

CONSOLIDATED VERSION

VERSION CONSOLIDÉE



BASIC EMC PUBLICATION

PUBLICATION FONDAMENTALE EN CEM

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

**Compatibilité électromagnétique (CEM) –
Partie 4-5: Techniques d'essai et de mesure – Essai d'immunité aux ondes
de choc**



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de choc**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 33.100.20

ISBN 978-2-8322-4706-8

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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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This Consolidated version of IEC 61000-4-5 bears the edition number 3.1. It consists of the third edition (2014-05) [documents 77B/711/FDIS and 77B/715/RVD] and its amendment 1 (2017-08) [documents 77B/762/CDV and 77B/773/RVC]. The technical content is identical to the base edition and its amendment.

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

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.

This third edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) new Annex E on mathematical modelling of surge waveforms;
- b) new Annex F on measurement uncertainty;
- c) new Annex G on method of calibration of impulse measuring systems;
- d) new Annex H on coupling/decoupling surges to lines rated above 200 A;
- e) moreover while surge test for ports connected to outside telecommunication lines was addressed in 6.2 of the second edition (IEC 61000-4-5:2005), in this third edition (IEC 61000-4-5:2014) the normative Annex A is fully dedicated to this topic. In particular it gives the specifications of the 10/700 μ s combined wave generator.

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 the base publication and its amendment 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

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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 (insofar 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 surge voltages and surge currents.

INTRODUCTION to the amendment

Rationale:

The method for testing DC products in the current revision of IEC61000-4-5 is causing many field related problems for test labs and manufacturers. Many products will not power up through the power CDN in the standard and in some cases may be damaged by the inductance that is necessary to apply the surge (see 77B/734/DC for further information).

The DC./DC converter problem is related to the switching of the converter which produces a voltage drop at the decoupling inductors on one hand and oscillations produced by the EUT impedance in combination with the source on the other hand. Measurements were performed using different brands of CDNs with a device known to show that problem as an EUT. The result shows different oscillations and signal forms of the voltage at the EUT for different CDNs. According to the outcome, the use of a CDN with a higher current rating (i.e. smaller decoupling inductivity) can solve the problem. At the meeting of SC77B/MT12 in Akishima, Japan on August 26, 2016, it was decided to add a statement into 7.3 allowing surge tests with higher current rated CDNs and to add a new Annex I to explain the problem in detail.

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 with regard to unidirectional surges caused by over-voltages 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 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 levels 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 equipment under test (EUT) under specified operational conditions to surge voltages caused by switching and lightning effects.

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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 abbreviations

3.1 Terms and definitions

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

3.1.1

avalanche device

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

3.1.2

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

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]

3.1.3

clamping device

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

3.1.4

combination wave generator

CWG

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

3.1.5

coupling network

CN

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

3.1.6

coupling/decoupling network

CDN

combination of a coupling network and a decoupling network

3.1.7

decoupling network

DN

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

3.1.8

duration

3.1.8.1

duration

T_d

<surge voltage> time interval between the instant at which the surge voltage rises to 0,5 of its peak value, and then falls to 0,5 of its peak value (T_w)

$$T_d = T_w$$

SEE: Figures 2 and A.2

3.1.8.2 **duration**

T_d

<surge current for 8/20 μ s> virtual parameter defined as the time interval between the instant at which the surge current rises to 0,5 of its peak value, and then falls to 0,5 of its peak value (T_w), multiplied by 1,18

$$T_d = 1,18 \times T_w$$

SEE: Figure 3.

3.1.8.3 **duration**

T_d

<surge current for 5/320 μ s> time interval between the instant at which the surge current rises to 0,5 of its peak value, and then falls to 0,5 of its peak value (T_w)

$$T_d = T_w$$

SEE: Figure A.3.

3.1.9 **effective output impedance**

<surge generator> ratio of the peak open-circuit voltage to the peak short-circuit current at the same output port

3.1.10 **electrical installation**

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

[SOURCE: IEC 60050-826:2004, 826-10-01]

3.1.11 **front time**

3.1.11.1 **front time**

T_f

<surge voltage> 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 A.2.

3.1.11.2 **front time**

T_f

<surge current> virtual parameter defined as 1,25 times the interval T_r between the instants when the impulse is 10 % and 90 % of the peak value

SEE: Figures 3 and A.3.

3.1.12 **high-speed communication lines**

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

3.1.13**immunity**

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]

3.1.14**interconnection lines**

I/O lines (input/output lines) and/or communication lines and/or low voltage d.c. input/output lines (≤ 60 V), where secondary circuits (isolated from the a.c. mains supply) are not subject to transient over-voltages (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)

3.1.15**power port**

port, at which the conductor or cable carrying the primary electrical power needed for the operation (functioning) of an apparatus or associated apparatus is connected to the apparatus

3.1.16**primary protection**

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

3.1.17**reference ground**

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

[SOURCE: IEC 60050-195:1998, 195-01-01]

3.1.18**rise time** **T_r**

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

SEE: Figures 3 and A.3.

[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”.]

3.1.19**secondary protection**

means by which the let-through energy from primary protection is suppressed

Note 1 to entry: It may be a special device or an inherent characteristic of the EUT.

3.1.20**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

[SOURCE: IEC 60050-161:1990, 161-08-11, modified – “surge” here applies to voltage, current and power]

3.1.21

symmetrical lines

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

3.1.22

system

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

Note 1 to entry: 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.

3.1.23

transient, adjective and noun

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

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

3.1.24

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 Abbreviations

AE	Auxiliary equipment
CD	Coupling device
CDN	Coupling/decoupling network
CLD	Clamping device
CN	Coupling network
CWG	Combination wave generator
DN	Decoupling network
EFT/B	Electrical fast transient/burst
EMC	Electromagnetic compatibility
ESD	Electrostatic discharge
EUT	Equipment under test
GDT	Gas discharge tube
MU	Measurement uncertainty
PE	Protective earth
SPD	Surge protective device

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, e.g. thyristors, transistors;
- 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 that produce voltages by either flowing through ground resistance or flowing through the impedance of the external circuit;
- b) 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 defined to simulate the above-mentioned phenomena as closely as possible.

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

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	
	kV	
	Line-to-line	Line-to-ground ^b
1	---	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. The level shall be specified in the dedicated 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.

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 General

Two types of combination wave generators are specified. Each has its own particular applications, depending on the type of port to be tested. The 10/700 μ s combination wave generator is used to test ports intended for connection to outdoor symmetrical communication lines (see Annex A). The 1,2/50 μ s combination wave generator is used in all other cases.

6.2 1,2/50 μ s combination wave generator

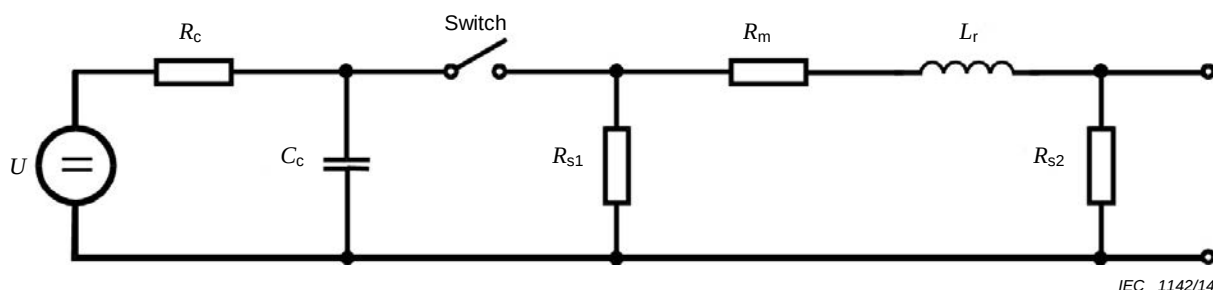
6.2.1 General

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 shall be 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 waveforms shall be as specified in Tables 4, 5, and 6. In the case where the surge is 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.

This generator is intended to generate a surge having:

- an open-circuit voltage front time of 1,2 μ s;
- an open-circuit voltage duration of 50 μ s;
- a short-circuit current front time of 8 μ s;
- a short-circuit current duration of 20 μ s.

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 μ s voltage surge at open-circuit conditions and an 8/20 μ s current surge into a short-circuit.



Key

U	High-voltage source
R_c	Charging resistor
C_c	Energy storage capacitor
R_s	Impulse duration shaping resistors
R_m	Impedance matching resistor
L_r	Rise time shaping inductor

Figure 1 – Simplified circuit diagram of the combination wave generator

The ratio of peak open-circuit output voltage to peak short-circuit current at the same output port of a combination wave generator shall be considered as the effective output impedance. For this generator, the ratio defines an effective output impedance of 2 Ω .

When the generator output is connected to the EUT, 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 μ s voltage and the 8/20 μ s current waves should be available from the same generator output as required by the load.

6.2.2 Performance characteristics 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 EUT 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

NOTE The time parameters are valid for the short-circuit current at the generator output without a 10 Ω resistor (see 6.3).

Short-circuit output current tolerance see Table 3

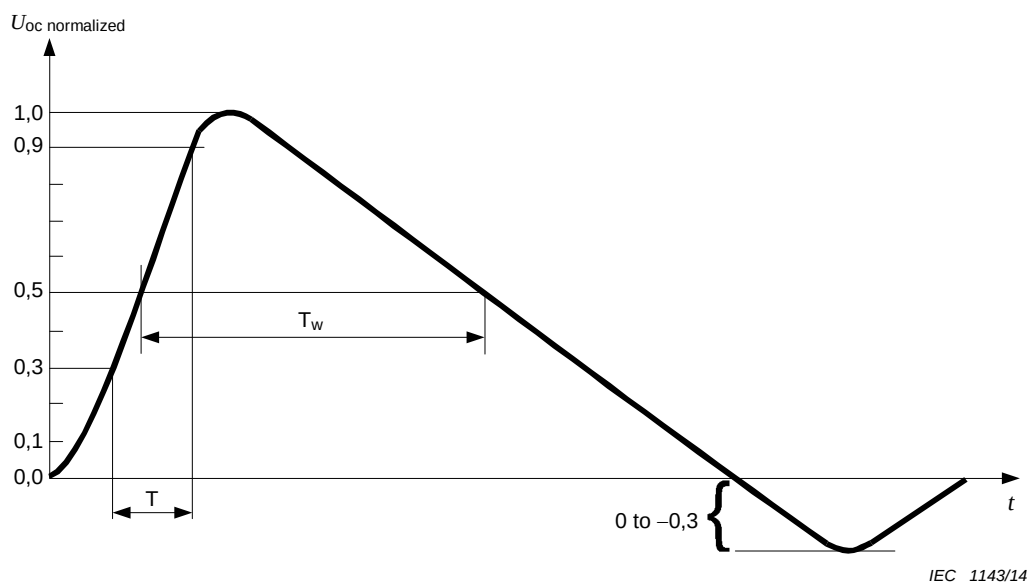
Table 2 – Definitions of the waveform parameters 1,2/50 μs and 8/20 μs

	Front time T_f μs	Duration T_d μs
Open-circuit voltage	$T_f = 1,67 \times T = 1,2 \pm 30 \%$	$T_d = T_w = 50 \pm 20 \%$
Short-circuit current	$T_f = 1,25 \times T_r = 8 \pm 20 \%$	$T_d = 1,18 \times T_w = 20 \pm 20 \%$

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

Open-circuit peak voltage ± 10 % at generator output	Short-circuit peak current ± 10 % at generator output
0,5 kV	0,25 kA
1,0 kV	0,5 kA
2,0 kV	1,0 kA
4,0 kV	2,0 kA

A generator with floating output shall be used.

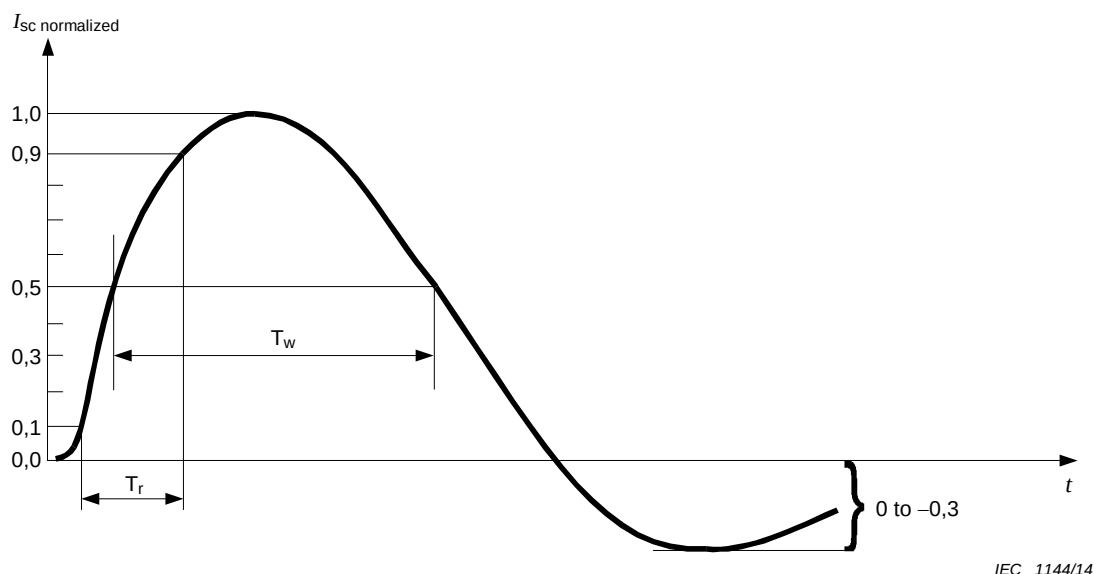


Front time: $T_f = 1,67 \times T = 1,2 \mu\text{s} \pm 30 \%$
Duration: $T_d = T_w = 50 \mu\text{s} \pm 20 \%$

NOTE The value 1,67 is the reciprocal of the difference between the 0,9 and 0,3 thresholds.

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

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



$$\begin{aligned} \text{Front time:} \quad T_f &= 1,25 \times T_r = 8 \mu\text{s} \pm 20 \% \\ \text{Duration:} \quad T_d &= 1,18 \times T_w = 20 \mu\text{s} \pm 20 \% \end{aligned}$$

NOTE 1 The value 1,25 is the reciprocal of the difference between the 0,9 and 0,1 thresholds.

NOTE 2 The value 1,18 is derived from empirical data.

Figure 3 – Waveform of short-circuit current (8/20 μs) at the output of the generator with no CDN connected

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

6.2.3 Calibration of the generator

The test generator characteristics shall be calibrated in order to establish that they meet the requirements of this standard. For this purpose the following procedure shall be undertaken (see also Annex G).

The generator output shall be connected to a measuring system with a sufficient bandwidth, voltage and current capability to monitor the characteristics of the waveforms. Annex E provides information concerning the bandwidth of the surge waveforms.

If a current transformer (probe) is used to measure short-circuit current it should be selected so that saturation of the magnetic core does not take place. The lower (-3 dB) corner frequency of the probe should be less than 100 Hz.

The characteristics of the generator shall be measured through an external capacitor of 18 μF in series with the output, both under open-circuit (load greater than or equal to 10 kΩ) and short-circuit conditions at the same set voltage. If the 18 μF capacitor is implemented in the generator, no external 18 μF capacitor is required for calibration.

All performance characteristics stated in 6.2.2, with the exception of phase shifting, 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.

NOTE 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. 12 Ω or 42 Ω, according to the requirements of the test setup, the front time and the duration of test impulses at the output of the coupling network can be significantly changed.

6.3 Coupling/decoupling networks

6.3.1 General

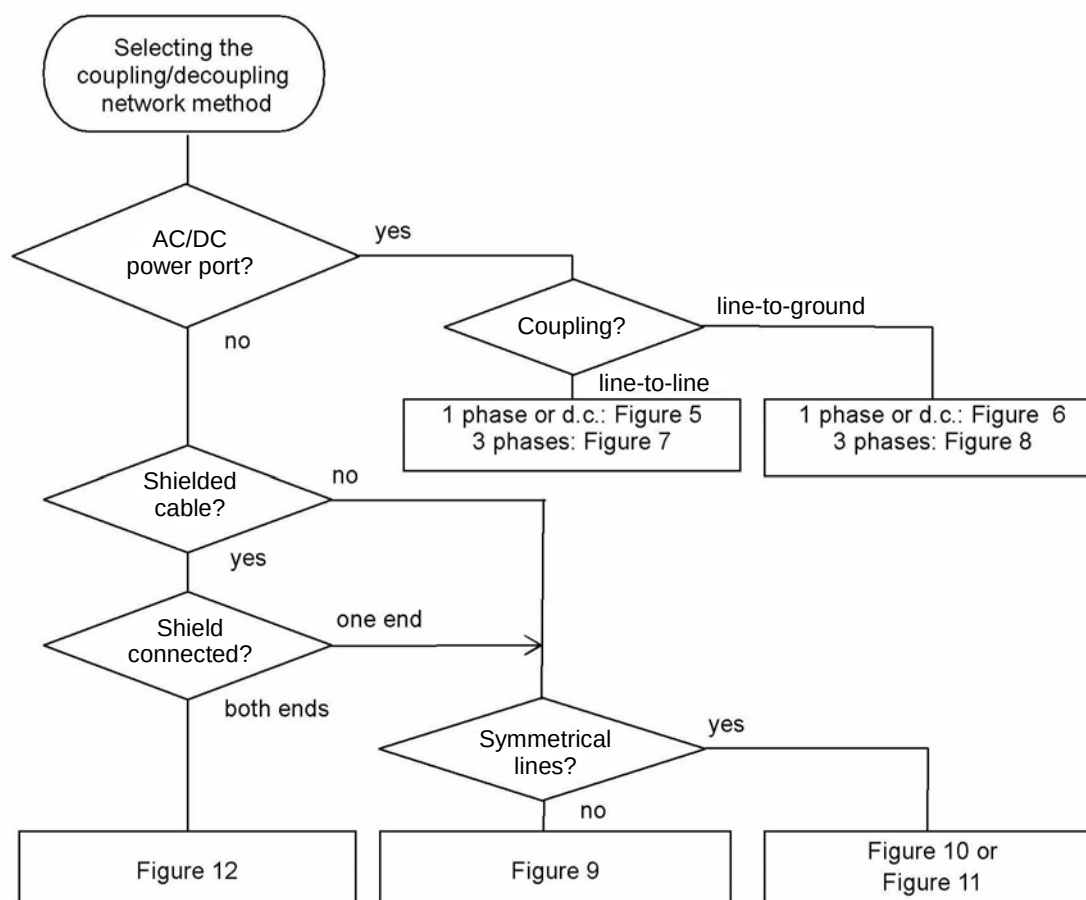
Each coupling/decoupling network (CDN) consists of a coupling network and a decoupling network as shown in the examples of Figures 5 through 11.

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

On the a.c. or d.c. power lines, the decoupling network provides relatively high impedance to the surge waveform 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 surge current from flowing back into the a.c. or d.c. 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 a.c. or d.c. power supply shall be designed so that the open-circuit voltage waveform and short-circuit current waveform meet the requirements of Tables 4, 5 and 6.

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 6.3.3.

Each coupling/decoupling network shall satisfy the requirements of 6.3.2 and 6.3.3 and shall comply with the calibration requirements in 6.4. Their use is made according to the following flowchart:



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Figure 4 – Selection of coupling/decoupling method

6.3.2 Coupling/decoupling networks for a.c./d.c. power port rated up to 200 A per line

The peak amplitude, front time and duration shall be verified, for voltage under open-circuit conditions and for current under short-circuit conditions, at the EUT output port. 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 30 % undershoot specification applies only at the generator output. At the output of the coupling/decoupling network there is no limitation on undershoot. The CDN shall be connected to a measuring system with a sufficient bandwidth, voltage and current capability to monitor the characteristics of the waveforms.

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 voltage and the duration of the open-circuit voltage waveform which is measured with no load can vary within the tolerances given in Tables 4, 5 and 6 below. High current EUTs represent lower impedances and cause surges close to short-circuit conditions. Therefore, for high current CDNs it is the current waveform which is predominant. Large tolerances on the voltage definition are acceptable.

**Table 4 – Voltage waveform specification
at the EUT port of the CDN**

Surge voltage parameters under open-circuit conditions ^{a, b}	Coupling impedance	
	18 μ F (line-to-line)	9 μ F + 10 Ω (line-to-ground)
Peak voltage		
Current rating ≤ 16 A	Set voltage +10 %/-10 %	Set voltage +10 %/-10 %
16 A < current rating ≤ 32 A	Set voltage +10 %/-10 %	Set voltage +10 %/-10 %
32 A < current rating ≤ 63 A	Set voltage +10 %/-10 %	Set voltage +10 %/-15 %
63 A < current rating ≤ 125 A	Set voltage +10 %/-10 %	Set voltage +10 %/- 20 %
125 A < current rating ≤ 200 A	Set voltage +10 %/-10 %	Set voltage +10 %/- 25 %
Front time	1,2 μ s $\pm$ 30 %	1,2 μ s $\pm$ 30 %
Duration		
Current rating ≤ 16 A	50 μ s +10 μ s/-10 μ s	50 μ s +10 μ s/-25 μ s
16 A < current rating ≤ 32 A	50 μ s +10 μ s/-15 μ s	50 μ s +10 μ s/-30 μ s
32 A < current rating ≤ 63 A	50 μ s +10 μ s/-20 μ s	50 μ s +10 μ s/-35 μ s
63 A < current rating ≤ 125 A	50 μ s +10 μ s/-25 μ s	50 μ s +10 μ s/-40 μ s
125 A < current rating ≤ 200 A	50 μ s +10 μ s/-30 μ s	50 μ s +10 μ s/-45 μ s
NOTE The current rating in Table 4 is the CDN rating.		
^a The measurement of the surge voltage parameters shall be performed with the a.c./d.c. power port of the CDN open-circuit. ^b The values shown in this table are for a CWG with ideal values. In case the CWG generates parameter values close to the tolerances, the additional tolerances of the CDN may generate values out of tolerances for the CWG-CDN combination.		

**Table 5 – Current waveform specification at the EUT port
of the CDN**

Surge current parameters under short-circuit conditions ^a	Coupling impedance	
	18 μ F (line-to-line)	9 μ F + 10 Ω (line-to-ground) ^b
Front time	$T_f = 1,25 \times T_r = 8 \mu\text{s} \pm 20 \%$	$T_f = 1,25 \times T_r = 2,5 \mu\text{s} \pm 30 \%$
Duration	$T_d = 1,18 \times T_w = 20 \mu\text{s} \pm 20 \%$	$T_d = 1,04 \times T_w = 25 \mu\text{s} \pm 30 \%$
^a The measurement of the surge current parameters shall be performed with the a.c./d.c. power port of the CDN open-circuit. ^b The value 1,04 is derived from empirical data.		

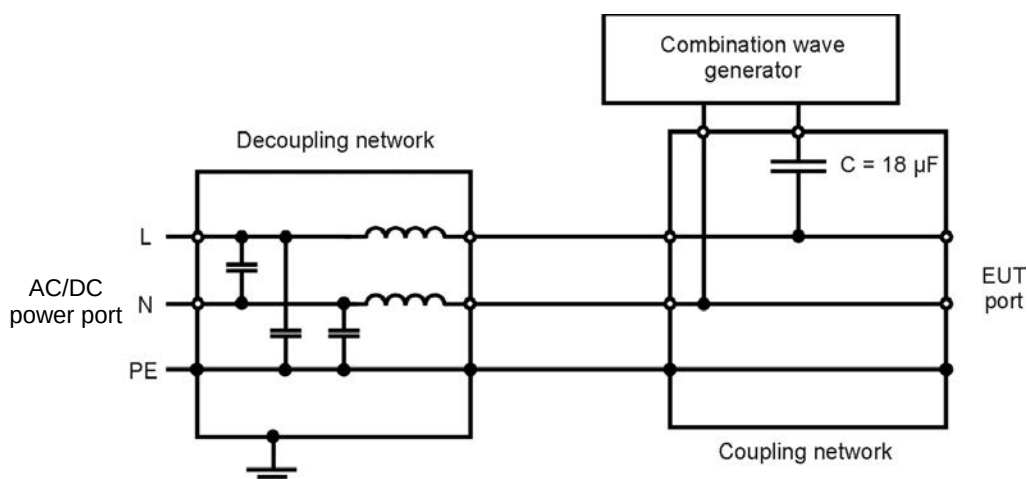
Table 6 – Relationship between peak open-circuit voltage and peak short-circuit current at the EUT port of the CDN

Open-circuit peak voltage $\pm 10\%$ at EUT port of the CDN	Short-circuit peak current $\pm 10\%$ at EUT port of the CDN (18 μF)	Short-circuit peak current $\pm 10\%$ at EUT port of the CDN (9 μF + 10 Ω)
0,5 kV	0,25 kA	41,7 A
1,0 kV	0,5 kA	83,3 A
2,0 kV	1,0 kA	166,7 A
4,0 kV	2,0 kA	333,3 A

Refer to Annex H for EUTs having a rated input current above 200 A per line.

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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 5 – Example of coupling network and decoupling network for capacitive coupling on a.c./d.c. lines line-to-line coupling

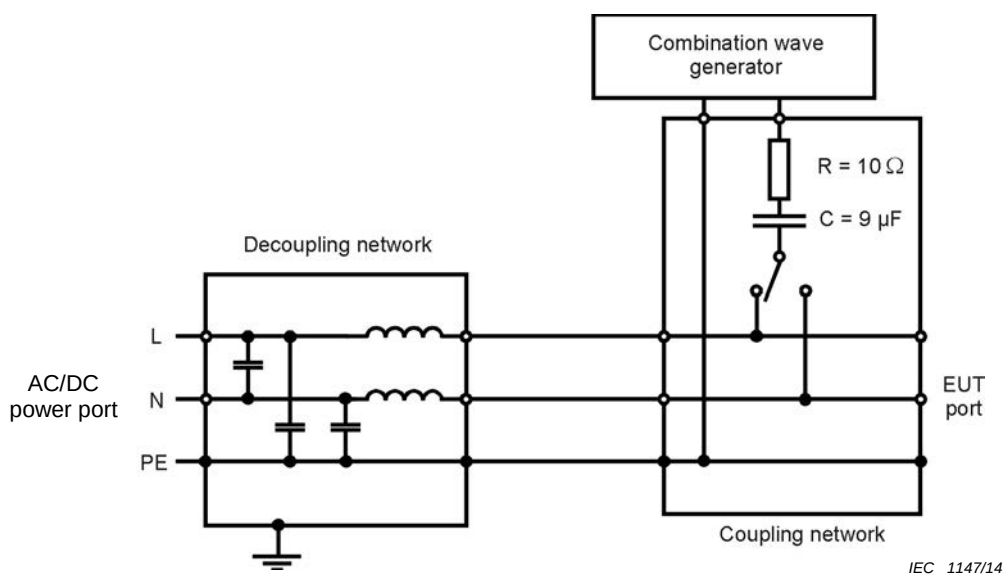
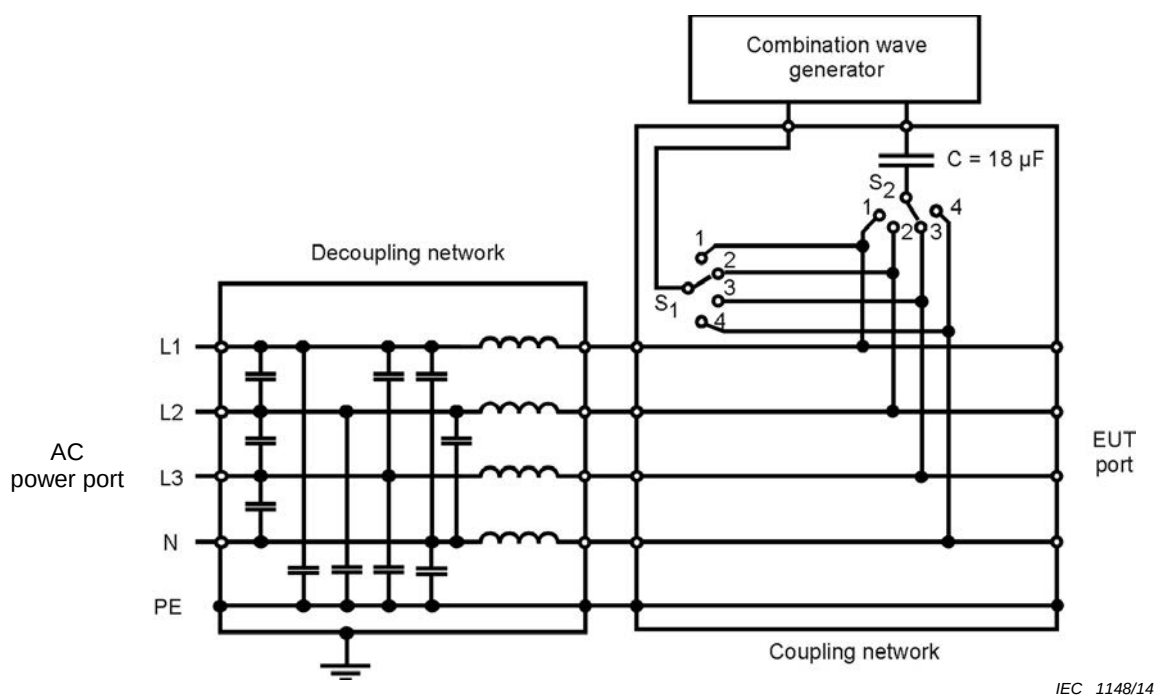


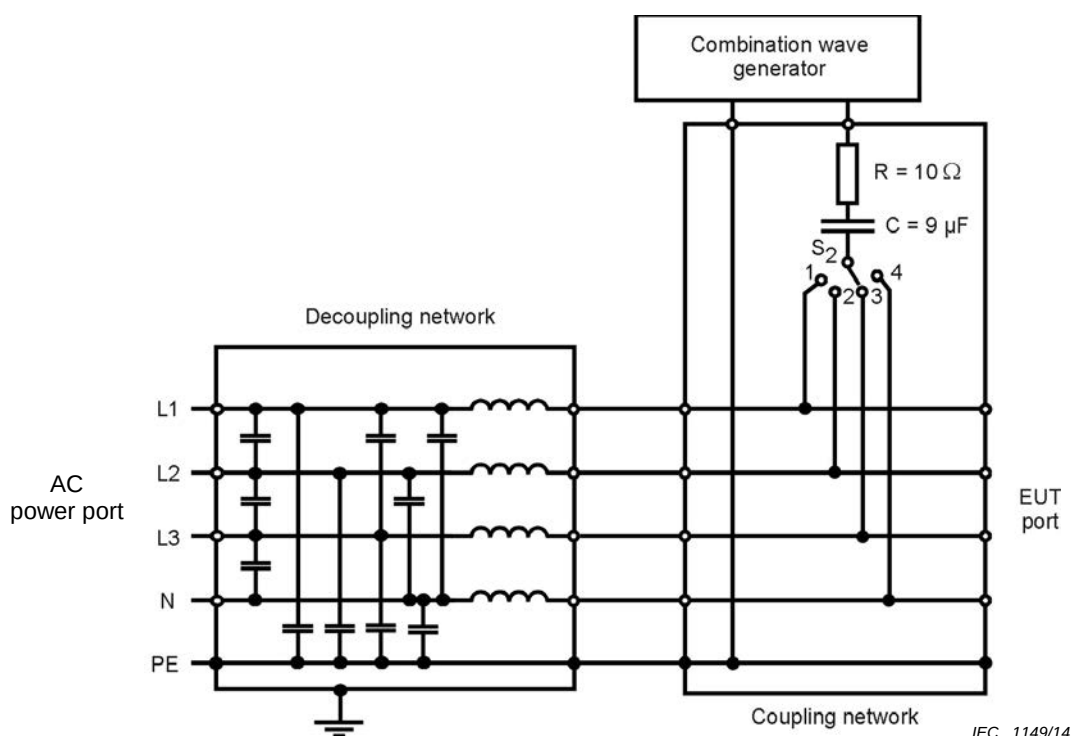
Figure 6 – Example of coupling network and decoupling network for capacitive coupling on a.c./d.c. lines: line-to-ground coupling



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 7 – Example of coupling network and decoupling network for capacitive coupling on a.c. lines (3 phases): line L2-to-line L3 coupling



Switch S_2 is used to select individual lines for test.

Figure 8 – Example of coupling network and decoupling network for capacitive coupling on a.c. lines (3 phases): line L3-to-ground coupling

6.3.3 Coupling/decoupling networks for interconnection lines

6.3.3.1 General

Subclause 6.3.3 describes the CDN for all types of interconnection lines except for unshielded outdoor symmetrical communication lines intended to interconnect to widely dispersed systems, which are described in Annex A.

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

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

Any CD, such as capacitors or gas discharge tubes (GDT) 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 comply with the calibration requirements in 6.4.

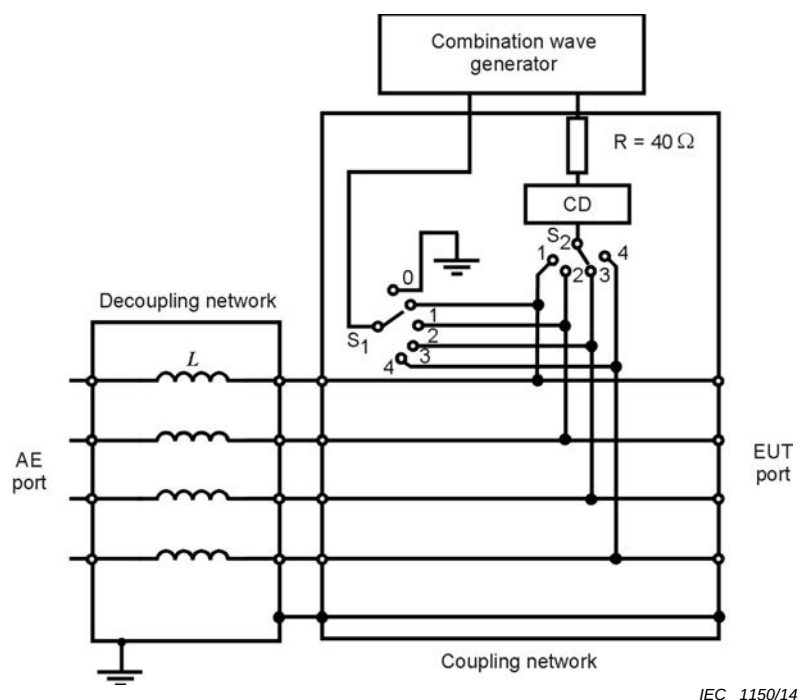
Current compensated inductors shall be used in the decoupling network if the signal lines are symmetrical.

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.

6.3.3.2 Coupling/decoupling surges 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 9.



- 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 CD: see Table 8.

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

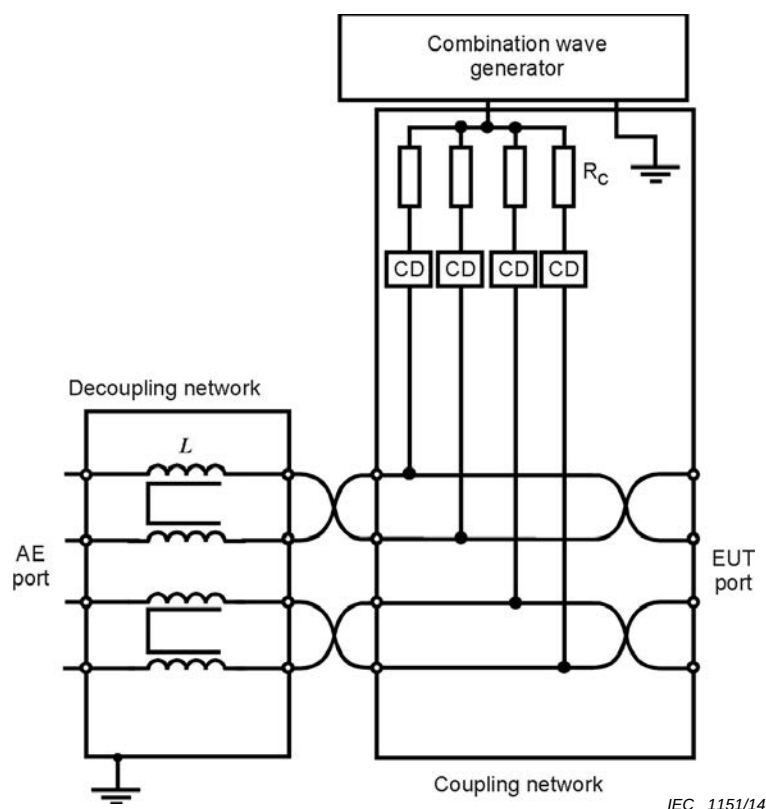
6.3.3.3 Coupling/decoupling networks for surges to unshielded, symmetrical interconnection lines

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 surge generator to the EUT is considered to be a constant which is independent from the number of lines in the cable, equivalent to a coupling impedance of about $40\ \Omega$. This equivalent coupling impedance is split between the lines in the cable. For this reason the coupling resistor value used on each line in a pair is a multiple of $40\ \Omega$. This rule applies for cables with up to 8 lines/4 pairs. The CDN shall be selected to match the number of lines/pairs existing in the cable; but for cables with more than 8 lines/4 pairs the pairs shall be split and linked through several 8-line/4-pair CDNs, using coupling resistor values as for testing 8-line/4-pair cables.

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 10.



Calculation of coupling resistor values R_C :

Example for $n = 4$:

$$R_C = 4 \times 40\ \Omega = 160\ \Omega$$

The coupling resistors values are selected so that their resistance in parallel is equivalent to $40\ \Omega$. A test on a four-line port for example, requires four resistors each of $160\ \Omega$.

L with current compensation may include all 4 coils or only pairs (as shown in Figure 10) to be effective.

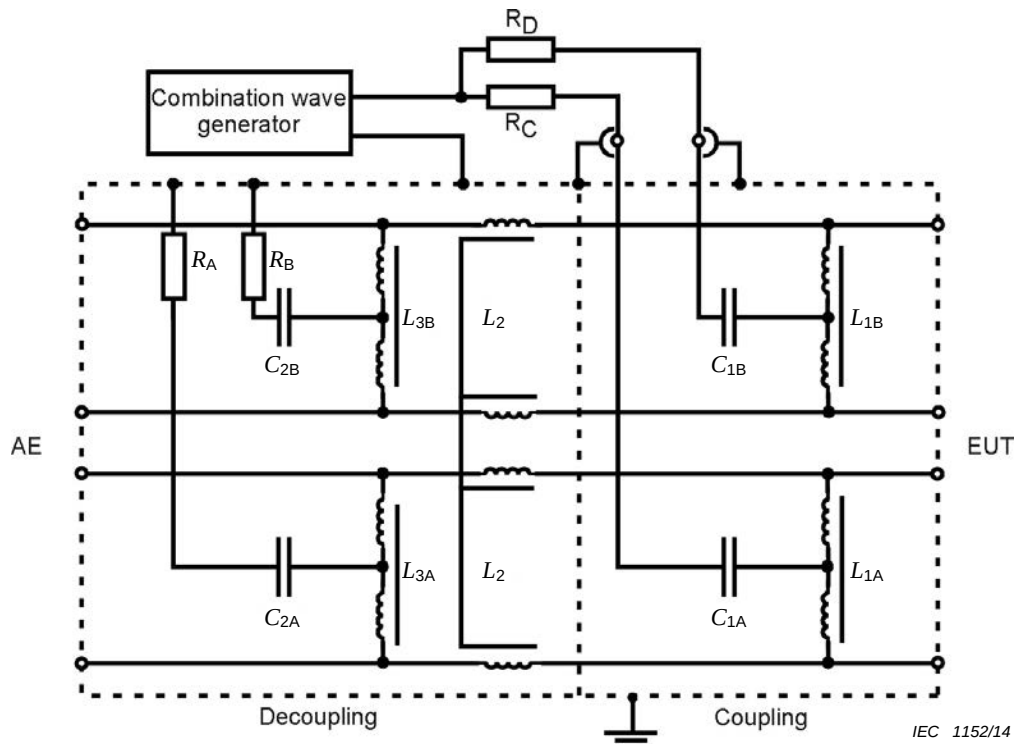
NOTE CD: see Table 10.

Figure 10 – 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 10 and Figure 11 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 11 shows an example of a coupling and decoupling network for symmetrical interconnection lines allowing tests with interconnection speed up to 1 000 Mbit/s.



Calculation of coupling resistors and capacitors values:

R_C and R_D : The coupling resistors values are selected so that their resistance in parallel is equivalent to 40 Ω . So, a test on a two-pair port for example, requires two resistors each of 80 Ω , and a test on a four-pair port, requires four resistors each of 160 Ω .

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.

Figure 11 – 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 surge immunity test is required.

6.4 Calibration of coupling/decoupling networks

6.4.1 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 6.2.3).

6.4.2 Calibration of CDNs for a.c./d.c. power port rated up to 200 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 surge voltage measured between surged lines and ground on the a.c./d.c. 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 surge voltage measured between non-surged 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 6.3.2 Tables 4, 5 and 6 shall be met at the output of the CDN with the a.c./d.c. power port open-circuit.

6.4.3 Calibration of CDNs for interconnection lines

6.4.3.1 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 surge voltage measured between the surged 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.

6.4.3.2 Calibration of CDNs for unsymmetrical interconnection lines

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

The peak amplitude, the front time and impulse duration shall be measured for the CDN rated impulse voltage and current at the EUT output port according to Table 7.

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 output port.

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

**Table 7 – Summary of calibration process for CDNs
for unsymmetrical interconnection lines**

	Coupling	Measuring	AE side	EUT side
Surge voltage at EUT side	Single line to PE	Single line Peak voltage, front time, duration	All lines shorted to PE	Open-circuit
Surge current at EUT side	Single line to PE	Single line Peak current, front time, duration	All lines shorted to PE	Short-circuit
Surge voltage at EUT side	Single line-to-line	Single line Peak voltage, front time, duration	All lines shorted to PE	Open-circuit
Surge current at EUT side	Single line-to-line	Single line Peak current, front time, duration	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 8.

**Table 8 – Surge waveform specifications at the EUT port of the CDN
for unsymmetrical interconnection lines**

Coupling method	CWG output voltage ^{a,b,c}	V_{oc} at CDN EUT output $\pm 10 \%$	Voltage front time T_f $T_f = 1,67 \times T_r$ $\pm 30 \%$	Voltage duration T_d $T_d = T_w$ $\pm 30 \%$	I_{sc} at CDN EUT output $\pm 20 \%$	Current front time T_f $T_f = 1,25 \times T_r$ $\pm 30 \%$	Current duration T_d $T_d = 1,18 \times T_w$ $\pm 30 \%$
Line to PE $R = 40 \Omega$ $CD = 0,5 \mu F$	4 kV	4 kV	1,2 μs	38 μs	87 A	1,3 μs	13 μs
Line to PE $R = 40 \Omega$ $CD = GDT$	4 kV	4 kV	1,2 μs	42 μs	95 A	1,5 μs	48 μs
Line-to-line $R = 40 \Omega$ $CD = 0,5 \mu F$	4 kV	4 kV	1,2 μs	42 μs	87 A	1,3 μs	13 μs
Line-to-line $R = 40 \Omega$ $CD = GDT$	4 kV	4 kV	1,2 μs	47 μs	95 A	1,5 μs	48 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. 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 CWG with ideal values. In case the CWG generates parameter values close to the tolerances, the additional tolerances of the CDN may generate values out of tolerances for the CWG-CDN combination.

6.4.3.3 Calibration of CDNs for symmetrical interconnection lines

Calibration measurements shall be performed as indicated in Table 9 at the CDN rated impulse voltage. The peak amplitude, the front time and duration shall be measured at the EUT output port according to Table 9.

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 output port.

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

It is recommended that the open-circuit voltage between wires of different pairs is also 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 9 – Summary of calibration process for CDNs
for symmetrical interconnection lines**

	Coupling	Measuring	AE side	EUT side
Surge voltage at EUT side	Common mode – all lines to PE 40 Ω path ^a	All lines shorted together Peak voltage, front time, duration	All lines shorted to PE	Open-circuit – all lines connect together
Surge current at EUT side	Common mode – all lines to PE 40 Ω path ^a	All lines shorted together Peak current, front time, duration	All lines shorted to PE	All lines shorted to PE
Residual voltage on AE side (with protection elements)	Common mode – all lines to PE 40 Ω path ^a	Each line to PE in turn Peak voltage	Open-circuit	Open-circuit
^a A 40 Ω path means that the transfer impedance is always 40 Ω . This means that for coupling to 1 pair 80 Ω per line or 40 Ω per pair are used, for coupling to 2 pairs 160 Ω per line or 80 Ω per pair are used, for coupling to 4 pairs 320 Ω per line or 160 Ω per pair are used.				

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 10.

**Table 10 – Surge waveform specifications at the EUT port
of the CDN for symmetrical interconnection lines**

Coupling method	CWG output voltage a b c	V_{oc} at CDN EUT output $\pm 10 \%$	Voltage front time T_f $T_f = 1,67 \times T_r$ $\pm 30 \%$	Voltage duration T_d $T_d = T_w$ $\pm 30 \%$	I_{sc} at CDN EUT output $\pm 20 \%$	Current front time T_f $T_f = 1,25 \times T_r$ $\pm 30 \%$	Current duration T_d $T_d = 1,18 \times T_w$ $\pm 30 \%$
Common mode CD ^d , 40 Ω path	2 kV	2 kV	1,2 μ s	45 μ s	48 A	1,5 μ s	45 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. 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 CWG with ideal values. In case the CWG generates parameter values close to the tolerances, the additional tolerances of the CDN may generate values out of tolerances for the CWG-CDN combination. ^d The coupling device (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 (EUT);
- auxiliary equipment (AE) when required;
- cables (of specified type and length);
- coupling/decoupling networks (CDNs);
- combination wave generator (CWG);
- reference ground plane for tests to shielded lines as described in 7.6.2 below and Figure 12.

NOTE If convenient, the test setup using a reference ground plane as defined in IEC 61000-4-4 can be used.

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 combination 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:

- surge impulse present at the output terminal of the CDN.

It is sufficient to verify that the surge 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 surges applied to EUT power ports

The 1,2/50 μ s surge shall be applied to the EUT power supply terminals via the capacitive coupling network (see Figures 5, 6, 7 and 8). 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.

The selection of the CDN specification from Table 4 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 complying with the specifications of a 16 A rated CDN). Any higher current rated CDN can be used if it meets the specification requirements in Table 4 for the relevant lower current rating of the EUT (for example: a CDN rated 64 A can be used for testing an EUT rated at 5 A, if it meets the specification requirements of a 16 A rated CDN).

In case, where an EUT having DC/DC input converters cannot power up through the appropriate current-rated CDN, it is permitted to use a higher current-rated CDN with ratings up to and including 125 A, which fulfills the specifications according to its current rating given in Table 4. In such case, the use of this higher rated CDN shall be described in the test report. Annex I includes further information regarding this special case.

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 standard, power ports have been considered to be those ports directly connected to either an a.c. mains supply or a d.c. mains supply (distribution network).

NOTE Product committees can decide that power ports not connected to distribution networks require testing according to this standard using a CDN defined in 6.3.2 or 6.3.3.

DC mains supply surge 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 surges are applied for double-insulated products (i.e. products without any dedicated earth terminal).

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

7.4 Test setup for surges 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 9.

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 surges are applied for double-insulated products (i.e. products without any dedicated earth terminal).

7.5 Test setup for surges applied to unshielded symmetrical interconnection lines

Examples of coupling networks for symmetrical interconnection lines are given in Figure 10 and Figure 11.

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

7.6 Test setup for surges applied to shielded lines

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 one or more shielded cables (see Figure 12).

NOTE 1 The reference ground plane mentioned in Figure 12 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.

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 12) 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 surge to shielded lines:

a) Shields grounded at both ends:

- the test shall be carried out according to Figure 12.

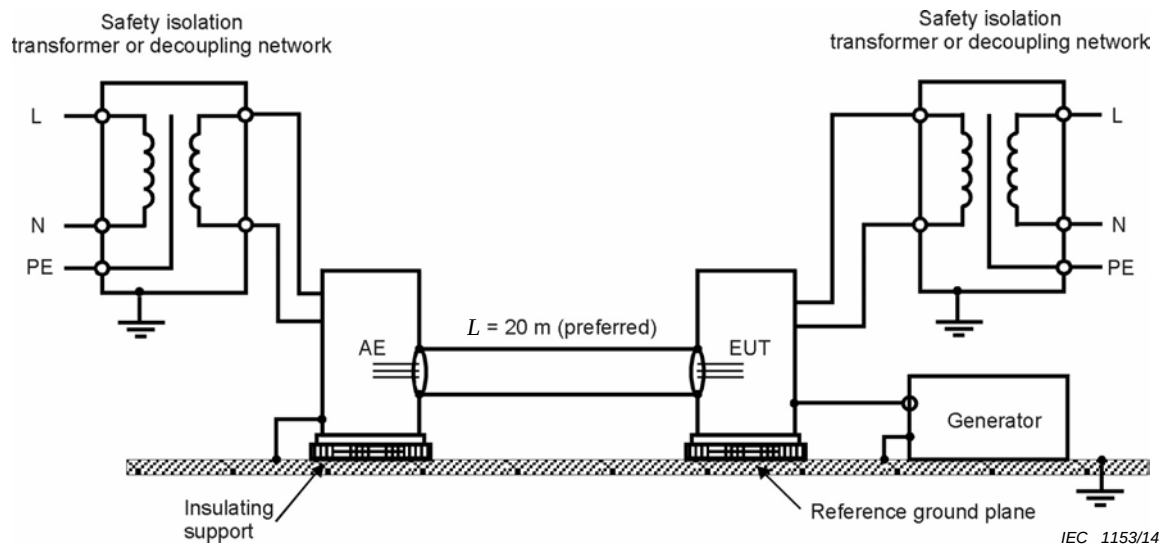
The test level is applied on shields with a $2\ \Omega$ generator source impedance and with the $18\ \mu\text{F}$ capacitor (see 6.2.3).

b) Shields grounded at one end:

- the test shall be carried out according to 7.4 or 7.5 (see Figure 4) because the shield does not provide any protection against surges induced by magnetic fields.

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

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



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 surge, 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 12 – Example of test setup for surges applied to shielded lines

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 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.

8.2.2 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 surge impulses unless otherwise specified by the relevant standard:
 - i) for d.c. power ports and interconnection lines five positive and five negative surge impulses;
 - ii) for a.c. 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.

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

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).

When testing 3-phase systems, the synchronization of phase angles shall be taken from the same line under test, e.g. when applying surge 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, e.g. between N and PE in TN-S power distribution systems. In this case, five positive impulses and five negative impulses shall be applied.

Surges to low voltage d.c. input/output ports (≤ 60 V) are not applied when 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.)

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 cause 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 surges 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 surges depends on the built-in protection devices of the EUT.

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

Equipment shall not become dangerous or unsafe as a result of the application of the tests.

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;
- drawing and/or pictures of the test setup and EUT arrangement;
- 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;
- all types of cables which were tested, including their length, and the interface port of the EUT to which they were connected;
- 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 (normative)

Surge testing for unshielded outdoor symmetrical communication lines intended to interconnect to widely dispersed systems

A.1 General

When testing symmetrical communication lines that are intended to be directly connected to outdoor telecommunication networks (e.g. public switched telecommunications networks (PSTN)) the 1,2/50 μ s – 8/20 μ s waveform may not be appropriate. Outdoor telecommunications networks typically have cable lengths in excess of 300 m and may be many kilometres in length. As a result of the nature of these networks the 10/700 μ s – 5/320 μ s waveform is more representative of actual surges encountered in the field. Annex A defines the testing methods and generator characteristics for testing using the 10/700 μ s – 5/320 μ s generator.

Long distance outdoor networks typically use some form of primary protection where the cables enter buildings or enclosures. To ensure correct operation of the port under test the performance of this primary protection needs to be considered. Testing should be performed with the intended primary protection so that co-ordination between the primary and any secondary protection inside the EUT can be verified. Where the exact characteristics of the primary protection cannot be controlled, product committees may define different test levels to be evaluated with and without primary protection fitted. Further detail on this phenomenon can be found in ITU-T K.44.

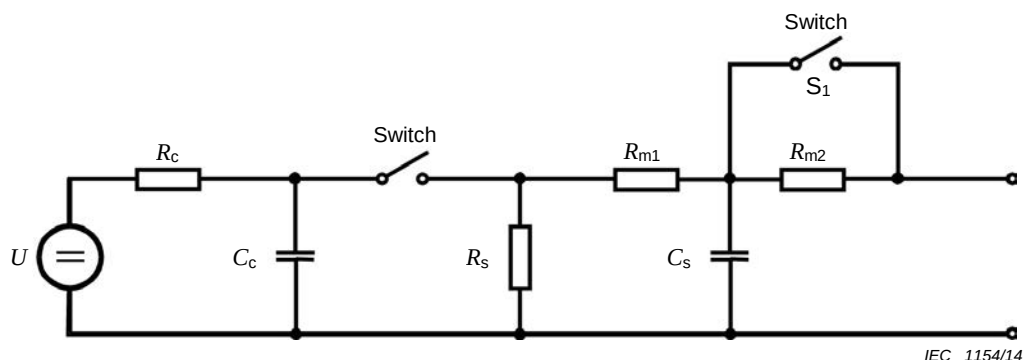
A.2 10/700 μ s combination wave generator

A.2.1 Characteristics of the generator

This generator is intended to generate a surge with the following characteristics:

- an open-circuit voltage front time of 10 μ s;
- an open-circuit voltage duration of 700 μ s;
- a short-circuit current front time of 5 μ s;
- a short-circuit current duration of 320 μ s.

The simplified circuit diagram of the generator is given in Figure A.1. The values for the different components are selected so that the generator delivers the above surge.



Key

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	Front time shaping capacitor
S_1	Switch closed when using external matching resistors

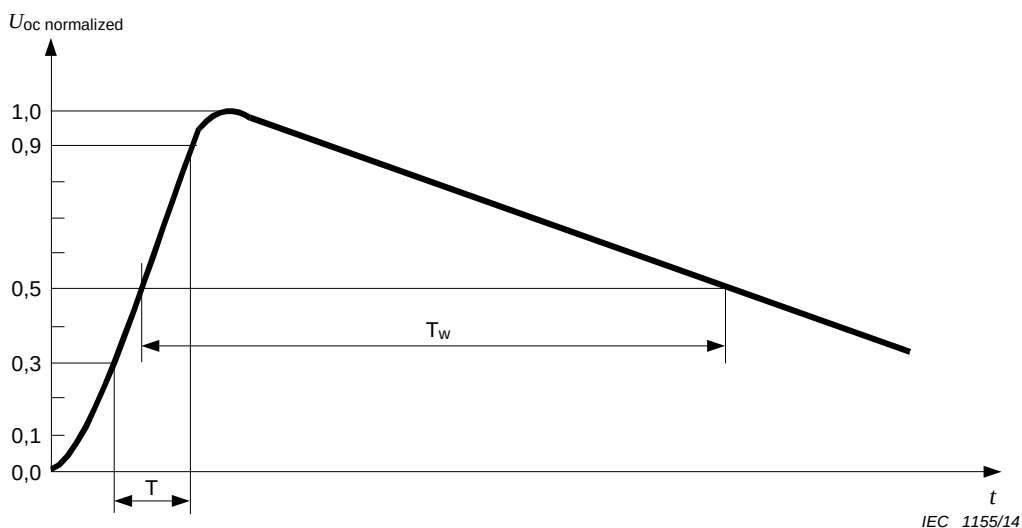
**Figure A.1 – Simplified circuit diagram of the combination wave generator
(10/700 μ s – 5/320 μ s)**

The ratio of peak open-circuit output voltage to peak short-circuit current of the combination wave generator shall be considered as the effective output impedance. For this generator, the ratio defines an effective output impedance of 40 Ω .

A.2.2 Performances of the generator

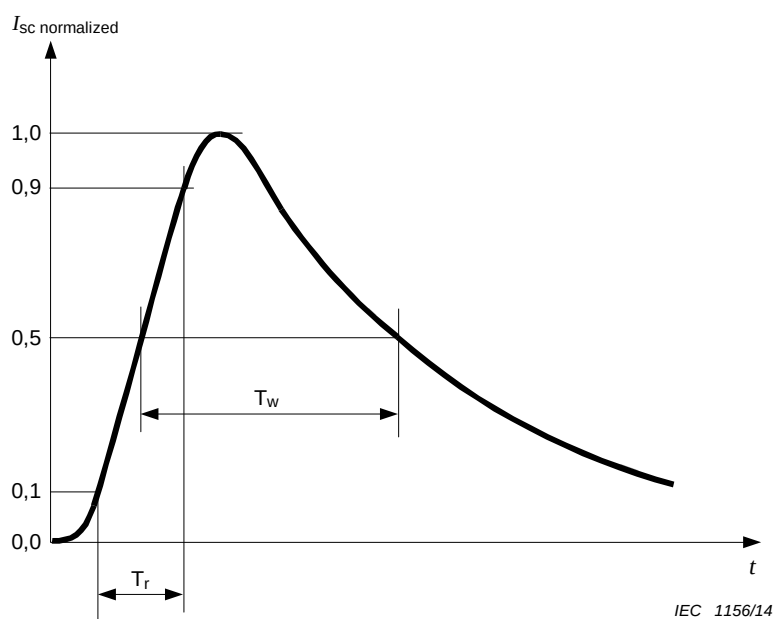
Polarity	positive and negative
Repetition rate	1 per minute or faster
Open-circuit peak output voltage	adjustable from 0,5 kV to the required test level
Waveform of the surge voltage	see Table A.1 and Figure A.2
Output voltage tolerance	see Table A.2
Short-circuit peak output current	depends on peak voltage setting (see Tables A.1 and A.2)
Short-circuit output current tolerance	see Table A.2

NOTE The effective output impedance typically consists of internal 15 Ω (R_{m1}) and 25 Ω (R_{m2}) resistors. The R_{m2} resistors can be bypassed, paralleled or shorted and replaced with external coupling resistors when used for multiple couplings, see Figure A.1.



Front time: $T_f = 1,67 \times T = 10 \mu\text{s} \pm 30 \%$
Duration: $T_d = T_w = 700 \mu\text{s} \pm 20 \%$

Figure A.2 – Waveform of open-circuit voltage (10/700 μs)



Front time: $T_f = 1,25 \times T_r = 5 \mu\text{s} \pm 20 \%$
Duration: $T_d = T_w = 320 \mu\text{s} \pm 20 \%$

Figure A.3 – Waveform of the 5/320 μs short-circuit current waveform

Table A.1 – Definitions of the waveform parameters 10/700 μs and 5/320 μs

	Front time μs	Duration μs
Open-circuit voltage	10 ± 30 %	700 ± 20 %
Short-circuit current	5 ± 20 %	320 ± 20 %

Table A.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 generator output
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 S_1 of Figure A.1 open.

The peak open-circuit voltage and the peak short-circuit current shall be measured with the same generator settings.

A.2.3 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 essential characteristics of the generator.

The generator output shall be connected to a measuring system with a sufficient bandwidth, voltage and current capability to monitor the characteristics of the waveforms. Annex E provides information concerning the bandwidth of the surge waveforms.

If a current transformer (probe) is used to measure short-circuit current it should be selected so that saturation of the magnetic core does not take place. The lower (-3 dB) corner frequency of the probe should be less than 10 Hz.

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 set voltage.

All performance characteristics stated in A.2.2 shall be met at the output of the generator.

A.3 Coupling/decoupling networks

A.3.1 General

Due to the nature of the wiring used for unshielded outdoor symmetrical communication lines (twisted pairs), the coupling is always in common mode. The coupling decoupling schematic is shown in Figure A.4.

Coupling via arrestors is the preferred coupling method for unshielded outdoor symmetrical communication lines as shown in Figure A.4. The coupling network also has the task of splitting the surge current into multiple pairs in multi-conductor cables. The internal matching resistor R_{m2} (25 Ω) is replaced by external $R_c = 25 \Omega$.

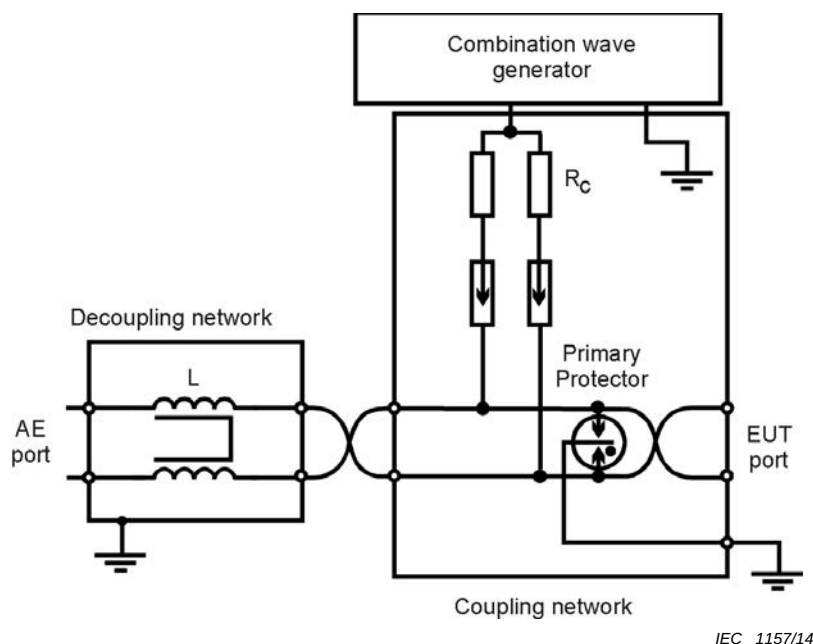
Recommended characteristics of the coupling/decoupling network:

Coupling impedance $R_c = 25 \Omega$ per line plus the impedance of the arrestor;

Decoupling inductors $L = 20$ mH.

The suggested coupling and decoupling network design and component values may not be suitable for high speed networks (e.g. DSL) as the wanted data transmission may be degraded.

A.3.2 Coupling/decoupling networks for outdoor communication lines



The internal matching resistor R_{m2} ($25\ \Omega$) is replaced by external $R_c = 25\ \Omega$.

NOTE 1 The gas arrestors shown can be replaced by a clamping circuit such as that shown in Figure 9.

NOTE 2 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.

Figure A.4 – Example of test setup for unshielded outdoor symmetrical communication lines: lines-to-ground coupling, coupling via gas arrestors (primary protection fitted)

A.4 Calibration of coupling/decoupling networks

Measurements shall be performed with the impulse applied to one coupling pair at a time.

The peak amplitude, the front time and impulse duration shall be measured for the CDN at the impulse voltage under open-circuit conditions and the current under short-circuit conditions. Values are given in Table A.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 output port.

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

The calibration process is listed in Table A.3.

Table A.3 – Summary of calibration process for CDNs for unshielded outdoor symmetrical communication lines

	Coupling	Measuring	AE side	EUT side
Surge voltage at EUT side	Common mode – one pair to PE	Both lines from one pair shorted together: peak voltage, front time, duration	All used lines shorted to PE	Open-circuit, both lines from one pair connected together
Surge current at EUT side	Common mode – one pair to PE	Both lines from one pair shorted together: peak current, front time, duration	All used lines shorted to PE	Both lines from one pair shorted to PE
Residual voltage on AE side (with protection elements)	Common mode – one pair to PE	Both lines from one pair shorted together: 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 A.4.

Table A.4 – Surge waveform specifications at the EUT port of the CDN for unshielded outdoor symmetrical communication lines

Coupling method	CWG output voltage _{a,b,c}	V_{oc} at CDN EUT output ± 10 %	Voltage front time T_f ± 30 %	Voltage duration T_d ± 30 %	I_{sc} at CDN EUT output ± 20 %	Current front time T_f ± 30 %	Current duration T_d ± 30 %
Common mode CD 1 pair 27,5 Ω	4 kV	4 kV	8 μs	250 μs	145 A	3,2 μs	250 μs
^a For CDN with more than one pair, each pair has to be calibrated separately, as described in Table A.3. ^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 minimize 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 CWG with ideal values. In case the CWG generates parameter values close to the tolerances, the additional tolerances of the CDN may generate values out of tolerances for the CWG-CDN combination.							

A.5 Test setup for surges applied to outdoor unshielded symmetrical communication lines

For symmetrical interconnection/communication circuits (see Figure A.4), 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 (the ignition point is about 300 V for a gas arrestor with a rated voltage of 90 V) cannot be specified.

Two test configurations are to be considered:

- To evaluate equipment level immunity a test shall be performed with only secondary protection at the EUT at a low test level, for example 0,5 kV or 1 kV.
- To evaluate system level immunity a test shall be performed 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.

The coupling is always in common mode, all conductors simultaneously with respect to reference ground (see Figure A.4).

NOTE Untested conductors are connected to earth via a coupling device that does not impact the wanted data traffic of the port under test (e.g. GDT).