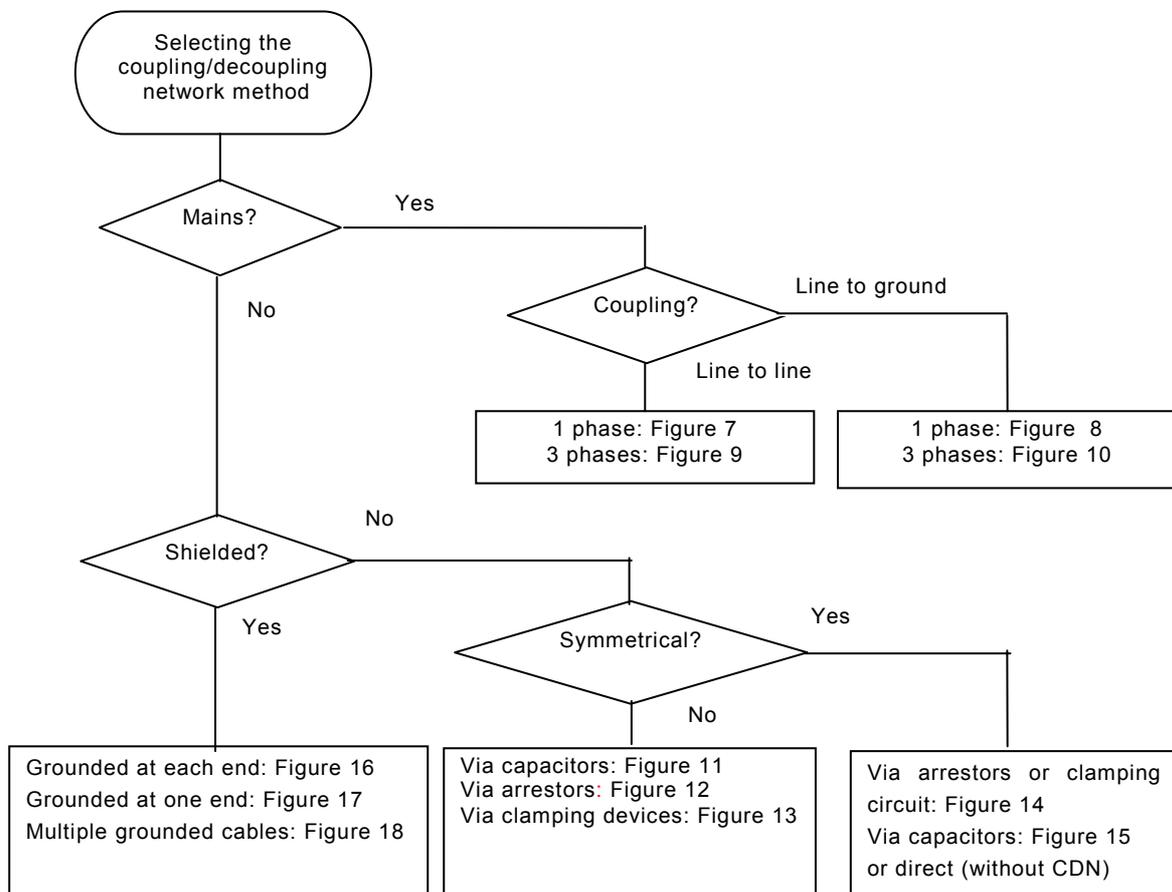
NOTE 4 It is not recommended that this design be used with the $10/700 \mu\text{s}$ waveform since inductors will likely saturate.

Figure 15 – Example of a coupling/decoupling network for symmetrical high speed communication lines using the $1,2/50 \mu\text{s}$ surge

On the a.c. or d.c. supply lines, the decoupling network provides relatively high back impedance to the surge waveform but at the same time, allows a.c. mains or d.c. current to flow to the EUT. This back impedance allows the voltage waveform to be developed at the output of the coupling/decoupling network and prevents surge current from flowing back into the a.c. or d.c. source. 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 a.c. or d.c. supply lines shall be designed so that the open-circuit voltage wave and short-circuit current wave meet the tolerance requirements of Tables 6 and 7.

For I/O and communication lines, the series impedance of the decoupling network will limit the available bandwidth for data transmission. Subclause 6.3.4 describes a procedure to be used in the case where a test cannot be performed with a coupling/decoupling network in place. Coupling elements can be a capacitor, in cases where the line will tolerate the capacitive loading effects (6.3.2.1), or an arrester (6.3.2.2, and 6.3.2.3). When coupling to interconnection lines, the waveforms may be distorted by the coupling mechanism as described in 6.3.2.

Each coupling/decoupling network shall satisfy the requirements of 6.3.1 through 6.3.3. Their use is made according to the following flowchart:



IEC 2337/05

6.3.1 Coupling/decoupling networks for a.c./d.c. power supply circuits

The front time and time to half value shall be verified for voltage under open-circuit conditions and for current under short-circuit conditions at the EUT output port. The 30 % undershoot specification applies only at the generator output. At the output of the coupling/decoupling network there is no limitation on undershoot or overshoot. The generator output or its coupling network shall be connected to a measuring system with a sufficient bandwidth and voltage capability to monitor the open-circuit voltage waveform.

For line-to-line coupling, the surge shall be coupled by an 18 μF capacitor as shown in Figures 7 and 9.

For line-to-ground coupling, the surge shall be coupled by a 9 μF capacitor and a 10 Ω resistor in series, as shown in Figures 8 and 10.

The decoupling inductance shall be selected by the simulator's manufacturer so that the a.c. mains voltage drop at the EUT connector of the coupling/decoupling network is less than 10 % at the specified current rating, but should not exceed 1,5 mH.

To prevent unwanted voltage drops in the coupling/decoupling networks, the value of the decoupling element generally must be reduced for coupling/decoupling networks rated at >25 A. For this case, the “time to half value” of the open-circuit voltage waveform may be reduced in accordance with Tables 6 and 7 below.

Table 6 – Voltage waveform specification at the EUT port of the coupling/decoupling network

Surge voltage parameters under open-circuit conditions	Coupling impedance	
	18 μF	9 μF + 10 Ω
Front time	1,2 μs \pm 30 %	1,2 μs \pm 30 %
Time to half value:		
Current rating < 25 A	50 μs +10 μs /-10 μs	50 μs +10 μs /-25 μs
Current rating 25 A – 60 A	50 μs +10 μs /-15 μs	50 μs +10 μs /-30 μs
Current rating 60 A – 100 A	50 μs +10 μs /-20 μs	50 μs +10 μs /-35 μs
NOTE The measurement of the surge voltage parameters should be done with the power supply input port of the coupling/decoupling network open-circuit.		

Table 7 – Current waveform specification at the EUT port of the coupling/decoupling network

Surge current parameters under short circuit conditions	Coupling impedance	
	18 μF	9 μF + 10 Ω
Front time	8 μs \pm 20 %	2,5 μs \pm 30 %
Time to half value	20 μs \pm 20 %	25 μs \pm 30 %
NOTE The measurement of the surge current parameters should be done with the power supply input port of the coupling/decoupling network open-circuit.		

NOTE For EUTs having a rated input current above 100 A, direct surge coupling to a non-powered EUT without the use of a coupling/decoupling network may be the only reasonable test method. Failure criteria in Clause 9 are only applicable for powered equipment, however if an EUT is tested non-powered, item d) of Clause 9 should apply after the EUT is turned back on. Partial testing of the EUT (e.g. of the control unit alone) is acceptable when it is not possible to test an entire system due to a.c. mains current requirements of greater than 100 A.

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 residual surge voltage on non-surged lines shall not exceed 15 % of the maximum applicable test voltage when the EUT is disconnected and the input of the coupling/decoupling network is open circuit.

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

6.3.2 Coupling/decoupling networks for interconnection lines

The coupling method shall be selected as a function of the circuits and operational conditions. This has to be specified in the product specification/standard.

Testing using a coupling/decoupling network with capacitive coupling may not produce the same test results as arrestor coupling. If a particular coupling method is preferred, it should be specified in the product standards. In any case, the coupling method used should be documented in the test report.

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

6.3.2.1 Coupling/decoupling networks using capacitors

Capacitive coupling is the preferred method for unshielded, unsymmetrical I/O circuits, provided that correct operation of the line can be maintained. An example of a coupling network is shown in Figure 11.

Recommended characteristics of the coupling/decoupling network:

Coupling element $R = 40 \Omega$, $C = 0,5 \mu\text{F}$;

Decoupling inductors $L = 20 \text{ mH}$.

6.3.2.2 Coupling/decoupling networks using clamping devices

This method can be used in cases where capacitive coupling is not possible because of functional problems caused by attachment of capacitors to the EUT (see Figure 11). Some clamping devices have a low parasitic capacitance and will allow connection to many types of I/O lines.

When coupling with a clamping device, the capacitor shown in Figure 11 is replaced by a single clamping device or circuit as shown in Figure 13.

The clamp voltage of the device shall be selected to be as low as possible but higher than the maximum working voltage of the lines to be tested.

Recommended characteristics of the coupling-/decoupling network:

Coupling impedance $R = 40 \Omega$ plus the impedance of the selected clamping device;

Decoupling inductors $L = 20 \text{ mH}$.

The impulse shape at the EUT output of the clamping device is dependent on the impulse amplitude and the characteristics of the clamping device itself; therefore, it is not possible to specify waveform values and tolerances.

6.3.2.3 Coupling/decoupling networks using avalanche devices

This method can be used in cases where the capacitive coupling is not possible because of functional problems caused by attachment of capacitors to the EUT (see Figure 11). Silicon avalanche devices or gas discharge arrestors have a low parasitic capacitance and will allow connection to most types of I/O lines. However, gas arrestors typically have a high ignition voltage that will strongly affect the waveshape of the coupled surge.

Figure 12 shows an example of a coupling/decoupling network using an arrester.

The operating voltage of the arrester shall be selected to be as low as possible but higher than the maximum working voltage of the lines to be tested.

Recommended characteristics of the coupling/decoupling network:

Coupling impedance $R = 40 \Omega$ plus the arrester impedance (gas-filled or solid state);

Decoupling inductors $L = 20 \text{ mH}$.

The impulse shape at the EUT output of the avalanche device is dependent on the impulse amplitude and the characteristics of the avalanche device itself; therefore, it is not possible to specify waveform values and tolerances.

6.3.3 Coupling/decoupling networks using arrestors for coupling to symmetrical lines

Coupling via arrestors is the preferred coupling method for unshielded symmetrical circuits (communication), as shown in Figure 14.

The coupling network also has the task of splitting the surge current into multiple pairs in multi-conductor cables.

Therefore, the resistance R_{m2} in the coupling network shall be, for n composite conductors,

$n \times 40 \Omega$ (for n equal to or greater than 2). R_{m2} shall not exceed 250Ω .

EXAMPLE 1: for 1,2/50 μs surges: $n = 4$, $R_{m2} = 4 \times 40 \Omega$. With the impedance of the generator the total value is approximately 42Ω .

EXAMPLE 2: for 10/700 μs surges: $n = 4$, $R_{m2} = 4 \times 25 \Omega$. With the impedance R_{m1} (15Ω) of the generator the total value is approximately 40Ω while S1 in the generator is closed, see Figure 4.

Recommended characteristics of the coupling/decoupling network:

Coupling impedance R_{m2} plus the impedance of the arrester;

Decoupling inductors $L = 20 \text{ mH}$.

The impulse shape at the EUT output of the arrester is dependent on the impulse amplitude and the characteristics of the arrester itself; therefore, it is not possible to specify waveform values and tolerances.

6.3.4 Coupling/decoupling networks for high-speed communication lines

Because of physical constraints, most coupling/decoupling networks are limited to handling frequencies of up to about 100 kHz. In cases where no adequate coupling/decoupling network is commercially available, surges shall be applied to the high-speed communication data port directly.

The coupling method shall be selected as a function of the circuits and operational conditions. This has to be specified in the product specification.

As long as it does not affect communications, a coupling/decoupling network for high speed lines such as that shown in Figure 15 can be used.

7 Test setup

If none of the coupling methods specified in this clause can be used for functional reasons, alternative methods (suitable for the special case) shall be developed by product committees and the respective results shall be placed into product or product family standards. It may also be necessary to specify a performance criterion.

7.1 Test equipment

The following equipment is part of the test setup:

- equipment under test (EUT);
- auxiliary equipment (AE) when required;
- cables (of specified type and length);
- coupling/decoupling networks;
- combination wave generator;
- decoupling network/protection devices;
- ground reference in the form of a metal plate is necessary when high frequency events are likely (i.e., coupling via gas arrestors) and for tests to shielded lines as described in 7.6.1 below and Figure 17. Connection to a ground reference is only required when the EUT is normally installed with a ground reference connection.

7.2 Test setup for tests applied to EUT power ports

The 1,2/50 μ s surge is to be applied to the EUT power supply terminals via the capacitive coupling network (see Figures 7, 8, 9 and 10). 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 surge wave so that the specified wave may be applied on the lines under test.

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

For purposes of this standard, power ports are considered to be only those ports directly connected to the a.c. mains or distributed d.c. power systems.

For double-insulated products without PE or external earth connections, the test shall be done in a similar way as for grounded products but without adding any additional external grounded connections. If there are no other possible connections to earth, line-to-ground tests may be omitted.

7.3 Test setup for tests applied to unshielded unsymmetrical interconnection lines

In general, the surge is applied to the lines in accordance with Figure 11 via capacitive coupling. The coupling/decoupling network shall not influence the specified functional conditions of the circuits to be tested.

Alternative test setups are given in Figures 12 and 13 for circuits with a higher signal transfer rate. Selection shall be made depending on the capacitive load with respect to the transmission frequency. This alternative reduces the capacitive load on the EUT and may be more suitable for high frequency circuits.

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

7.4 Test setup for tests applied to unshielded symmetrical interconnections communication lines

For symmetrical interconnection/communication circuits (see Figure 14), the capacitive coupling method cannot normally be used. In this case, the coupling is performed via gas arrestors. Test levels below the ignition point of the coupling arrestor (about 300 V for a 90 V gas arrestor) cannot be specified.

NOTE Two test configurations are to be considered:

- a) for the equipment level immunity test with only secondary protection at the EUT at a low test level, for example 0,5 kV or 1 kV,
- b) for the system level immunity test with additional primary protection at a higher test level, for example 2 kV or 4 kV.

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

7.5 Test setup for tests applied to high speed communications lines

This test setup is used when coupling/decoupling networks, an example of which is shown in Figure 15, cannot be used due to high data rates or high transmission frequencies.

Prior to the test, the correct operation of the port shall be verified; the external connection shall then be removed and the surge applied directly to the port's terminals with no coupling/decoupling network. After the surge, the correct operation of the port shall again be verified.

The EUT should be functional during the surge test with the port disconnected, however it is noted that some EUTs may attempt to shut down or disconnect communications ports internally if the data/communication line is removed. If possible, steps should be taken to keep the data/communication port active during the test.

NOTE Coupling/decoupling networks contain low pass filter elements designed to block the high frequency components of the surge, but pass lower frequency signals and power. When the desired signal frequencies exceed about 100 kHz or data rates about 100 kbit/s, the filter components necessary to work with the surge will significantly degrade the desired signals.

7.6 Test setup for tests applied to shielded lines

In the case of shielded lines, a coupling/decoupling network is not applicable, in which case the setup in 7.6.1 or 7.6.2 shall be used.

7.6.1 Direct application

The EUT is isolated from ground and the surge 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 single or multiple shielded cables. See Figures 16 and 17.

NOTE The ground reference mentioned in Figure 16 or 17 represents a low impedance reference, preferably realized by either a dedicated cable or by a ground plane.

All connections to the EUT other than the port(s) under test shall be isolated from ground by suitable means such as safety isolation transformers or a suitable coupling/decoupling network. The length of the cable between the port(s) under test and the device attached to the other end of the cable (AE in Figures 16 and 17) shall be the lesser of: the maximum length permitted by the EUT's specification, or 20 m. Where the length exceeds 1 m, the cable shall be non-inductively bundled.

Rules for application of the surge to shielded lines:

a) *Shields grounded at both ends*

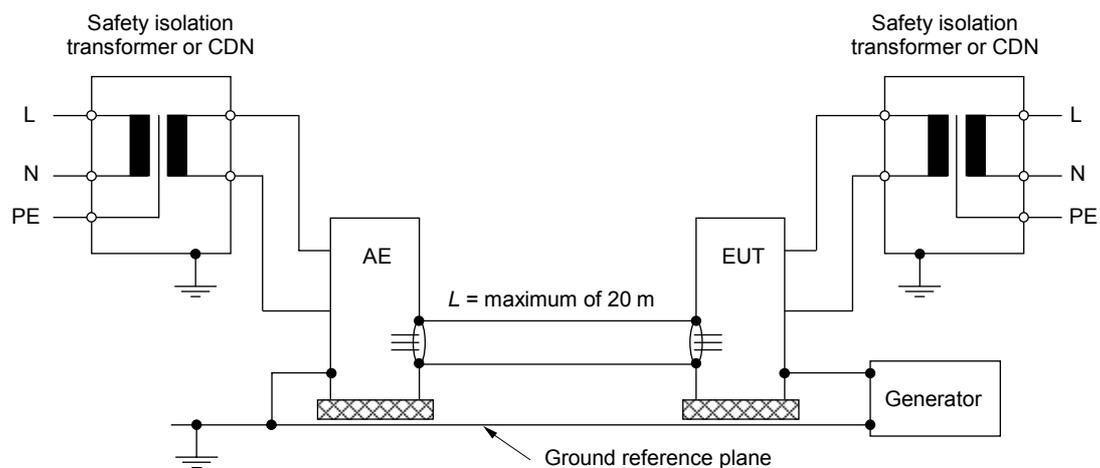
- the surge injection on the shield shall be carried out according to Figure 16.

b) *Shields grounded at one end*

- the test shall be carried out according to Figure 17. If in the installation the shield is connected only at the auxiliary equipment, test shall be done in that configuration but with the generator still connected to the EUT side as shown in Figure 17. If cable lengths allow, the cables shall be on insulated supports 0,1 m above the ground plane or cable tray.

The test level is applied on shields with a 2 Ω generator source impedance.

For products which do not have metallic enclosures, the surge is applied directly to the shielded cable.

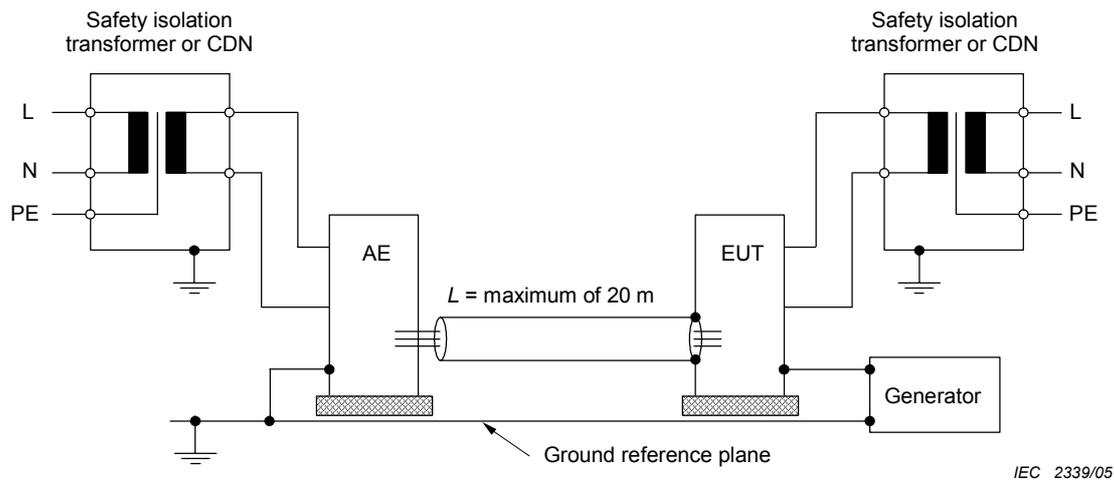


IEC 2338/05

NOTE 1 It is permissible for the power to the EUT and/or the AE to be provided via a decoupling network as shown in e.g. Figure 7, rather than via the isolation transformer shown. In this case, the EUT's protective earth connection should be left open circuit.

NOTE 2 This example of setup also applies to d.c. supplied EUTs.

Figure 16 – Example of test setup for tests applied to shielded lines (according to 7.6) and to apply potential differences (according to 7.7)



NOTE 1 It is permissible for the power to the EUT and/or the AE to be provided via a decoupling network as shown in, for example Figure 7, rather than via the isolation transformer shown. In this case, the EUT's protective earth connection should be left open circuit.

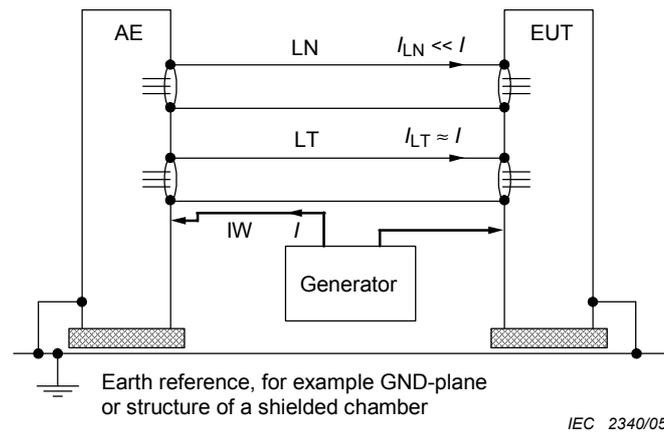
NOTE 2 This example of setup also applies to d.c. supplied EUTs.

Figure 17 – Example of test setup for tests applied to shielded lines grounded only at one end (according to 7.6) and to apply potential differences (according to 7.7)

7.6.2 Alternative coupling method for testing single cables in a multi-shield configuration

Surges are applied in close proximity to the interconnection cable under test by a wire according to Figure 18. This coupling method is useful for multiple shielded cable wiring with multiple ground connections, between two or more EUTs (or one EUT and AE) of a test configuration, in order to apply the surge to a particular cable or bundle of cables. If individual cables are typically bundled in an installation, they should be tested in a bundle.

The length of the cable between the port(s) under test and the device attached to the other end of the cable shall be the lesser of: the maximum length permitted by the EUT's specification, or 20 m. Where the length exceeds 1 m, excess lengths of cables shall be bundled at the approximate centre of the cables with the bundles 30 cm to 40 cm in length. If it is impractical to do so because of cable bulk or stiffness, or because the testing is being done at a user installation, the disposition of the excess cables shall be precisely noted in the test report.



Designations:

- LT Signal interface line *especially* to be tested
 LN Signal interface line *not intended* to be tested
 IW Injection wire

NOTE This example of setup also applies to d.c. supplied EUTs.

Characteristics of the test setup: (AE shall be connected to GND)

The generator is located near the EUT;

Common output of the generator is connected to the structure of the EUT;

The impulse output of the generator is routed to the AE via an insulated injection line extremely close to the interface cable between EUT and AE. The cross section of the injection cable is not critical.

With $I_{LT} \approx I$ and $I_{LN} \ll I$, the bulk injected current will run over the shield of the cable under test (proximity effect).

The cable lengths shall be chosen according to the installation with a maximum length of 20 m.

The cable to be tested should be kept at least 1 m from ground planes or walls of shielded enclosures.

The cables NOT being tested should be at least 0,4 m from the cable being tested and from ground planes or walls of shielded enclosures in order to avoid other return paths for the current.

Figure 18 – Coupling method and test setup for tests applied to shielded lines and to apply potential differences, especially in configurations with multiple shielded cable wiring

7.7 Test setup to apply potential differences

In system level tests, it may be necessary to apply potential differences which simulate voltages that can occur between exposed conductive parts/chassis within the system due to, for example leakage currents, defects or lightning. The tests may be carried out in accordance with Figure 16 for systems with shielded lines, shields grounded at both ends, and in accordance with Figure 17 for systems with unshielded lines or shielded lines grounded only at one end.

7.8 EUT mode of operation

The operational test conditions and the installation conditions shall be in accordance with the product specification and shall include:

- the test configuration (hardware);
- the test procedure (software).

8 Test procedure

8.1 Laboratory reference conditions

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

8.1.1 Climatic conditions

Unless otherwise specified in generic, product family or product standards, 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.

8.1.2 Electromagnetic conditions

The electromagnetic environment of the laboratory shall not influence the test results.

8.2 Application of the surge in the laboratory

Verification shall be performed on the generators and coupling/decoupling network prior to the test. This performance check can usually be limited to the existence of the surge pulse and its voltage and/or current.

The characteristics and performance of the generators shall be as specified in 6.1.1 and 6.2.1; the calibration of the generators shall be performed on a regular basis according to 6.1.2 and 6.2.2. (typically once per year).

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

- test level (voltage) (refer to Annex A);
- number of surges:
 - number of surge pulses unless otherwise specified by the relevant product standard:
 - for d.c. power ports and interconnection lines five positive and five negative surge pulses;
 - for a.c. power ports five positive and five negative pulses each at 0°, 90°, 180° and at 270°;
- time between successive pulses: 1 min or less;
- representative operating conditions of the EUT;
- locations to which the surges are applied.

Power ports (a.c. or d.c.) can be input ports or output ports.

NOTE 1 Surges to output ports are recommended in applications where surges are likely to enter the EUT via those output ports (e.g. switching of loads with large power consumption).

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

In the case of several identical circuits, representative measurements on a selected number of circuits may be sufficient.

If testing done at rates faster than 1/min cause failures and tests done at 1/min do not, the test done at 1/min prevails.

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

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

Further information on the application of the tests is given in Clause B.2.

When testing line to ground, the lines are tested singly 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 the test voltage has to be increased by steps up to the test level specified in the product standard or test plan/report without exceeding it. All lower levels including the selected test level shall be satisfied.

For testing the secondary protection, the output voltage of the generator shall be adjusted to be just below the worst case voltage breakdown level (let-through level) of the primary protection.

If the actual operating signal sources are not available, they may be simulated.

For acceptance test, a previously unstressed equipment shall be used, or the protection devices shall be replaced before the test.

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 by Clause 8 of this standard;
- 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);
- test configuration (software);

Equipment shall not become dangerous or unsafe as a result of the application of the tests defined in this part of IEC 61000.

Annex A (informative)

Selection of generators and test levels

The selection of the test levels should be based on the installation conditions. Unless otherwise specified in product or product-family standards, Table A.1 should be used, together with information given in Clause B.3 where:

- 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.

Additional information is given in Annex B.

To demonstrate the system level immunity, additional measures relevant to the actual installation conditions, for example primary protection, should be taken.

Table A.1 – Selection of the test levels (depending on the installation conditions)

Installation class	Test levels (kV)											
	AC power supply and a.c. I/O directly connected to the mains network Coupling mode		AC power supply and a.c. I/O not directly connected to the mains network Coupling mode		DC power supply and d.c. I/O directly connected thereto Coupling mode		Unsymmetrical operated ^{d,f} circuits/lines Coupling mode		Symmetrical operated ^{d,f} circuits/lines Coupling mode		Shielded I/O and communication lines ^f 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	Line-to-line	All lines-to-ground	Line-to-line	Line-to-ground
0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	NA	0,5	NA	NA	NA	NA	NA	0,5	NA	0,5	NA	NA
2	0,5	1,0	NA	NA	NA	NA	0,5	1,0	NA	1,0	NA	0,5
3	1,0	2,0	1,0 ^e	2,0 ^{b,e}	1,0 ^e	2,0 ^{b,e}	1,0 ^c	2,0 ^{b,c}	NA	2,0 ^{b,c}	NA	2,0 ^c
4	2,0	4,0 ^b	2,0 ^e	4,0 ^{b,e}	2,0 ^e	4,0 ^{b,e}	2,0 ^c	4,0 ^{b,c}	NA	2,0 ^{b,c}	NA	4,0 ^c
5	^a	^a	2,0	4,0 ^b	2,0	4,0 ^b	2,0	4,0 ^b	NA	4,0 ^b	NA	4,0 ^c

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

^b Normally tested with primary protection.

^c The test level may be lowered by one level if the cable length is shorter or equal to 10 m.

^d No test is advised at data connections intended for cables shorter than 10 m.

^e If protection is specified upstream from the EUT, the test level should correspond to the protection level when the protection is not in place.

^f High speed communications lines could be included under unsymmetrical, symmetrical, shielded I/O and/or communications lines.

The surges (and generators) related to the different classes are as in the following:

Classes 1 to 4: 1,2/50 μ s (8/20 μ s).

Class 5: 1,2/50 μ s (8/20 μ s) for ports of power lines and short-distance signal circuits/lines.

Class 1 to 5: 10/700 μ s (5/320 μ s) for symmetrical communication lines

The source impedance shall be as indicated in the figures of the test setups concerned.

Annex B (informative)

Explanatory notes

B.1 Different source Impedance

The selection of the source impedance of the generator depends on:

- the kind of cable/conductor/line (a.c. power supply, d.c. power supply, interconnection, etc.);
- the length of the cables/lines;
- indoor/outdoor conditions;
- application of the test voltage (line-to-line or lines-to-ground).

The impedance of $2\ \Omega$ represents the source impedance of the low-voltage power supply network. The generator with its effective output impedance of $2\ \Omega$ is used.

The impedance of $12\ \Omega$ ($10\ \Omega + 2\ \Omega$) represents the source impedance of the low-voltage power supply network and ground. The generator with an additional resistor of $10\ \Omega$ in series is used.

The effective impedance of $42\ \Omega$ ($40\ \Omega + 2\ \Omega$) represents the source impedance between all other lines and ground. The generator with an additional resistor of $40\ \Omega$ in series is used.

In some countries, (for instance, USA) other non-IEC standards for a.c. lines may require the tests according to Figures 8 and 10 with a $2\ \Omega$ impedance; this is a more severe test.

B.2 Application of the tests

Two different kinds of tests are to be distinguished: at equipment level and at system level.

B.2.1 Equipment level immunity

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

The test voltage shall not exceed the specified capability of the EUT's insulation to withstand high-voltage stress.

B.2.2 System level immunity

Preferential ranges of test levels are given in Table A.1. 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.

The test carried out in the laboratory refers to an EUT, but immunity at the EUT does not necessarily assure the immunity of a larger 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. This simulated installation shall be comprised of individual EUTs and shall 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 will be used, all of which can affect the overall system protection level.

The simple addition of an external SPD that is not co-ordinated with other internal SPDs, might have no effect, might reduce the effect on the overall system protection, or might improve overall system protection.

Additional information can be found in IEC Surge protective devices standards series IEC 61643 and IEC 62305 series (Protection against lightning electromagnetic impulse).

This test is aimed at simulating as closely as possible the installation conditions in which the EUT or EUTs are intended to function.

In a real installation, higher voltage levels can be applied, but the surge energy will be limited by the installed protective devices in accordance with their current-limiting characteristics.

The system level test is also intended to show that secondary effects produced by the protective devices (change of waveform, mode, amplitude of voltages or currents) do not cause unacceptable effects on the EUT. To check that no damage windows within the EUT at a specific test voltage exists, it is necessary to perform the tests with progressively raised test voltages up to the required value. This specific test voltage is determined by the operating points of the protection components or protective devices within the EUT (see IEC 61643-21 6.2.1.8 Blind spot test).

B.3 Installation classification

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 A.1).

Surge voltage may not exceed 25 V.

Class 1 Partly protected electrical environment

All incoming cables to the room are provided with overvoltage (primary) protection.

The units of the equipment are well-interconnected by a ground connection network, which is not significantly influenced by the power installation or lightning.

The electronic equipment has its power supply completely separated from the other equipment.

Switching operations can generate interference voltages within the room.

Surge voltage may not exceed 500 V.

- Class 2** Electrical environment where the cables are well-separated, even at short runs.
The installation is grounded via a separate connection to the grounding system of the power installation which can be subjected to interference voltages generated by the installation itself or by lightning. The power supply to the electronic equipment is separated from other circuits, usually by a dedicated transformer for the mains power supply.
Non-protected circuits are present in the installation, but well-separated and in restricted numbers.
Surge voltages may not exceed 1 kV.
- Class 3** Electrical environment where power and signal cables run in parallel
The installation is grounded to the common grounding system of the power installation which can be subjected to interference voltages generated by the installation itself or by lightning.
Current due to ground faults, switching operations and lightning in the power installation may generate interference voltages with relatively high amplitudes in the grounding system. Protected electronic equipment and less sensitive electric equipment are connected to the same power supply network. The interconnection cables can be partly outdoor cables, but close to the grounding network.
Unsuppressed inductive loads are present in the installation and usually there is no separation of the different field cables.
Surge may not exceed 2 kV.
- Class 4** Electrical environment where the interconnections are running as outdoor cables along with power cables, and cables are used for both electronic and electric circuits
The installation is connected to the grounding system of the power installation which can be subjected to interference voltages generated by the installation itself or by lightning.
Currents in the kA range due to ground faults, switching operations and lightning in the power supply installation may generate interference voltages with relatively high amplitudes in the grounding system. The power supply network can be the same for both the electronic and the other electrical equipment. The interconnection cables are run as outdoor cables, even to the high-voltage equipment.
A special case of this environment is when the electronic equipment is connected to the telecommunication network within a densely populated area. There is no systematically constructed grounding network outside the electronic equipment, and the grounding system consists only of pipes, cables, etc.
Surge voltage may not exceed 4 kV.
- Class 5** Electrical environment for electronic equipment connected to telecommunication cables and overhead power lines in a non-densely populated area
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 ground faults (currents up to 10 kA) and lightning (currents up to 100 kA) can be extremely high.
The requirements of this class are covered by the test level 4 (see Annex A).
- Class x** Special conditions specified in the product specifications

B.4 Minimum immunity level of ports connected to the power supply network

The minimum immunity level for connection to the public supply network is:

- Line-to-line coupling: 0,5 kV (for test setup, see Figures 7 and 9);
- Line-to-ground coupling: 1 kV (for test setup, see Figures 8 and 10).

B.5 Equipment level immunity of ports connected to interconnection lines

Surge tests on interconnection circuits are only required for external connections (outside of the cabinet/housing).

If it is possible to test at the system level (EUT with interconnection cables connected), 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. If the installation of the plant is carried out by someone other than the manufacturers of the equipment, the admissible voltage for the inputs/outputs (especially for the process interface) of the EUT should be specified.

The manufacturer should test his 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, lightning strokes does not exceed the chosen immunity level.

Annex C (informative)

Considerations for achieving immunity for equipment connected to low voltage power systems

This test standard, IEC 61000-4-5, describes the tests to determine the immunity from voltage and current surges for electronic equipment and systems. The equipment or system to be tested is regarded as a black box and the results of the tests are judged by the following criteria:

- a) normal performance;
- b) temporary loss of function or temporary degradation of performance not requiring an operator;
- c) temporary loss of function or temporary degradation of performance requiring an operator;
- d) loss of function with permanent damage to equipment (which means failing the test).

Whereas the tests of IEC 61000-4-5 investigate the full range of possible effects of comparatively low current surges on electronic equipment and systems, including permanent damage and destruction of equipment and systems, there are other related test standards which are not so much concerned with temporary loss of function, but more with actual damage or destruction of equipment.

IEC 60664-1 is concerned with insulation coordination for equipment within low voltage systems and IEC 61643-1 is a test standard for surge protective devices connected to low-voltage power distribution systems. In addition, both of these standards are concerned with the effect of temporary overvoltage on equipment. IEC 61000-4-5 and the other standards in the IEC 61000 series do not consider the effect of temporary overvoltages on equipment or systems.

Permanent damage is hardly ever acceptable, since it results in system downtime and expense of repair or replacement. This type of failure is usually due to inadequate or no surge protection, which allows high voltages and excessive surge currents into the circuitry of the equipment, causing disruption of operation, component failures, permanent insulation breakdown and hazards of fire, smoke or electrical shock. It is also undesirable, however, to experience any loss of function or degradation of equipment or system, particularly if the equipment or system is critical and must remain operational during surge activity.

For the tests described in IEC 61000-4-5, the magnitude of the applied voltage test level (installation class) and the resultant surge current will have a direct effect on the response of the equipment. Simply stated, the higher the voltage level of a surge, the higher the likelihood of loss of function or degradation, unless the equipment has been designed to provide an appropriate surge immunity.

To test surge protective devices (SPDs) used on low voltage power systems, IEC 61643-1, test class III, specifies a combination wave generator with an effective output impedance of 2Ω , which produces an $8/20 \mu\text{s}$ short-circuit current waveshape and a $1,2/50 \mu\text{s}$ open-circuit voltage waveshape. IEC 61000-4-5, uses the same combination wave generator for the surge immunity test for powered equipment and systems but with different coupling elements and also sometimes an additional series impedance. The meaning of voltage test level (installation class) of this standard and the peak open-circuit voltage U_{oc} of IEC 61643-1 are equivalent. This voltage determines the peak short-circuit current value at the generator terminals. Due to differences in the test methods test results may not be directly comparable.

Surge immunity of equipment or systems may be achieved by built-in surge protective components or devices (SPDs), or external SPDs. One of the most important selection criteria for SPDs is the voltage protection level, U_p , defined and described in IEC 61643-1. This parameter should be coordinated with the withstand voltage of the equipment U_w according to IEC 60664-1 and is the maximum voltage to be expected across the terminals of the SPD during the tests in specific conditions. U_p is only used in IEC 61643-12 for coordination with the withstand voltage of the equipment U_w . The value of the voltage protection level at a comparable stress should also be below the voltage immunity level at this comparable stress of the equipment tested to IEC 61000-4-5 but this is not addressed at the present time, especially because waveshapes are not always comparable between the two standards.

In general, surge immunity levels of equipment according to IEC 61000-4-5 are lower than insulation withstand levels according to IEC 60664-1, however care should be taken regarding the effects of temporary overvoltages according to IEC 60364-4-44 on an SPD (or built-in surge protective component) having an excessively low protection level. It is quite possible to choose an SPD that will protect equipment from failure, remain operational during surge activity and withstand most temporary overvoltage conditions.

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IEC 60050(311), *International Electrotechnical Vocabulary – Electrical and electronic measurements and measuring instruments – Part 311: General terms relating to measurements - Part 312: General terms relating to electrical measurements – Part 313: Types of electrical measuring instruments – Part 314: Specific terms according to the type of instrument*

IEC 60364 (all parts), *Electrical installations of buildings*

IEC 60664 (all parts), *Insulation coordination for equipment within low-voltage systems*

IEC 61643 (all parts), *Low-voltage surge protective devices*



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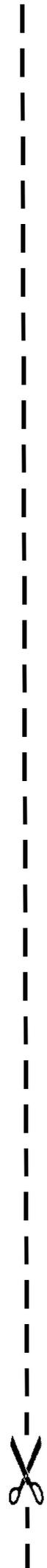
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