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6KV Touch Screen Surge

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Surge Generator
Product No: SG61000-5

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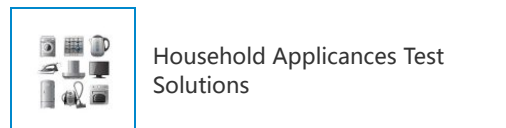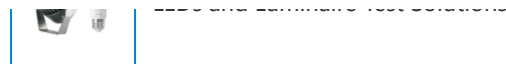| Name* | | Company* |
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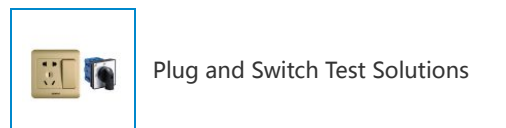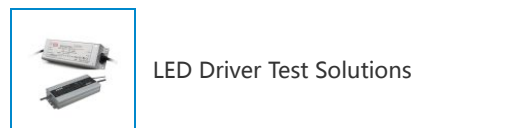
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Description   Video   Download

The SG61000-5 fully automatic **surge generator** (also called lightning surge immunity test, combination wave generator, surge current generator/surge voltage generator, combined surge voltage and current generator) .

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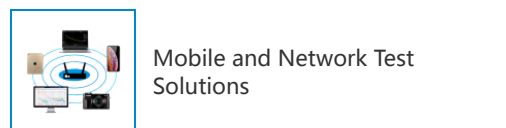
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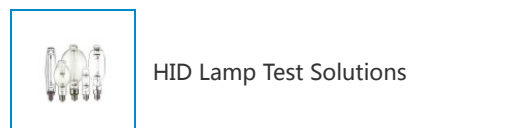Household Applicances Test Solutions

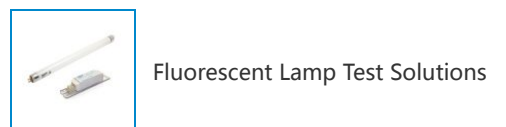Plug and Switch Test Solutions
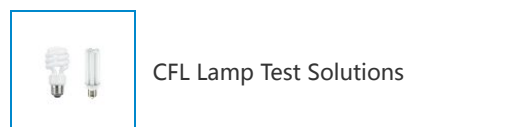
LED Driver Test Solutions

Mobile and Network Test Solutions

HID Lamp Test Solutions

Fluorescent Lamp Test Solutions

CFL Lamp Test Solutions

Product Model	SG61000-5SA	SG61000-5SB	SG61000-5	SG61000-5H-SP	SG61000-5T
Output Voltage (Open)	1.2/50µs±20%	1.2/50µs±20%	1.2/50µs±20%	1.2/50µs±20%	1.2/50µs±20%
Output Current (Short)	8/20µs±20%	8/20µs±20%	8/20µs±20%	8/20µs±20%	8/20µs±20%
Output Impedance	2Ω and 12Ω	2Ω and 12Ω	2Ω and 12Ω	2Ω 12Ω and 500Ω	2Ω and 12Ω
Output Voltage Range	0~4.8KV±10%	0~4.8KV±10%	0~6KV±10%	0~10KV±10%	0~6KV±10%
Output Current Range	0~2.4KA±10%	0~2.4KA±10%	0~3KA±10%	0~5KA±10%	0~3KA±10%
Surge Repetition	1~9999 times	1~9999 times	1~9999 times	1~9999 times	1~9999 times
Interval Time	20~9999s	20~9999s	20~9999s	30~9999s	20~9999s
Polarity	Positive, Negative or Positive/Negative automatic				
Phase Shift	Asynchronous, Synchronization 0°~ 360° or Specific Angle				
Special Function	N/A		Built-in High voltage and current 2000:1 attenuator probe (Less than 10KV surge generator is 1000:1), connect with LISUN OSP1102 directly		
Operation Way	Button Input		Touch screen with super big LCD and built-in Windows CE		
Dimensions (WxDxH)	44x45x35cm	44x45x35cm	44x45x35cm	56x69x155cm	44x45x55cm
Gross Weight	About 30kg	About 30kg	About 30kg	About 270kg	About 48kg
Coupling/Decoupling Network (CDN)	Includes a 16A single phase CDN			Includes a 20A 3phases CDN	
Isolution Transformer for EUT (Optional)	LISUN ITEU-SP4K (220V Single phase) or ITUS-SP2K (110V)			LISUN ITEU-TP10K or ITUS-	

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IEC International Electrotechnical Commission

ISO International Organization for Standardization

BIS Bureau of Indian Standards

ANSI American National Standards Institute

SASO Saudi Arabian Standards Organization

TSE Turkish Standards Institution

NOM Norma Oficial Mexicana

GB China Guo Biao

Protect Device for Surge Test PD-E01

We suggest you choose LISUN SG-DESK Surge Generator desk to work with SG61000-5 Surge Generator and Isolation Transformer.

Tags : SG61000-5 , SG61000-5H , Surge Generator

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What is a combination wave?

A **Combination Wave** Generator (CWG) sends a voltage impulse into an open circuit while also delivering a current impulse into a short circuit to mimic both of these situations. The SG61000-5 Surge Generator's **combination wave** is 1.2/50us and 8/20us as below:
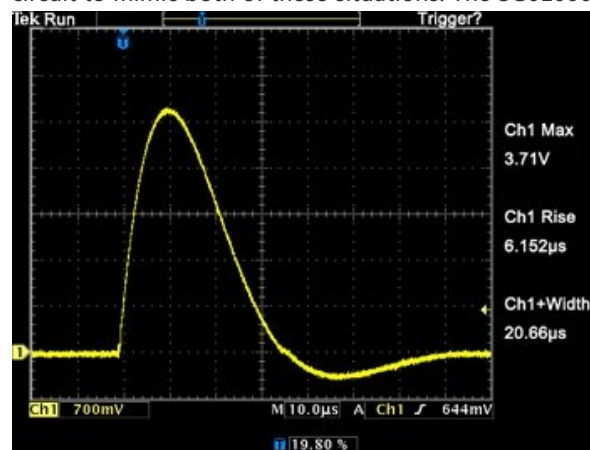
6KV Short Circuit Current Output Waveform (780:1)
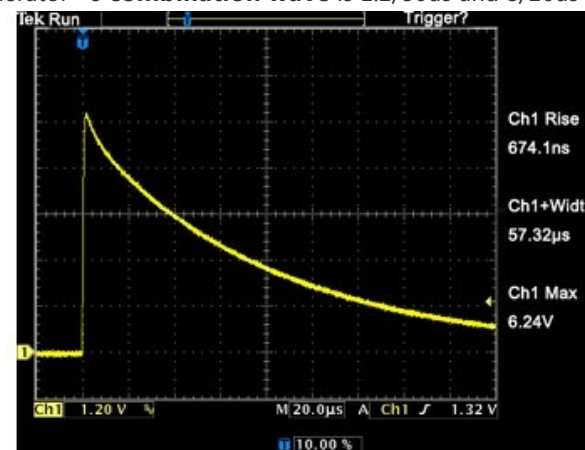
6KV Open Circuit Voltage Output Waveform (1000:1)

77B/711/FDIS

FINAL DRAFT INTERNATIONAL STANDARD
PROJET FINAL DE NORME INTERNATIONALE

Project number Numéro de projet	**IEC 61000-4-5 Ed.3.0**

IEC/TC or SC CEI/CE ou SC **77B**	Secretariat / Secrétariat **France**

☒ Submitted for parallel voting in CENELEC Soumis au vote parallèle au CENELEC	Distributed on / Diffusé le **2014-01-17**	Voting terminates on / Vote clos le **2014-03-21**

Also of interest to the following committees Intéresse également les comités suivants TC 61	Supersedes document Remplace le document 77B/685/CDV & 77B/705/RVC

Horizontal standard
Norme horizontale

☐ Other TC/SCs are requested to indicate their interest, if any, in this FDIS to the TC/SC secretary
Les autres CE/SC sont requis d'indiquer leur intérêt, si nécessaire, dans ce FDIS à l'intention du secrétaire du CE/SC

Functions concerned
Fonctions concernées

☐ Safety Sécurité	☒ EMC CEM	☐ Environment Environnement	☐ Quality assurance Assurance de la qualité

Titre
IEC 61000-4-5: Compatibilté électromagnétique: Partie 4-5: Techniques d'essai et de mesure – Essai d'immunité aux ondes de choc

Title
IEC 61000-4-5: Electromagnetic compatibility (EMC): Part 4-5: Testing and measurement techniques – Surge immunity test

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE
_____

ELECTROMAGNETIC COMPATIBILITY (EMC) –

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

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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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.

This third edition cancels and replaces the second edition published in 2005, and 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:–) the normative Annex A is fully dedicated to this topic. In particular it gives the specifications of the 10/700 µs combined wave generator.

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

FDIS	Report on voting
77B/xxx/FDIS	77B/xxx/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.

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

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

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

The National Committees are requested to note that for this publication the stability date is 2019.

THIS TEXT IS INCLUDED FOR THE INFORMATION OF THE NATIONAL COMMITTEES AND WILL BE DELETED AT THE PUBLICATION STAGE.

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

INTRODUCTION

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

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (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.

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 μs> 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 μs> 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 μs combination wave generator is used to test ports intended for connection to outdoor symmetrical communication lines (see Annex A). The 1,2/50 μs combination wave generator is used in all other cases.

6.2   1,2/50 μs 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 μs;
- an open-circuit voltage duration of 50 μs;
- a short-circuit current front time of 8 μs;
- a short-circuit current duration 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 an 8/20 μs current surge into a short-circuit.

Key
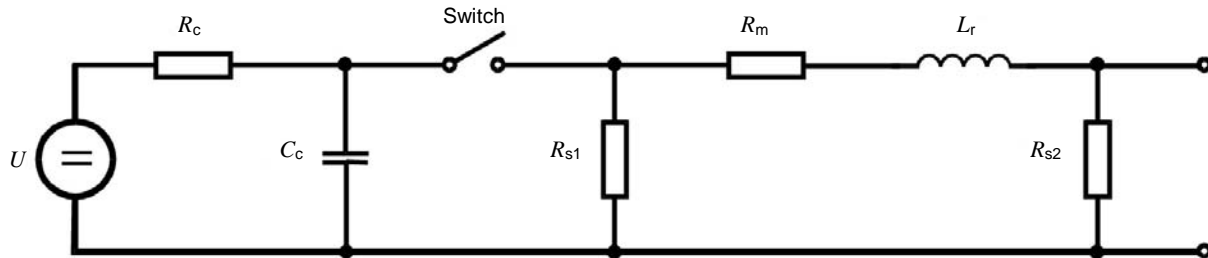
U High-voltage source

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 μs voltage and the 8/20 μs 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 ± 10°
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.
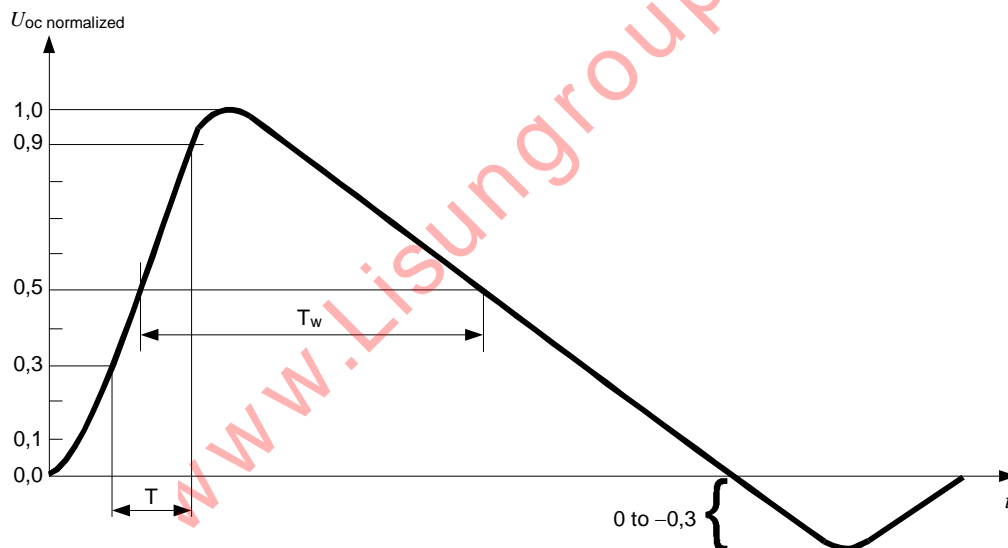
Front time: $T_f = 1{,}67 \times T = 1{,}2~\mu s \pm 30~\%$
Duration: $T_d = T_w = 50~\mu s \pm 20~\%$

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.
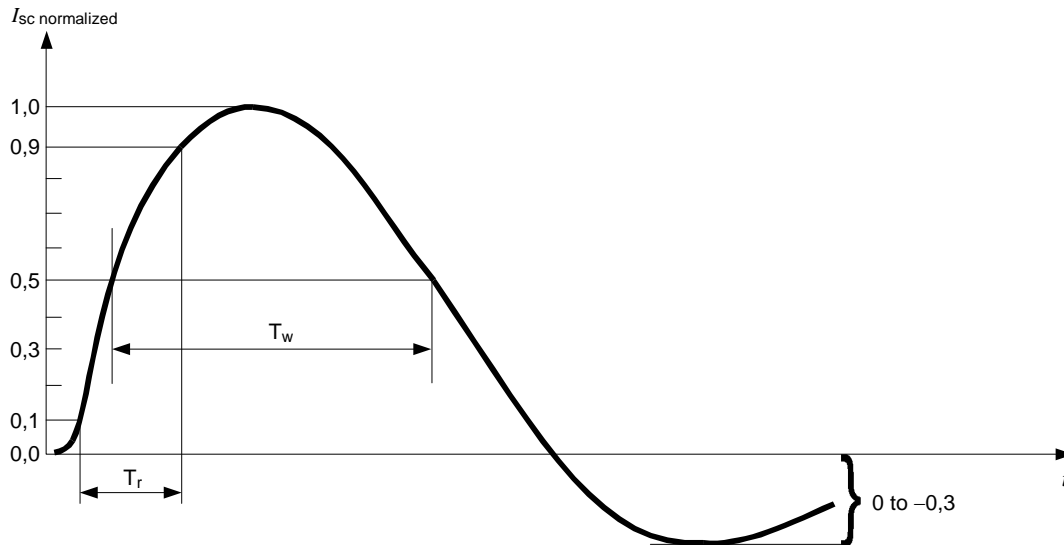
Front time: $T_f = 1,25 \times T_r = 8\ \mu s \pm 20\ \%$
Duration: $T_d = 1,18 \times T_w = 20\ \mu s \pm 20\ \%$

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:
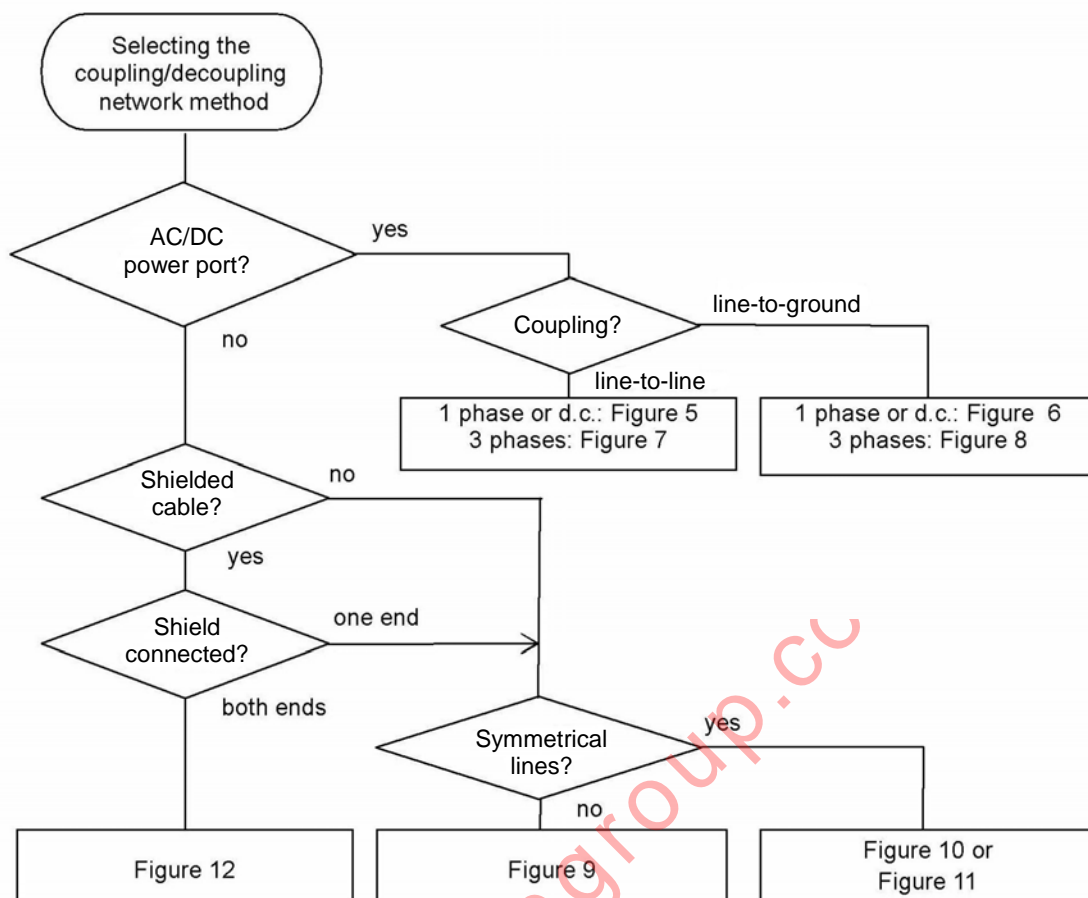
Figure 4 – Selection of coupling/decoupling method

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 μF (line-to-line)	9 μF + 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 μs ± 30 %	1,2 μs ± 30 %
Duration		
Current rating ≤ 16 A	50 μs +10 μs/-10 μs	50 μs +10 μs/-25 μs
16 A < current rating ≤ 32 A	50 μs +10 μs/-15 μs	50 μs +10 μs/-30 μs
32 A < current rating ≤ 63 A	50 μs +10 μs/-20 μs	50 μs +10 μs/-35 μs
63 A < current rating ≤ 125 A	50 μs +10 μs/-25 μs	50 μs +10 μs/-40 μs
125 A < current rating ≤ 200 A	50 μs +10 μs/-30 μs	50 μs +10 μs/-45 μs

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 μF (line-to-line)	9 μF + 10 Ω (line-to-ground) [b]
Front time	$T_f = 1,25 \times T_r = 8$ μs ± 20 %	$T_f = 1,25 \times T_r = 2,5$ μs ± 30 %
Duration	$T_d = 1,18 \times T_w = 20$ μs ± 20 %	$T_d = 1,04 \times T_w = 25$ μs ± 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 ± 10 % at EUT port of the CDN	Short-circuit peak current ± 10 % at EUT port of the CDN (18 µF)	Short-circuit peak current ± 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.

The above mentioned characteristics are applicable for single-phase systems (line, neutral, protective earth) and three-phase systems (three-phase wires, neutral and protective earth).
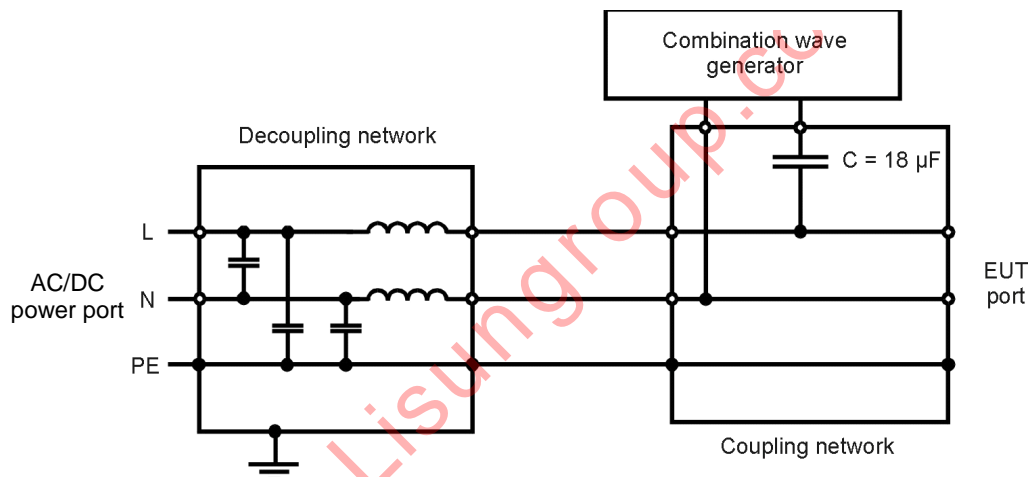
**Figure 5 – Example of coupling network and decoupling network
for capacitive coupling on a.c./d.c. lines line-to-line coupling**
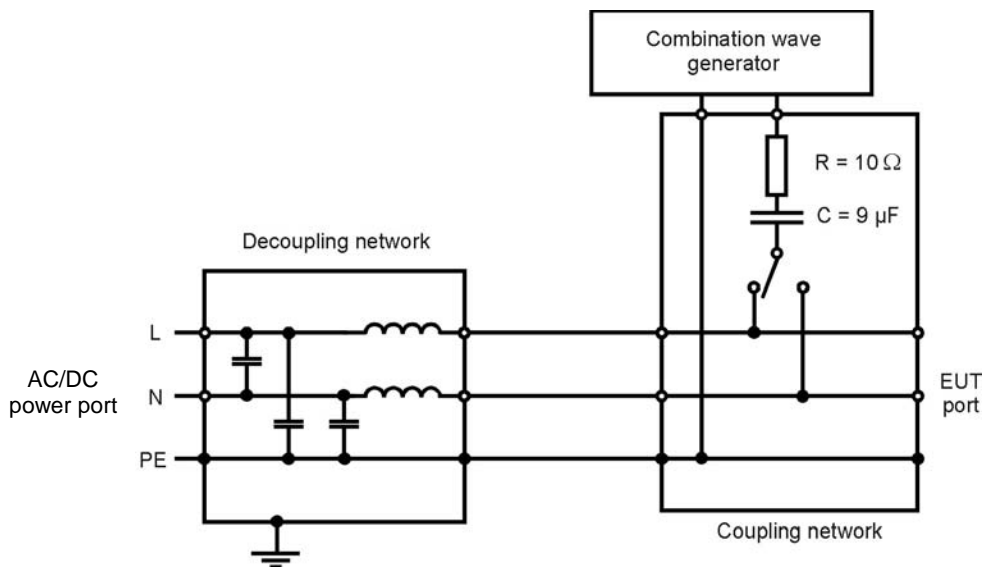
Figure 6 – Example of coupling network and decoupling network for capacitive coupling on a.c./d.c. lines: line-to-ground coupling
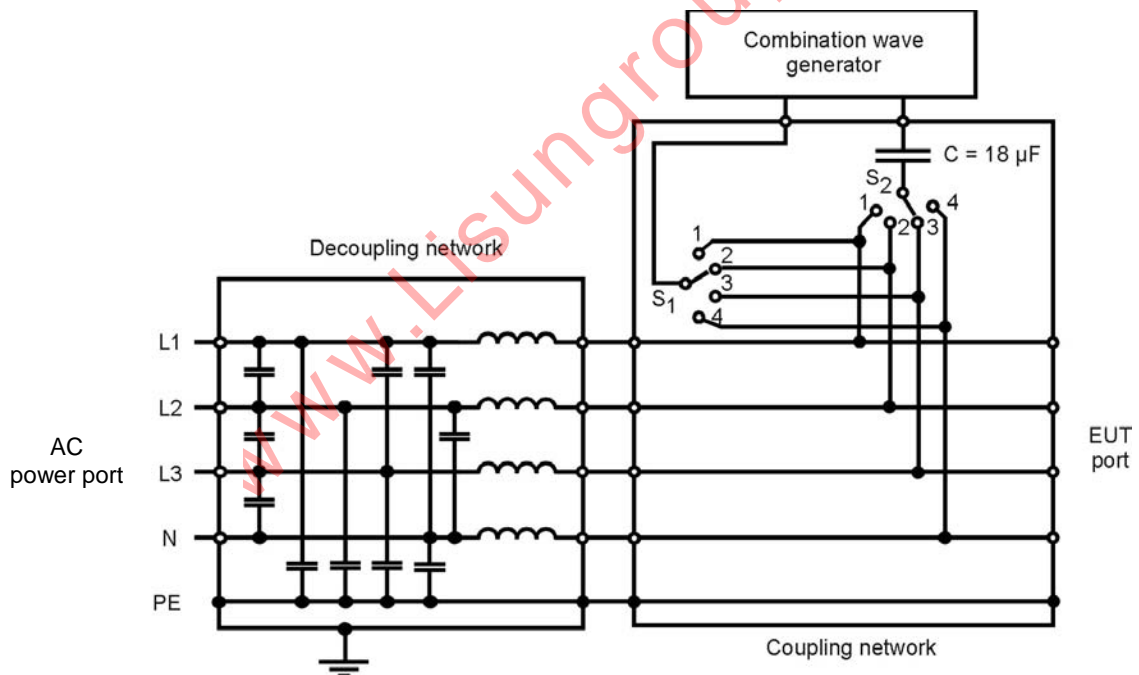
Switches S_1 and S_2 are used to select individual lines for test.

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
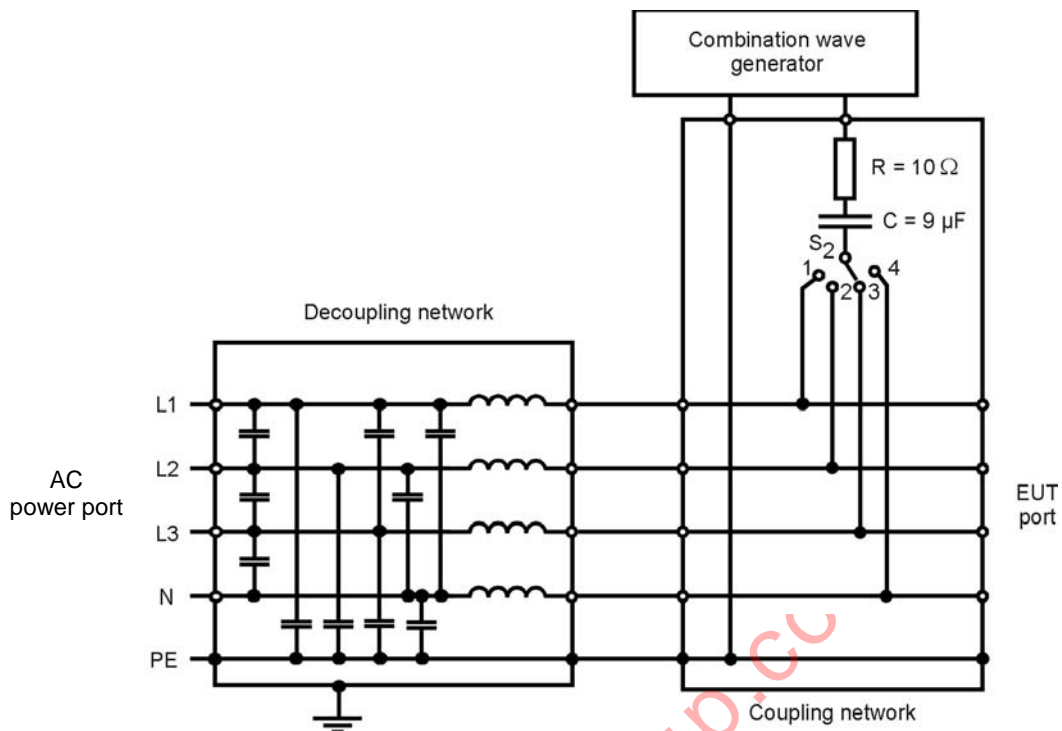
Switch S_2 is used to select individual lines for test.

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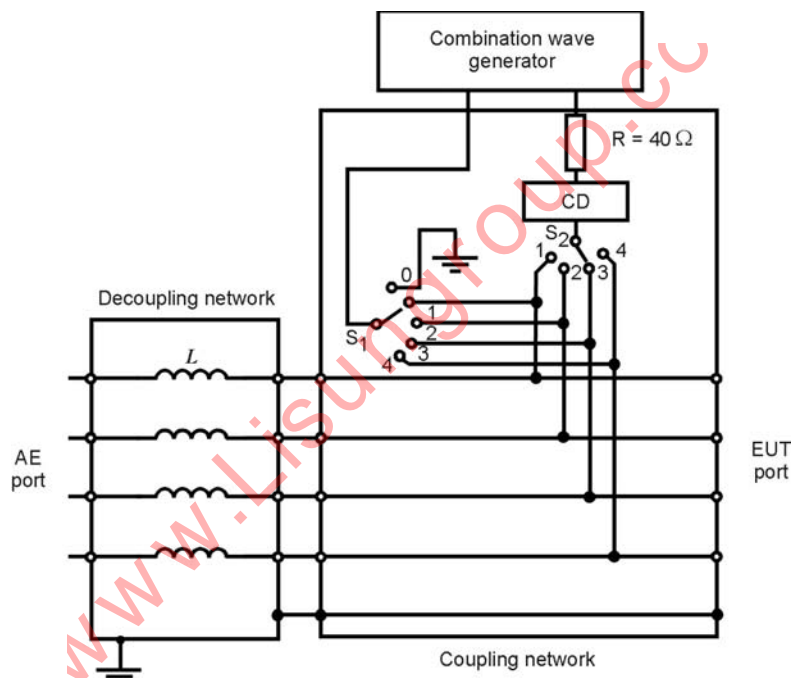
1) Switch S_1
  – line-to-ground: position 0
  – line-to-line: positions 1 to 4
2) Switch S_2: positions 1 to 4
  – during testing, the position of switch S_2 is different from the position of switch S_1

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 Ω. 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 Ω. 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 resistors 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.
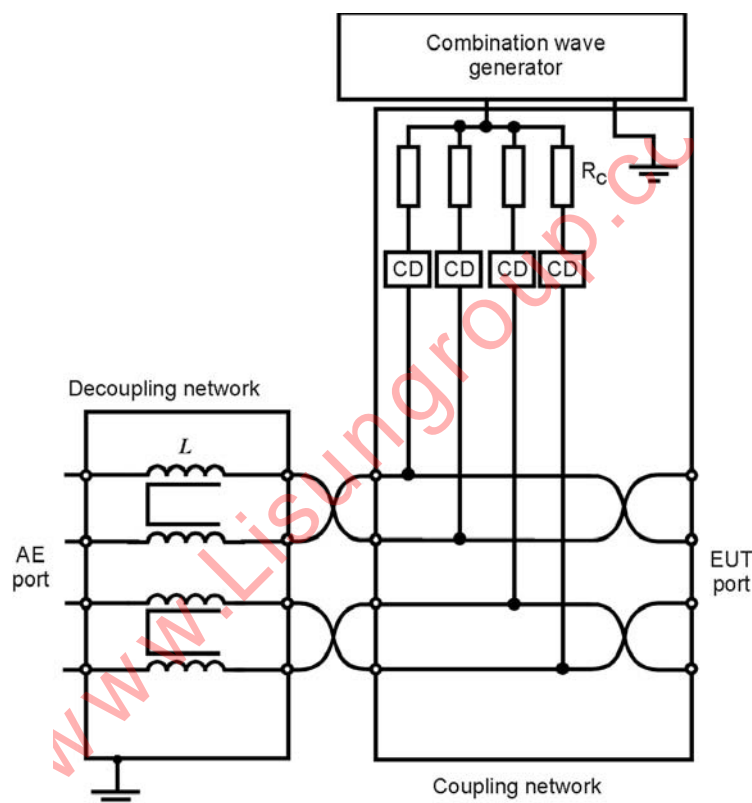
Calculation of coupling resistor values R_C:

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 Ω. A test on a four-line port for example, requires four resistors each of 160 Ω.

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.
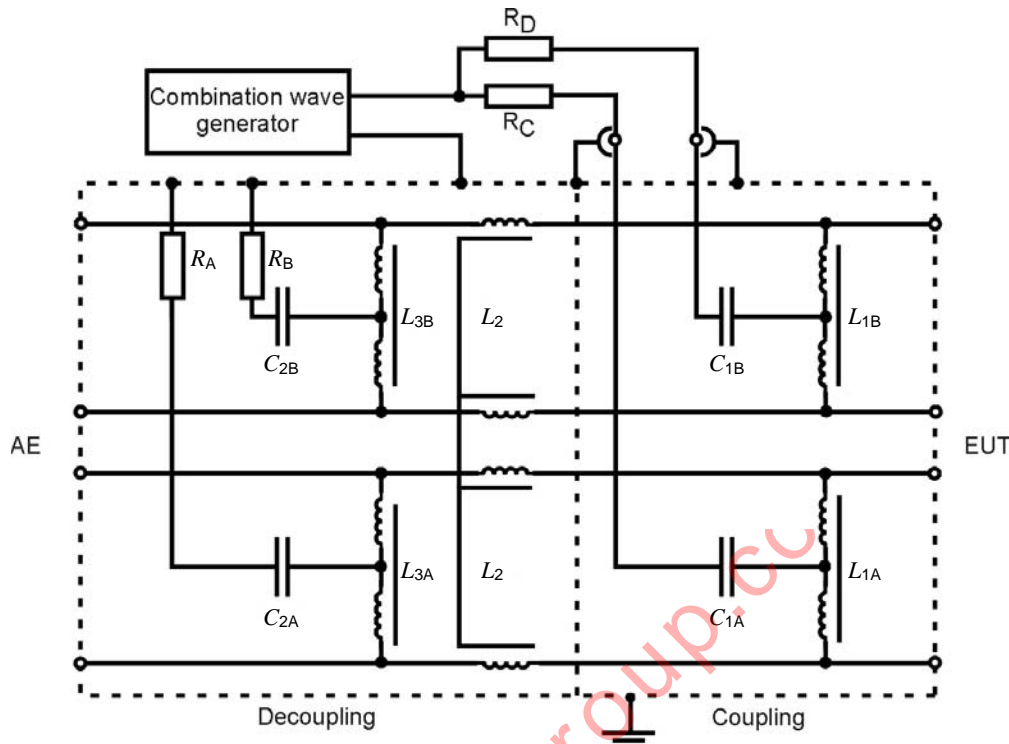
Calculation of coupling resistors and capacitors values:

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 kΩ) 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	Single line to PE	Line to PE at a time	Open-circuit	Open-circuit

	Coupling	Measuring	AE side	EUT side
elements)		Peak voltage		

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 ± 10 %	Voltage front time T_f $T_f = 1{,}67 \times T_r$ ± 30 %	Voltage duration T_d $T_d = T_w$ ± 30 %	I_{sc} at CDN EUT output ± 20 %	Current front time T_f $T_f = 1{,}25 \times T_r$ ± 30 %	Current duration T_d $T_d = 1{,}18 \times T_w$ ± 30 %
Line to PE R = 40 Ω CD = 0,5 μF	4 kV	4 kV	1,2 μs	38 μs	87 A	1,3 μs	13 μs
Line to PE R = 40 Ω CD = GDT	4 kV	4 kV	1,2 μs	42 μs	95 A	1.5 μs	48 μs
Line-to-line R = 40 Ω CD = 0,5 μF	4 kV	4 kV	1,2 μs	42 μs	87 A	1,3 μs	13 μs
Line-to-line R = 40 Ω 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 ± 10 %	Voltage front time T_f $T_f = 1,67 \times T_r$ ± 30 %	Voltage duration T_d $T_d = T_w$ ± 30 %	I_{sc} at CDN EUT output ± 20 %	Current front time T_f $T_f = 1,25 \times T_r$ ± 30 %	Current duration T_d $T_d = 1,18 \times T_w$ ± 30 %
Common mode CD [d], 40 Ω path	2 kV	2 kV	1,2 µs	45 µs	48 A	1,5 µs	45 µs

[a] It is recommended to calibrate the CDN at the highest rated impulse voltage, as this will minimise the effects of the switching noise generated by CLDs and GDTs. The value shown in the table is for a generator setting of 2 kV. 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 µs 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 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).

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 Ω generator source impedance and with the 18 μF 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.
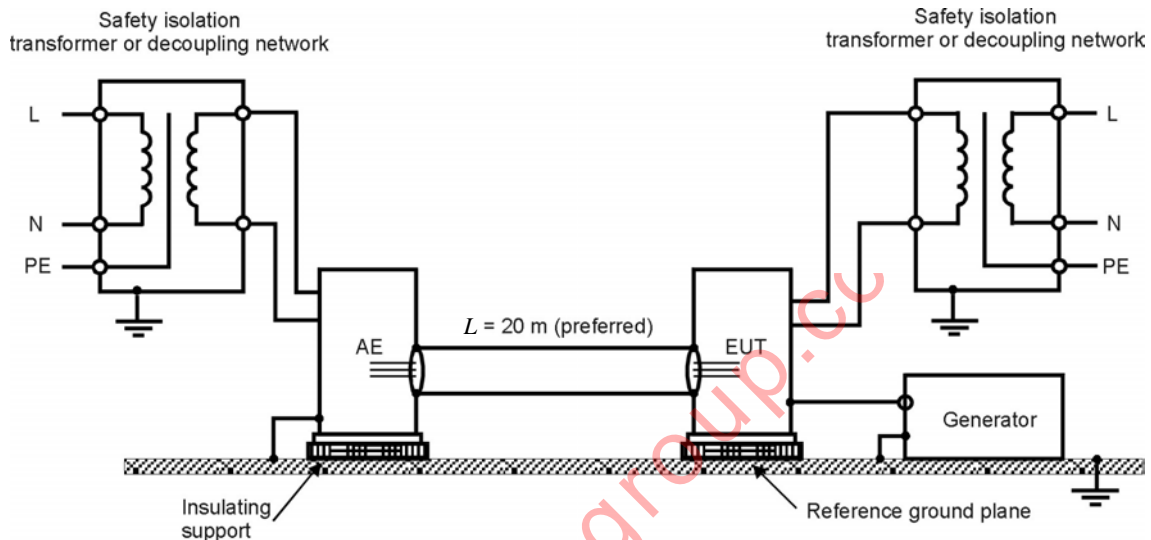
It is permissible for the power to the EUT and/or the AE to be provided via a decoupling network, rather than via the isolating transformer shown. In this case, the EUT's protective earth connection should not be connected to the decoupling network.

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 0º, 90º, 180º and at 270º;
- 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;

−   identificdion 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 μs – 8/20 μs 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 μs – 5/320 μs 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 μs – 5/320 μs 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 μs 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 μs;

– an open-circuit voltage duration of 700 μs;

– a short-circuit current front time of 5 μs;

– a short-circuit current duration of 320 μs.

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
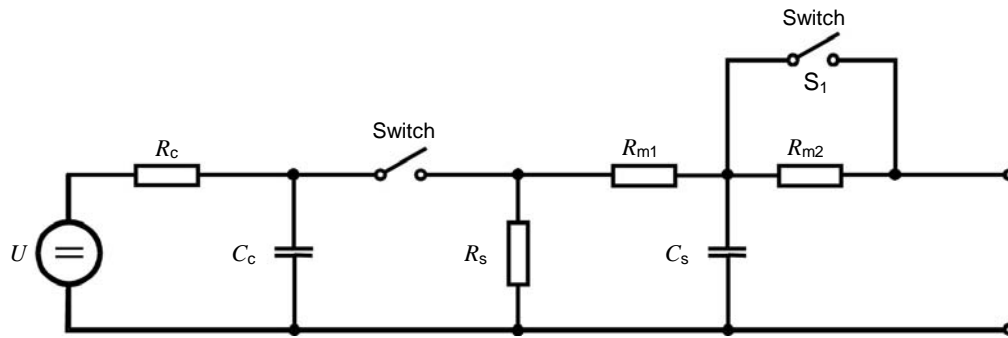
U High-voltage source

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 μs – 5/320 μs)**

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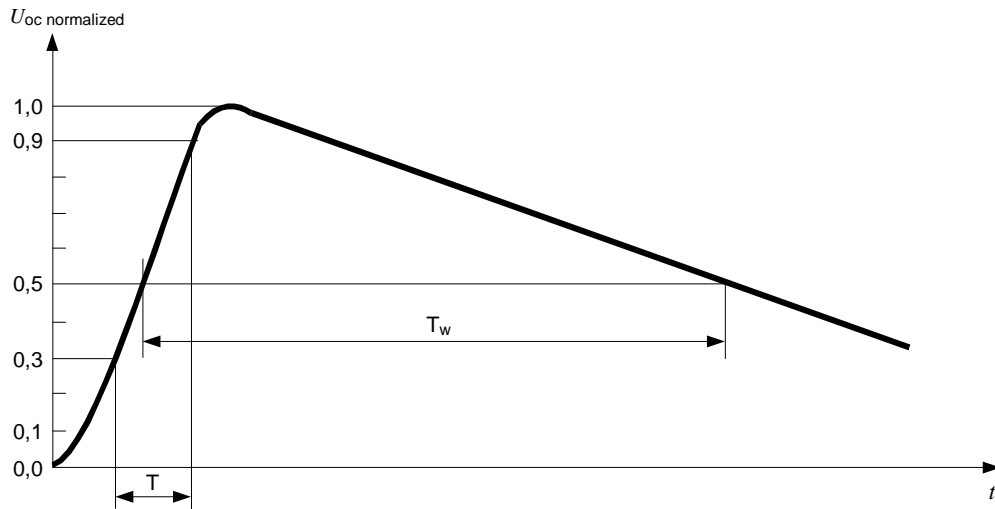
Front time: $T_f = 1,67 \times T = 10 \ \mu s \pm 30 \ \%$
Duration: $T_d = T_w = 700 \ \mu s \pm 20 \ \%$

Figure A.2 – Waveform of open-circuit voltage (10/700 μs)
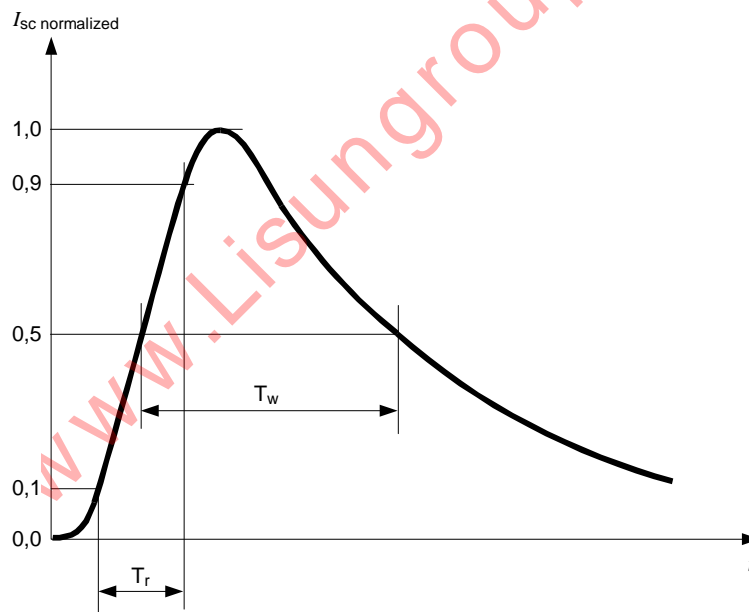
Front time: $T_f = 1,25 \times T_r = 5 \ \mu s \pm 20 \ \%$

Duration: $T_d = T_w = 320 \ \mu s \pm 20 \ \%$

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 ± 10 % at generator output	Short-circuit peak current ± 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 kΩ) 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 Ω.

Recommended characteristics of the coupling/decoupling network:

   Coupling impedance R_c = 25 Ω 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
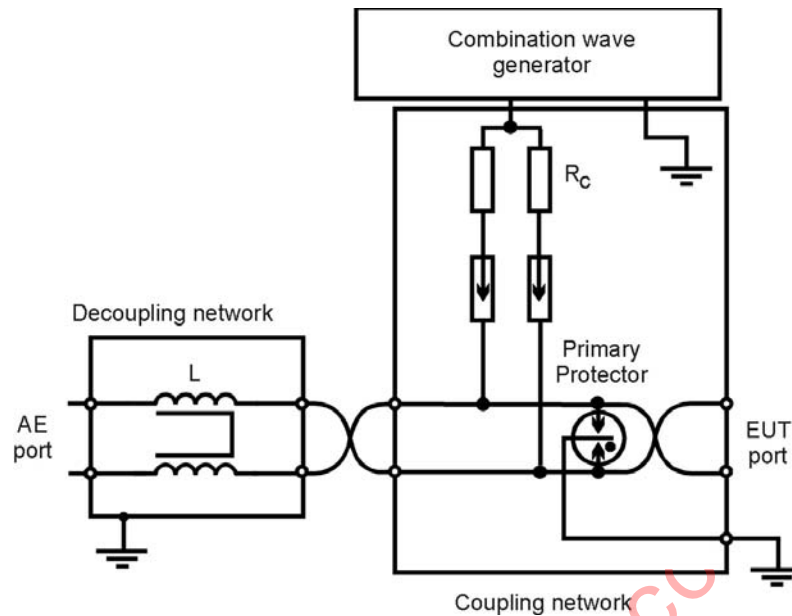
The internal matching resistor R_{m2} (25 Ω) is replaced by external R_c = 25 Ω.

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:

a) 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.

b) 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).

Annex B
(informative)

Selection of generators and test levels

B.1   General

The selection of the test levels should be based on the installation conditions and may be specified in product or product family standards. Where there are no defined levels, Tables B.1 and B.2 should be used, together with information given in C.3. These values are included for illustration only and do not form a recommendation or requirement. The values have been chosen only for explanatory purposes and are not put forward as some recommended practice.

B.2   The classification of environments

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

Class 1:   Partly protected electrical environment

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

Class 3:   Electrical environment where cables run in parallel

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

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

Class x: Special conditions specified in the product specification

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

B.3   The definition of port types

Intra-system port:

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

Internal port:

- Only connected to cables within the same building.

- The port is not intended to provide a service that can be directly connected to an outdoor connection.

- The port will not have a conductive connection to a cable which leaves the building via other equipment (e.g., via a splitter).

External port:

- The port is intended to connect directly to lines which exit a building.

- The port has a conductive connection to a cable which leaves the building via other equipment (e.g., via a splitter).

B.4 Generators and surge types

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

Classes 1 to 5: 1,2/50 µs (8/20 µs) for ports of power lines, short-distance signal circuits/lines and local area networks (e.g. Ethernet, token ring, etc.) and similar networks.

Classes 4 to 5: 10/700 µs (5/320 µs) for symmetrical communication lines intended to interconnect widely dispersed systems via such means as direct connection to multi-user telecommunications networks (e.g. public switched telecommunications networks (PSTN), x-type digital subscriber lines (xDSL), etc.); lines typically greater than 300 m in length.

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

B.5 Tables

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

Installation class	Test levels (kV)							
	AC power supply and a.c. I/O External ports [a]		AC power supply and a.c. I/O Internal ports [a,d]		DC power supply and d.c. I/O External ports [a]		DC power supply and d.c. I/O Internal ports [a,d]	
	Coupling mode		Coupling mode		Coupling mode		Coupling mode	
	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground
0	NA	NA	NA	NA	NA	NA	NA	NA
1	NA	0,5	NA	NA	NA	NA	NA	NA
2	0,5	1,0	NA	NA	NA	NA	NA	NA
3	1,0	2,0	1,0	2,0	NA	NA	NA	NA
4	2,0 [b]	4,0 [b]	2,0 [b]	4,0 [b]	2,0 [b]	4,0 [b]	2,0 [b]	4,0 [b]
5	[c,b]	[c,b]	2,0 [b]	4,0 [b]	2,0 [b]	4,0 [b]	2,0 [b]	4,0 [b]

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

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

[c] Depends on the class of the local power supply system.

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

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

Installation class	Test levels (kV)											
	Unsymmetrical operated circuits/lines [a,c,e]				Symmetrical operated circuits/lines [a,c,e]				Shielded circuits/lines [a,d,e]			
	External port		Internal port		External port		Internal port		External port		Internal port	
	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Line-to-ground	Line-to-line	Shield-to-ground	Line-to-line	Shield-to-ground
0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	NA	NA	NA	0,5	NA	NA	NA	0,5	NA	NA	NA	NA
2	NA	NA	0,5	1,0	NA	NA	NA	1,0	NA	NA	NA	0,5
3	NA	NA	1,0	2,0	NA	NA	NA	2,0	NA	NA	NA	2,0
4	2,0 [b]	4,0 [b]	2,0 [b]	4,0 [b]	NA	4,0 [b]	NA	4,0 [b]	NA	4,0 [b]	NA	4,0 [b]
5	2,0 [b]	4,0 [b]	2,0 [b]	4,0 [b]	NA	4,0 [b]	NA	4,0 [b]	NA	4,0 [b]	NA	4,0 [b]

[a]   No test is advised for data connections intended for cables shorter than 10 m.

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

[c]   Line-to-line surges (transverse) may occur in networks where SPDs (surge protective devices) with connection to ground are used for protection. Such surges are outside the scope of this standard. This phenomenon can however be simulated by applying common mode surges through the defined primary protection elements.

[d]   The testing of ports connecting to antennas is outside the scope of this standard.

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

Annex C
(informative)

Explanatory notes

C.1   Different source impedance

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

–   the kind of cable/conductor/line (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 Ω represents the source impedance of the low-voltage power supply network. The generator with its effective output impedance of 2 Ω is used.

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

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

NOTE   D.C. ports that are intended to be connected to an a.c/d.c power converter (e.g. laptop power supply d.c. connection) are not regarded as low voltage power supply ports. If d.c. power is fed on conductors included in a signal cable then these connections are not regarded as low voltage power supply ports.

In some countries, (for instance, USA) other non-IEC standards for a.c. lines may require the tests according to Figures 5 and 7 with a 2 Ω impedance; these are more severe tests.

C.2   Application of the tests

C.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.

C.2.2   System level immunity

Preferential ranges of test levels are given in Tables B.1 and B.2.

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 the surge protective devices standards series IEC 61643 and IEC 62305-1.

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 exist, 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 61643-21:2000 and Amendment 2: 2012, 6.2.1.8).

C.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 B.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.

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

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.

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

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.

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

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.

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

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.

Class x   Special conditions specified in the product specifications

C.4   Minimum immunity level of ports connected to the a.c./d.c. mains supply

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

– line-to-line coupling: 0,5 kV;
– line-to-ground coupling: 1 kV.

C.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 D
(informative)

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

This standard 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 this standard 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 and systems.

IEC 60664-1 is concerned with insulation coordination for equipment within low voltage systems and IEC 61643-11 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. The IEC 61000 series does 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 shall remain operational during surge activity.

For the tests described in this standard, the magnitude of the applied voltage test level (installation class) and the resultant surge current 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 61643-11, test class III, specifies a combination wave generator with an effective output impedance of 2 Ω, which produces an 8/20 μs short-circuit current waveshape and a 1,2/50 μs open-circuit voltage waveshape. This standard 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 the voltage test level (installation class) of this standard and the peak open-circuit voltage U_{oc} of IEC 61643-11 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 61643-11. 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 this standard 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 this standard 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.

Annex E
(informative)

Mathematical modelling of surge waveforms

E.1 General

Annex E provides reference mathematical waveforms for:

- designing surge generators,

- simulations of surge performance on digital apparatus.

The formulae have been defined considering the following requirements:

1) To reproduce the nominal front time and duration as defined in the standard dedicated to surge generators with output in open and short-circuit condition.

2) To help the designers of digital apparatus to build up a circuit model of the source generators by using the simplified circuits reported in the dedicated standard with the nominal values of the circuit elements, if any.

3) To have derivative equal to zero at starting time in order to avoid instability when numerical simulations are performed.

4) To have the same basic formula used in IEC for transient phenomena such as ESD, EFT/B and surge.

NOTE   For voltage surge (1,2/50 µs) and current surge (8/20 µs), the defined mathematical waveforms match well with those defined in IEEE Std C62.45-2002. Comparison for voltage surge (10/700 µs) cannot be done because IEEE Std C62.45-2002 provides values for voltage surge (10/1000 µs). For current surge (5/320 µs) the values are not available.

The following parameter definitions are used:

1) T_w is the width time defined as the time between the 50 % of rising and falling front of the waveform.

2) T is the rise time for voltage surge defined as the time between the 30 % and 90 % of the early time response of the waveform.

3) T_r is the rise time for current surge defined as the time between the 10 % and 90 % of the early time response of the waveform.

4) T_d is the duration time between the minimum value of the early time response and the 50% of the falling time.

5) T_f is the front time defined as the time between the intersection of a line, having a slope that approximates the early time response, with the horizontal line that passes through the minimum and maximum value of the waveform respectively. The following values are defined that match well with the waveforms provided by the simplified circuits using model simulations:

   - voltage surge (1,2/50 µs): $T_f = 1{,}67 \times T$; $T_d = T_w$

   - current surge (8/20 µs): $T_f = 1{,}25 \times T_r$; $T_d = 1{,}18 \times T_w$

   - voltage surge (10/700 µs): $T_f = 1{,}67 \times T$; $T_d = T_w$

   - current surge (5/320 µs): $T_f = 1{,}25 \times T_r$; $T_d = T_w$

6) BW is the bandwidth of the surge waveforms defined at the frequency where the spectral response begins to roll off with a slope of −60 dB/decade.

E.2   Normalized time domain voltage surge (1,2/50 µs)

The normalized time domain expression of the 1,2/50 µs voltage surge is given by

$$v_{\text{SURGE}}(t) = k_{\text{V}} \cdot \left[\frac{v_1}{k_{\text{SURGE}}} \cdot \frac{\left(\dfrac{t}{\tau_1}\right)^{\eta_{\text{SURGE}}}}{1 + \left(\dfrac{t}{\tau_1}\right)^{\eta_{\text{SURGE}}}} \cdot e^{\frac{-t}{\tau_2}} \right] \tag{E.1}$$

The coefficients that appear in Equation (E.1) have the following values

$k_{\text{V}} = 1$ $\tau_1 = 0{,}356$ µs $\tau_2 = 65{,}845$ µs $v_1 = 0{,}94$ $\eta_{\text{SURGE}} = 1{,}852$

$$k_{\text{SURGE}} = e^{\frac{-\tau_1}{\tau_2} \left(\frac{\eta_{\text{SURGE}} \cdot \tau_2}{\tau_1} \right)^{\frac{1}{\eta_{\text{SURGE}}}}}$$

The plot of the 1,2/50 µs voltage surge as a function of time is shown in Figure E.1.

Figure E.1 – Voltage surge (1,2/50 µs): width time response T_w

An expansion to highlight the early time response is plotted in Figure E.2.

Figure E.2 – Voltage surge (1,2/50 µs): rise time response T

The magnitude of the spectral response corresponding to Equation (E.1) is shown in Figure E.3.

Figure E.3 – Voltage surge (1,2/50 µs): spectral response with Δf = 3,333 kHz

The voltage impulse in the time domain is simulated well for frequencies up to 2 MHz, therefore the associated bandwidth BW = 2 MHz.

E.3   Normalized time domain current surge (8/20 µs)

The normalized time domain expression of the 8/20 µs current surge is given by

$$I_{SURGE}(t) = k_i \cdot \left[\frac{i_1}{k_{SURGE}} \cdot \frac{\left(\dfrac{t}{\tau_1}\right)^{\eta_{SURGE}}}{1 + \left(\dfrac{t}{\tau_1}\right)^{\eta_{SURGE}}} \cdot e^{\frac{-t}{\tau_2}} \right] \qquad (E.2)$$

The coefficients that appear in Equation (E.2) have the following values

$$k_i = 1 \qquad \tau_1 = 47,52\ \mu s \qquad \tau_2 = 4,296\ \mu s \qquad i_1 = 0,939 \qquad \eta_{SURGE} = 2,741$$

$$k_{SURGE} = e^{\frac{-\tau_1}{\tau_2} \cdot \left(\frac{\eta_{SURGE} \cdot \tau_2}{\tau_1}\right)^{\frac{1}{\eta_{SURGE}}}}$$

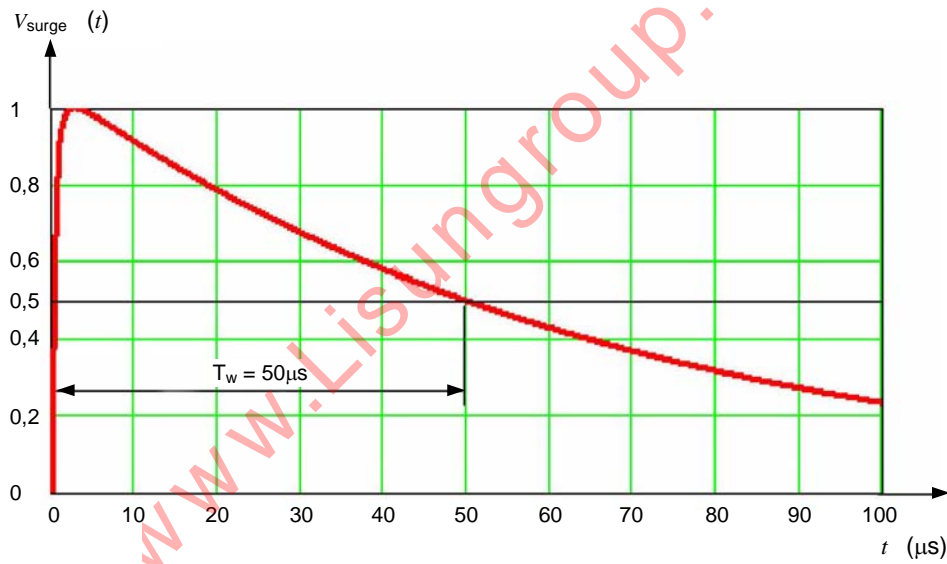The plot of the 8/20 μs current surge as a function of time is shown in Figure E.4.

Figure E.4 – Current surge (8/20 μs): width time response T$_w$

An expansion to highlight the early time response is plotted in Figure E.5.
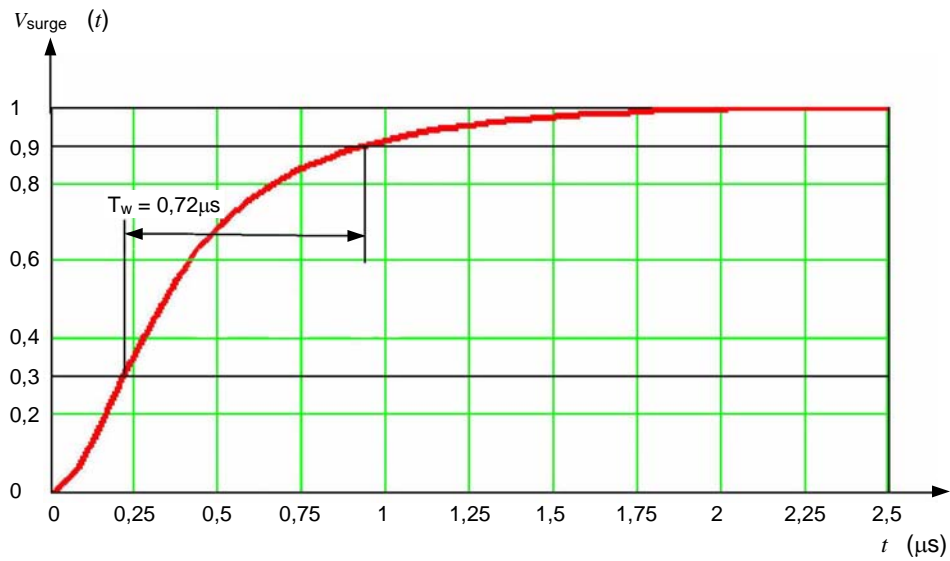
Figure E.5 – Current surge (8/20 μs): rise time response T_r

The magnitude of the spectral response corresponding to Equation (E.2) is shown in Figure E.6.
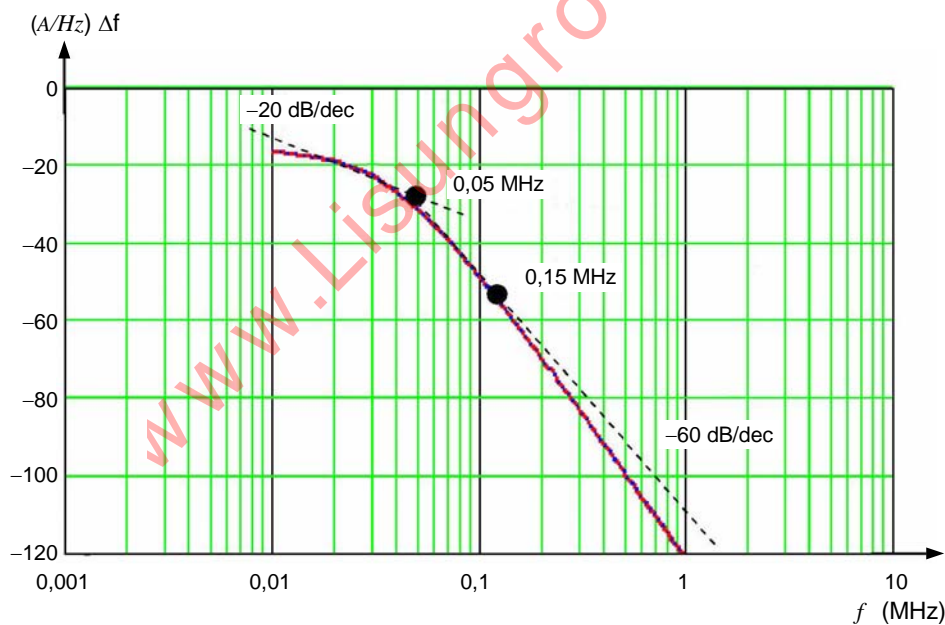
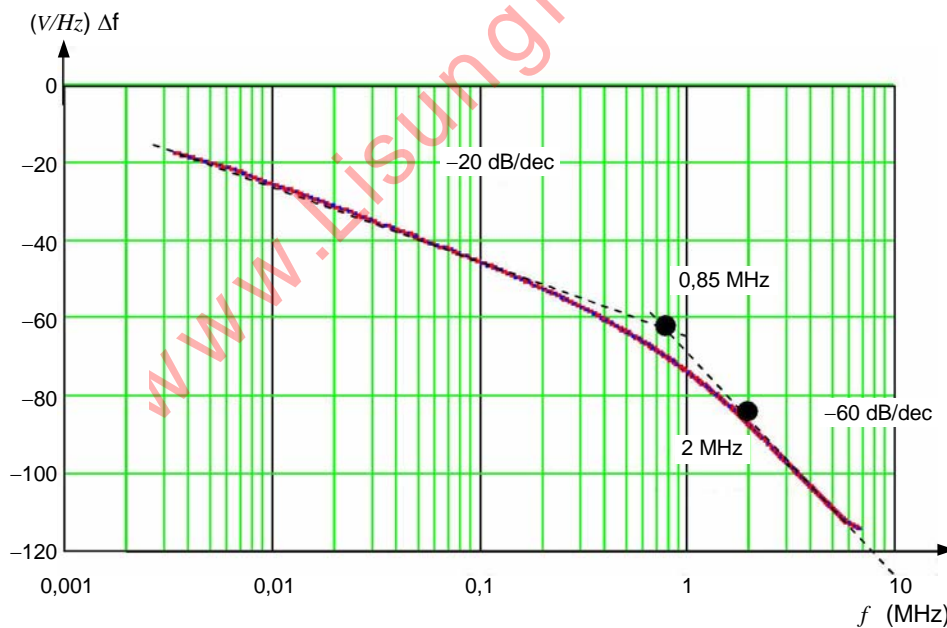**Figure E.6 – Current surge (8/20 μs): spectral response with Δf = 10 kHz**

The current impulse in the time domain is simulated well for frequencies up to 0,15 MHz, therefore the associated bandwidth BW = 0,15 MHz.

E.4   Normalized time domain voltage surge (10/700 μs)

The normalized time domain expression of the 10/700 μs voltage surge is given by

$$v_{\text{SURGE}}(t) = k_V \cdot \left[\frac{v_1}{k_{\text{SURGE}}} \cdot \frac{\left(\dfrac{t}{\tau_1}\right)^{\eta_{\text{SURGE}}}}{1 + \left(\dfrac{t}{\tau_1}\right)^{\eta_{\text{SURGE}}}} \cdot e^{\frac{-t}{\tau_2}} \right] \tag{E.3}$$

The coefficients that appear in Equation (E.3) have the following values

$$k_V = 1 \qquad \tau_1 = 2{,}574~\mu s \qquad \tau_2 = 945{,}1~\mu s \qquad v_1 = 0{,}937 \qquad \eta_{\text{SURGE}} = 1{,}749$$

$$k_{\text{SURGE}} = e^{\frac{-\tau_1}{\tau_2}} \left(\frac{\eta_{\text{SURGE}} \cdot \tau_2}{\tau_1} \right)^{\frac{1}{\eta_{\text{SURGE}}}}$$

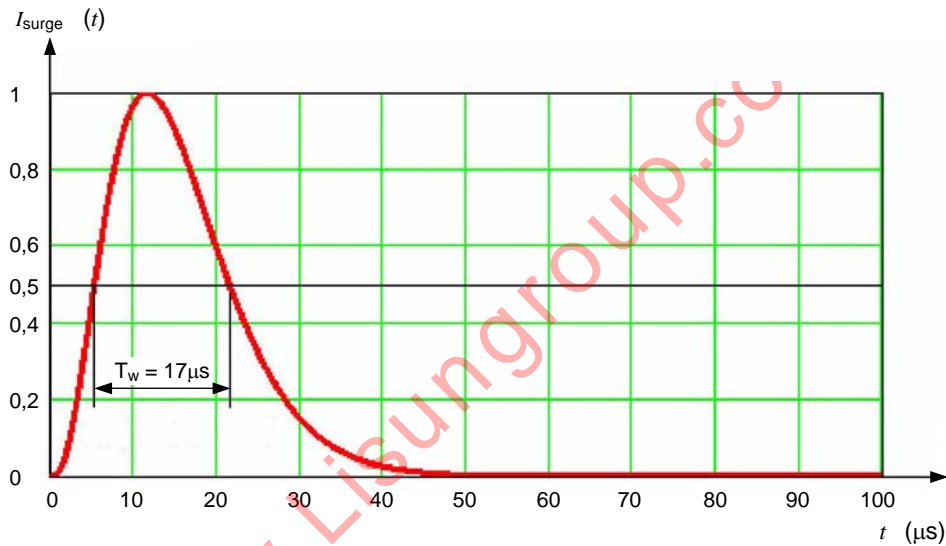The plot of the 10/700 μs voltage surge as a function of time is shown in Figure E.7.
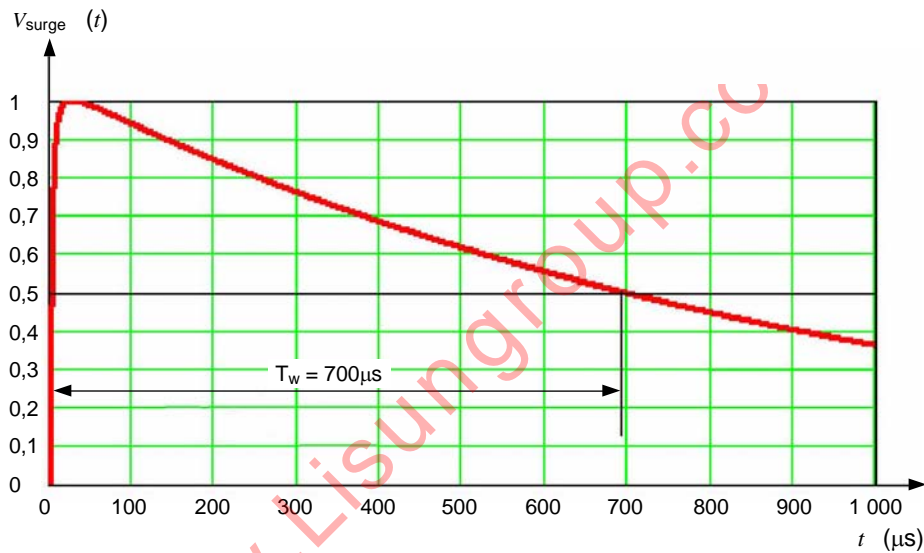
Figure E.7 – Voltage surge (10/700 μs): width time response T$_w$

An expansion to highlight the early time response is plotted in Figure E.8.
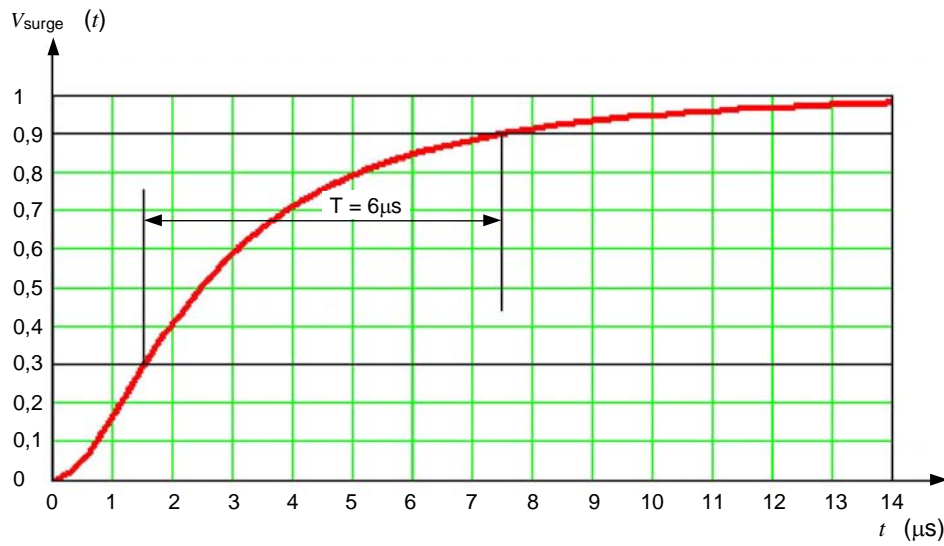
Figure E.8 – Voltage surge (10/700 μs): rise time response T

The magnitude of the spectral response corresponding to Equation (E.3) is shown in Figure E.9.
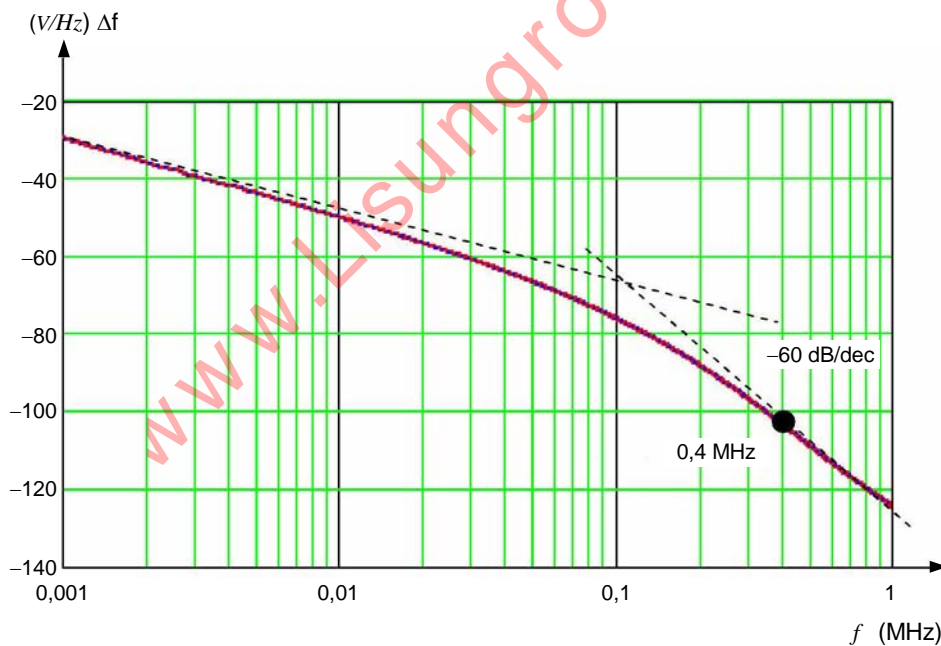
Figure E.9 – Voltage surge (10/700 μs): spectral response with Δf = 0,2 kHz

The voltage impulse in the time domain is simulated well for frequencies up to 0,4 MHz, therefore the associated bandwidth BW = 0,4 MHz.

E.5 Normalized time domain current surge (5/320 μs)

The normalized time domain expression of the 5/320 μs current surge is given by

$$I_{\text{SURGE}}(t) = k_i \cdot \left[\frac{i_1}{k_{\text{SURGE}}} \cdot \frac{\left(\dfrac{t}{\tau_1} \right)^{\eta_{\text{SURGE}}}}{1 + \left(\dfrac{t}{\tau_1} \right)^{\eta_{\text{SURGE}}}} \cdot e^{\frac{-t}{\tau_2}} \right] \tag{E.4}$$

The coefficients that appear in (E.4) have the following values

$$k_i = 1 \quad \tau_1 = 1{,}355~\mu s \quad \tau_2 = 429{,}1~\mu s \quad i_1 = 0{,}895 \quad \eta_{\text{SURGE}} = 1{,}556$$

$$k_{\text{SURGE}} = e^{\frac{-\tau_1}{\tau_2} \left(\frac{\eta_{\text{SURGE}} \cdot \tau_2}{\tau_1} \right)^{\frac{1}{\eta_{\text{SURGE}}}}}$$

The plot of the 5/320 μs current surge as a function of time is shown in Figure E.10.
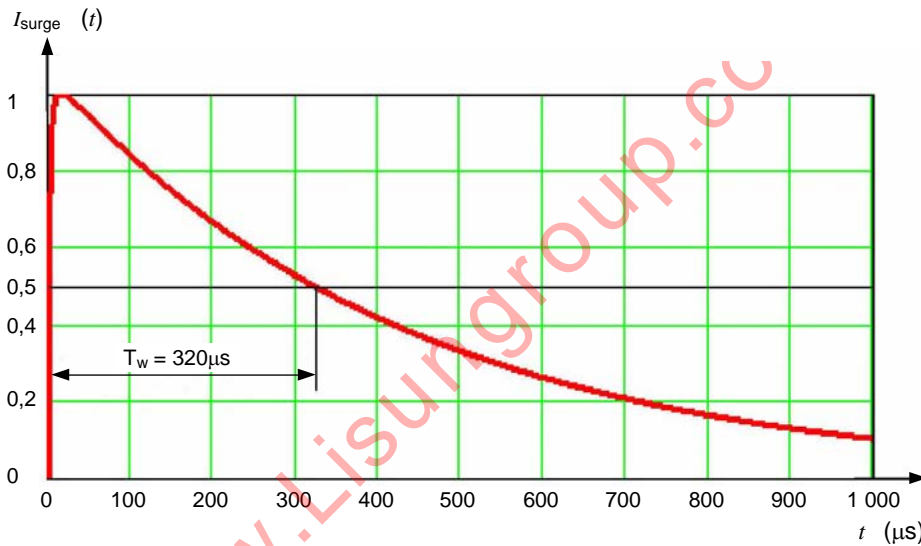
Figure E.10 – Current surge (5/320 μs): width time response T_w

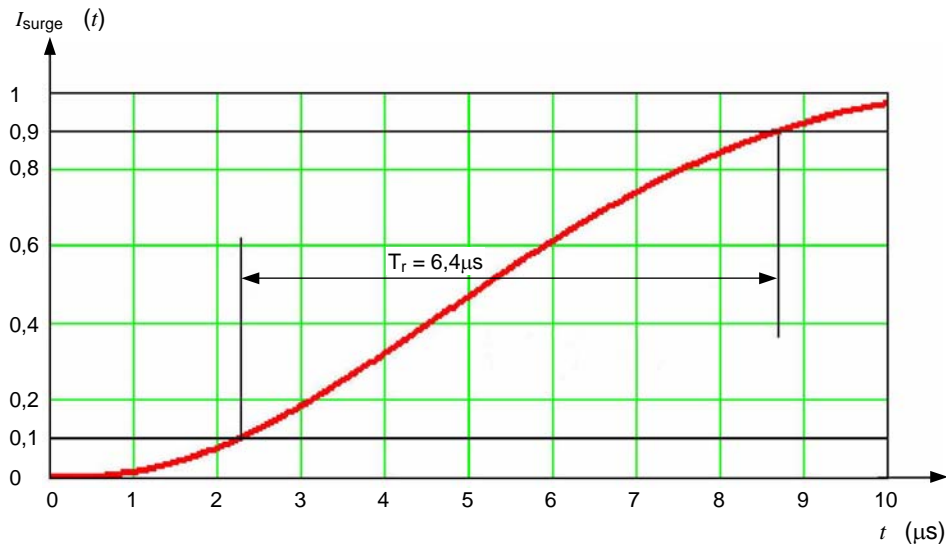An expansion to highlight the early time response is plotted in Figure E.11.
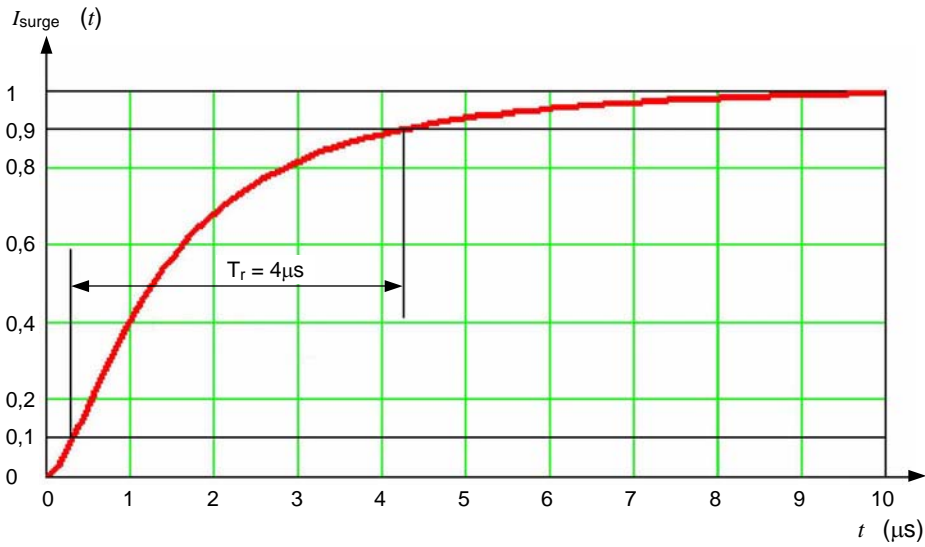
Figure E.11 – Current surge (5/320 μs): rise time response T$_r$

The magnitude of the spectral response corresponding to Equation (E.4) is shown in Figure E.12.
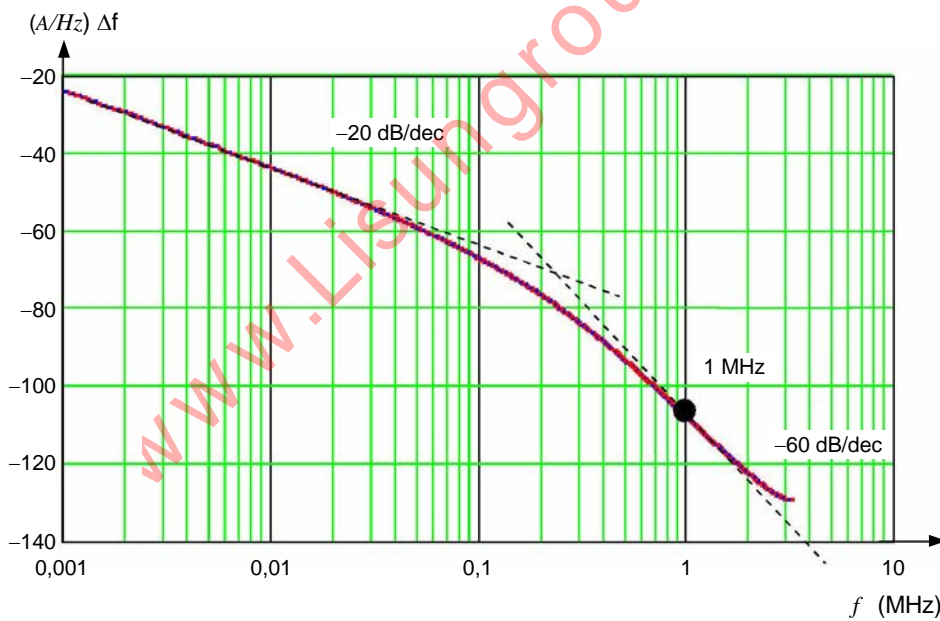
Figure E.12 – Current surge (5/320 μs): spectral response with Δf = 0,4 kHz

The current impulse in the time domain is simulated well for frequencies up to 1 MHz, therefore the associated bandwidth BW = 1 MHz.

Annex F
(informative)

Measurement uncertainty (MU) considerations

F.1   Legend

V_P peak of the open-circuit voltage impulse

T_{fV} front time of the open-circuit voltage impulse: $T_{fV} = 1,67\ T_V$

T_V rise time of the open-circuit voltage impulse defined as the time from 30 % to 90 % of the peak value

T_{rV} rise time of the open-circuit voltage impulse, defined as the time from 10 % to 90 % of the peak value: $T_{rV} = 0,80\ T_{fV} = 1,33\ T_V$

T_w width of the open-circuit voltage impulse

I_P peak of the short-circuit current impulse

T_{fI} front time of the short-circuit current impulse: $T_{fI} = 1,25\ T_{rI}$

T_{rI} rise time of the short-circuit current impulse, defined as the time from 10 % to 90 % of the peak value

T_d duration of the short-circuit current impulse

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

F.2   General

The compliance of the realized disturbance quantity with the disturbance quantity specified by this standard is usually confirmed through a set of measurements (e.g. measurement of the rise time of an impulse with an oscilloscope by using attenuators). The result of each measurement includes a certain amount of measurement uncertainty (MU) due to the imperfection of the measuring instrumentation as well as to the lack of repeatability of the measurand itself. The evaluation of MU is here done according to the principles and methods described in IEC/TR 61000-1-6.

In order to evaluate MU it is necessary to:

a) identify the sources of uncertainty, related both to the measuring instrumentation and to the measurand,

b) identify the functional relationship (measurement model) between the influence (input) quantities and the measured (output) quantity,

c) obtain an estimate and standard uncertainty of the input quantities,

d) obtain an estimate of the interval containing, with a high level of confidence, the true value of the measurand.

Further details are given in IEC/TR 61000-1-6.

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

These estimates and uncertainties, derived for a particular disturbance quantity, do not describe the degree of agreement between the simulated electromagnetic phenomenon, as

defined in the basic standard, and the real electromagnetic phenomenon in the world outside the laboratory.

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

F.3   Uncertainty contributors to the surge measurement uncertainty

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

- reading of peak value

- reading of 10 % (or 30 %) level

- reading of 90 % level

- reading of 50 % level

- bandwidth of the measuring system

- shape of the impulse response of the measuring system

- oscilloscope horizontal axis measurement error

- oscilloscope vertical axis measurement error

- measurement system, measurand and setup repeatability (type A)

- calibration of oscilloscope and measuring system

F.4   Uncertainty of surge calibration

F.4.1   General

In the case of the surge test, the disturbance quantities are the surge voltage and the surge current generated by the surge generator and applied to the EUT. As discussed in F.2, an uncertainty budget for each measured parameter of the disturbance quantity is required. The parameters of these disturbance quantities are V_P, T_{fV} and T_w for the open-circuit voltage and I_P, T_{fI} and T_d for the short-circuit current.

The approach here adopted to evaluate impulse MU is described in F.4.6 and F.4.7. Tables F.1, F.2 and F.3 give examples of uncertainty budgets for the surge parameters. The tables include the input quantities that are considered most significant for these examples, the details (numerical values, type of probability density function, etc.) of each contributor to MU and the results of the calculations required for determining each uncertainty budget.

F.4.2   Front time of the surge open-circuit voltage

The measurand is the surge open-circuit voltage front time calculated by using the functional relationship

$$T_{fV} = 1{,}25\sqrt{\left[1{,}33\left(T_{90\%} - T_{30\%} + \delta R\right)\right]^2 - T_{MS}^2}$$

where

$$T_{MS} = \frac{\alpha}{B} \tag{F.1}$$

and:

$T_{30\%}$ time at 30 % of peak amplitude

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

δR correction for non-repeatability

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

B −3 dB bandwidth of the measuring system

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

Table F.1 – Example of uncertainty budget for surge open-circuit voltage front time (T_{fV})

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divi sor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
$T_{30\%}$	0,25	μs	0,005 0	μs	triangular	2,45	0,002 0	−2,08	1	0,004 3	μs
$T_{90\%}$	1,15	μs	0,005 0	μs	triangular	2,45	0,002 0	2,08	1	0,004 3	μs
δR	0	μs	0,025	μs	normal ($k=1$)	1,00	0,025	2,08	1	0,052	μs
α	360	μs·kHz	40	μs·kHz	rectangular	1,73	23,1	−0,001 9	1/kHz	0,043	μs
B	500	kHz	50	kHz	rectangular	1,73	28,9	0,001 4	μs/kHz	0,039	μs
							$u_c(y) = \sqrt{\Sigma u_i(y)^2}$			0,08	μs
							$U(y) = 2\ u_c(y)$			0,16	μs
							y			1,20	μs

a   Probability density function.

$T_{30\%}$, $T_{90\%}$: is the time reading at 30 % or 90 % of the peak amplitude. The error bound is obtained assuming a sampling frequency of 100 MS/s and trace interpolation capability of the scope (triangular probability density function). Would this not be the case, a rectangular probability density function should be assumed. Only the contributor to MU due to the sampling rate is considered here, for additional contributors see F.4.5. The readings are assumed to be $T_{30\%}$ = 0,25 μs and $T_{90\%}$ = 1,15 μs.

T_{MS}: is the calculated rise time of the step response of the measuring system. The coefficient α (see F.1) depends on the shape of the impulse response of the measuring system. The range (360 ± 40) μs•kHz is representative of a wide class of systems, each having a different shape of the impulse response (see F.4.6 and Table F.4). The bandwidth B of the measuring system can be experimentally obtained (direct measurement of the bandwidth) or calculated from the bandwidth B_i of each element of the measurement system (essentially a voltage probe, a cable and a scope) by using the following equation:

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

An estimate of 500 kHz and a 50 kHz error bound of a rectangular probability density function are assumed for B.

δR: is the 30 % to 90 % rise time non-repeatability. It quantifies the lack of repeatability in the measurement of $T_{90\%} - T_{30\%}$ due to the measuring instrumentation, the layout of the measurement setup and the surge generator itself. It is determined experimentally. This is a type A evaluation based on the formula of the experimental standard deviation $s(q_k)$ of a sample of n repeated measurements q_j and given by

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

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

NOTE   For the short-circuit current, the budget can be similarly obtained. In that case T_{MS} includes the bandwidth of the current probe in place of the voltage probe. Further the functional relationship is modified as follows:

$$T_{fV} = 1{,}25\sqrt{\left(T_{90\%} - T_{10\%} + \delta R\right)^2 - T_{MS}^2}$$

F.4.3   Peak of the surge open-circuit voltage

The measurand is the peak of the surge open-circuit voltage calculated by using the functional relationship

$$V_p = \frac{V_{PR}\left(1 + \delta R + \delta V\right)}{1 - \left(\dfrac{\beta}{B}\right)^2} A$$

where

V_{PR}	voltage peak reading
A	d.c. attenuation of the voltage probe
δR	correction for non-repeatability
δV	d.c. vertical accuracy of the scope
B	−3 dB bandwidth of the measuring system
β	coefficient whose value is (12,7 ± 1,4) kHz

Table F.2 – Example of uncertainty budget for surge open-circuit voltage peak value (V_P)

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
V_{PR}	3,84	V	0,007 5	V	triangular	2,45	0,0031	1001	1	3,06	V
A	1 000	1	50	1	rectangular	1,73	28,9	3,84	V	111	V
δR	0	1	0,03	1	normal (k = 1)	1,00	0,03	3,84 x 10^3	V	115	V
δV	0	1	0,02	1	rectangular	1,73	0,012	3,84 x 10^3	V	44,4	V
B	12,7	kHz	1,4	kHz	rectangular	1,73	0,81	0,38	V/kHz	0,32	V
B	500	kHz	50	kHz	rectangular	1,73	28,9	-0,009 6	V/kHz	0,29	V
							$u_c(y) = \sqrt{\Sigma u_i(y)^2}$			0,166	kV
							$U(y) = 2\, u_c(y)$			0,33	kV
							y			3,84	kV
							Expressed in % of 3,84 kV			8,6	%

[a]   Probability density function.

V_{PR}: is the voltage peak reading. The error bound is obtained assuming that the scope has an 8-bit vertical resolution with interpolation capability (triangular probability density function).

A: is the d.c. attenuation of the voltage probe. An estimated value of 1 000 and an error bound of 5 % (rectangular probability density function) are assumed.

δR: quantifies the non-repeatability of the measurement setup, layout and instrumentation. It is a type A evaluation quantified by the experimental standard deviation of a sample of repeated measurements of the peak voltage. It is expressed in relative terms and an estimate of 0 % and an error bound of 3 % (1 standard deviation) are assumed.

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

β: is a coefficient which depends on the shape of both the impulse response of the measuring system and the standard impulse waveform in the neighborhood of the peak (see F.4.7). The interval (12,7 ± 1,4) kHz is representative of a wide class of systems, each having a different shape of the impulse response.

B: see F.4.2., same meaning and same values both for the estimate and error bound.

NOTE   For the short-circuit current, the budget can be treated similarly. In that case B includes the bandwidth of the current probe in place of the voltage probe. Further the parameter β is modified according to Table F.5 in F.4.7.

F.4.4   Duration of the surge open-circuit voltage

The measurand is the duration of the surge open-circuit voltage calculated by using the functional relationship

$$T_W = \left(T_{50\%,F} - T_{50\%,R} + \delta R\right)\cdot\left[1-\left(\frac{\beta}{B}\right)^2\right]$$

where

$T_{50\%,R}$ time at 50 % of peak amplitude at the rising edge of the surge

$T_{50\%,F}$ time at 50 % of peak amplitude at the falling edge of the surge

δR correction for non-repeatability

B − 3 dB bandwidth of the measuring system

β coefficient which value is (12,7 ± 1,4) kHz

Table F.3 – Example of uncertainty budget for surge open-circuit voltage duration (T_d)

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
$T_{50\%,R}$	0,5	μs	0,005 0	μs	triangular	2,45	0,002 0	-1,00	μs	0,002 0	μs
$T_{50\%,F}$	51,2	μs	0,005 0	μs	triangular	2,45	0,002 0	1,00	μs	0,002 0	μs
δR	0	μs	0,15	μs	normal (k=1)	1,00	0,15	1,00	μs	0,15	μs
β	12,7	kHz	1,4	kHz	rectangular	1,73	0,81	-0,005 2	μs/kHz	0,004 2	μs
B	500	kHz	50	kHz	rectangular	1,73	28,9	0,000 13	μs/kHz	0,003 8	μs
							$U_c(y) = \sqrt{\Sigma u_i(y)^2}$			0,15	μs
							$U(y) = 2\,u_c(y)$			0,3	μs
							Y			50,7	μs

[a]   Probability density function.

$T_{50\%,R}$, $T_{50\%,F}$: is the time reading at 50 % of the peak amplitude on the rising or falling edge of the surge open-circuit voltage. The error bound is obtained assuming a sampling frequency of 100 MS/s (the same as in F.4.2) and a trace interpolation capability of the scope (triangular probability density function). Would this not be the case, a rectangular probability density function should be assumed. Only the contributor to MU due to sampling rate is considered here. For additional contributors see F.4.5. The readings are assumed to be $T_{50\%,R}$ = 0,5 μs and $T_{50\%,F}$ = 51,2 μs.

δR: quantifies the non-repeatability of the $T_{50\%,F} - T_{50\%,R}$ time difference measurement due to the measuring instrumentation, the layout of the measurement setup and the surge generator itself. It is determined experimentally. This is a type A evaluation quantified by the experimental standard deviation of a sample of repeated measurements. An error bound $s(q_k)$ = 150 ns (1 standard deviation of a normal probability density function) and an estimate of 0 ns are assumed.

β: see F.4.3, same meaning and same values both for the estimate and error bound.

B: see F.4.2, same meaning and same values both for the estimate and error bound.

NOTE For the time duration T_d of the short-circuit current, the budget can be treated similarly. In that case B includes the bandwidth of the current probe, in place of the voltage probe. Further the parameter β is modified according to Table F.5 in F.4.7 and the functional relationship is

$$T_d = 1{,}18 \cdot \left(T_{50\%,F} - T_{50\%,R} + \delta R\right) \cdot \left[1 - \left(\frac{\beta}{B}\right)^2\right]$$

F.4.5   Further MU contributions to time and amplitude measurements

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

Vertical resolution: the contribution depends on the vertical amplitude resolution ΔA and on the slope of the trace dA/dt. The uncertainty is related to the half width of the resolution and is $(\Delta A/2)/(dA/dt)$. If trace interpolation is performed (see the oscilloscope manual) a triangular probability density function is used, otherwise a rectangular probability density function is used. This contribution may not be negligible, when $|dA/dt| < (\Delta A/T_i)$, where T_i is the sampling interval of the scope.

DC offset: The DC offset of the scope contributes to the voltage peak measurement uncertainty, if the peak is measured from the nominal DC zero line of the scope. This contribution can be ignored, if the readout software of the scope measures the peak from the impulse base line.

F.4.6   Rise time distortion due to the limited bandwidth of the measuring system

The distortion of the rise time is evaluated through the usual rule of combination of the rise times, which is valid when two non-interacting systems are cascaded and their step responses monotonically increase (see Elmore), i.e.

$$T_{rd} = \sqrt{T_r^2 + T_{MS}^2} \tag{F.2}$$

where T_{rd} is the rise time of the signal at the output of the measuring system (distorted rise time), T_r is the rise time of the signal at the input of the measuring system, and T_{MS} is the rise time of the step response of the measuring system. It is important to observe that the derivation of Equation (F.2) is based on the following definition of the rise time (see Elmore)

$$T_{MS} = \sqrt{2\pi \int_0^\infty (t - T_s)^2 h_0(t)\,dt} \tag{F.3}$$

where $h_0(t)$ is the impulse response of the measuring system having a normalized area, i.e. $\int_0^\infty h_0(t)\,dt = 1$, and T_s is the delay time given by

$$T_s = \int_0^\infty t h_0(t)\,dt \tag{F.4}$$

Equation (F.3) is much easier to handle, from the mathematical point of view, than the usual one based on the 10 % and 90 % threshold levels. Nonetheless, in the technical applications, the 10 % to 90 % rise times are usually combined through Equation (F.2). Given the

bandwidth of the system the two definitions lead to comparable rise times. Indeed, if we define

$$\alpha = T_{MS} \cdot B \tag{F.5}$$

We find that the α values derived from the two definitions of rise time do not differ very much. The values of α, corresponding to different shapes of the impulse response $h(t)$, are given in Table F.4. It is evident from Table F.4 that it is not possible to identify a unique value of α since α depends both on the adopted definition of the rise time (e.g. based on thresholds or on equation (F.3)) and on the shape of the impulse response of the measuring system. A reasonable estimate of α can be obtained as the arithmetic mean between the minimum (321×10^{-3}) and maximum (399×10^{-3}) values that appear in Table 1, that is 360×10^{-3}. Further, it can be assumed that, if no information is available about the measuring system apart from its bandwidth, any value of α between 321×10^{-3} and 399×10^{-3} is equally probable. Differently stated, α is assumed to be a random variable having a rectangular probability density function with lower and upper bounds 321×10^{-3} and 399×10^{-3}, respectively. The standard uncertainty of α quantifies both: a) the indifference to the mathematical model adopted for the definition of the rise time, and b) the indifference to the shape of the impulse response of the system.

Table F.4 – α factor, Equation (F.5), of different unidirectional impulse responses corresponding to the same bandwidth of the system B

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

F.4.7 Impulse peak and width distortion due to the limited bandwidth of the measuring system

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

$$V_{out}(t) = \int_0^t V_{in}(\tau) \cdot h(t-\tau) d\tau \tag{F.6}$$

where $V_{in}(t)$ is the input impulse waveform and $h(t)$ is the impulse response of the measuring system. Note that $A \cdot h(t) = h_0(t)$, where A is the d.c. attenuation of the measuring system. The input waveform can be approximated by its Taylor series expansion about the time instant t_p when the input reaches its peak value V_p.

$$V_{in}(t) = V_p + \frac{V_{in}''(t_p)}{2} \cdot (t-t_p)^2 + \frac{V_{in}'''(t_p)}{6} \cdot (t-t_p)^3 + ... \tag{F.7}$$

Note that the first order term is missing from Equation (F.7) since $V'(t_p) = 0$. Further $V_{in}''(t_p) < 0$, because the concavity points downwards (maximum), and $V_{in}'''(t_p) > 0$, because – for the standard waveforms of interest here – the rise time is lower than the fall time. Substituting Equation (F.7) into Equation (F.6) and after simplifications, valid when the bandwidth of the measuring system is large with respect to the bandwidth of the input signal (so that the power series terms whose order is greater than two are negligible), we obtain

$$V_{pd} = \frac{V_p}{A}\left[1 - \left(\frac{\beta}{B}\right)^2\right] \qquad (F.8)$$

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

$$\beta = \alpha \cdot \sqrt{\frac{\left|V_{in}''(t_p)\right|}{4\pi V_p}} \qquad (F.9)$$

Note that the parameter β depends on the second derivative of the standard input waveform and on the parameter α defined and derived in F.4.6. Since the mathematical expression for the standard surge waveforms are given in Annex F of this standard, the value of β can be numerically calculated and is reported in Table F.5.

The estimate of the distortion of the input impulse width T_w is simply obtained considering that the area of the output impulse is that of the input impulse divided by the d.c. attenuation A. Therefore

$$V_p T_W = A V_{pd} T_{wd} \qquad (F.10)$$

where T_{wd} is the output impulse width. Hence

$$T_{wd} = \frac{V_p}{A V_{pd}} \cdot T_W = \frac{1}{1 - \left(\frac{\beta}{B}\right)^2} \cdot T_W \qquad (F.11)$$

Table F.5 – β factor, Equation (F.9), of the standard surge waveforms

kHz	1,2/50 µs	8/20 µs	10/700 µs	5/320 µs
β	12,7 ± 1,4	14,8 ± 1,6	1,05 ± 0,11	2,00 ± 0,22

F.5 Application of uncertainties in the surge generator compliance criterion

Generally, in order to be confident that the generator is within its specifications, the calibration results should be within the specified limits of this standard (tolerances are not reduced by MU). Further guidance is given in Clause 6 of IEC/TR 61000-1-6:2012.

Annex G
(informative)

Method of calibration of impulse measuring systems

G.1   General

The calibration of the generator requires the use of a measurement system that, unfortunately, introduces a distortion of the measured impulse waveform. The distortion is a function of the applied impulse and of the used measuring system characteristics.

An estimate of the response of the measurement system to the standardized impulse can be obtained from the convolution integral (IEEE Std 4-1995 and IEC 60060-2). The method requires the acquisition of the experimental step response of the measurement system and then, through numerical computation, the distortion induced to the theoretical impulse waveform by the measurement system is evaluated. This allows one to estimate the effect of the measuring system response on the parameters of the impulse, i.e. rise time, peak value and duration. The detected systematic errors can be used to correct the calibration results, allowing an increase in accuracy of the calibration.

G.2   Estimation of measuring system response using the convolution integral

Theoretically, the transfer function of the measuring system used for calibration (transducer plus oscilloscope) can be determined by applying the Dirac ideal impulse to the input of the system. The availability of the transfer function allows one to estimate the distortion induced by the measuring system. Let $V_{in}(t)$ be the impulse applied at the input of the measuring system. The impulse at the output, $V_{out}(t)$, is calculated by using the convolution integral:

$$V_{out}(t) = \int_0^t V_{in}(\tau) \cdot h_0(t-\tau) d\tau \tag{G.1}$$

where $h_0(t)$ is the normalized impulse response of the measuring system, i.e. $\int_0^\infty h_0(t)dt = 1$.

Since it is more practical to measure the step response than the impulse response of the measuring system, the experimental normalized step response $g(t)$ is used in place of $h_0(t)$ and Equation G.1 is modified as follows:

$$V_{out}(t) = \frac{d}{dt}\int_0^t V_{in}(\tau) \cdot g(t-\tau) d\tau \tag{G.2}$$

where $g(t) = \int_0^t h_0(\tau)d\tau$. For the determination of $g(t)$, the measuring system is subjected to a voltage/current step and its output is measured. The rise time of the applied step should be less than 1/10 of the front/rise time of the impulse (see Table 2) since the unavoidable non-ideality of the stepped source propagates to $V_{out}(t)$, and therefore it appears as a non-ideality of the measurement system used. Moreover, due to the transducer attenuation, the step amplitude should be high enough to ensure, at the oscilloscope input, a signal with sufficient dynamics for good accuracy.

Annex E gives a mathematical model of the surge standard waveforms generated by the 1,2/50 μs and 10/700 μs combination wave generators. Such mathematical waveforms can be adopted as the input $V_{in}(t)$. The corresponding distorted output $V_{out}(t)$ is calculated through Equation (G.2). By comparison between $V_{in}(t)$ and $V_{out}(t)$ the systematic error produced by the measuring system on the parameters of the standard waveform (rise time, peak value and duration) is easily detected.

The calibration method involves the use of a transducer (voltage/current divider) and an oscilloscope. Both the transducer and the oscilloscope shall have sufficient bandwidth and voltage/current capability to handle the open-circuit voltage/short-circuit current waveform. For the oscilloscope, a bandwidth of at least 10 MHz and a sampling frequency of 100 MS/s are required.

G.3   Impulse measuring system for open-circuit voltage (1,2/50 μs, 10/700 μs)

A voltage step signal is applied at the input of the voltage divider and the step response is recorded by using a digital storage oscilloscope. The voltage step generator should meet the requirements in G.1. The recorded step response is then normalized so that the steady-state level becomes unity. The measuring system (voltage divider plus oscilloscope) response $U_{out}(t)$ to the standardized open-circuit voltage can be calculated as

$$U_{out}(t) = \frac{d}{dt}\int_{0}^{t} U_{in}(\tau) \cdot g_u(t - \tau)d\tau \qquad (G.3)$$

where

 $g_u(t)$ is the normalized experimental step response of the voltage measurement system

   $U_{in}(t)$ is the standardized open-circuit voltage waveform

The systematic error introduced by the measuring system is evaluated by comparing $U_{in}(t)$ with $U_{out}(t)$. The surge calibration result is then corrected for the systematic error.

The scaling factor of the voltage divider shall be evaluated at d.c. for the purpose of open-circuit voltage calibration. In order to reduce measurement uncertainty, the same oscilloscope should be used both for recording the step response of the measuring system and for the calibration of the surge generator. Since the voltage amplitude of the step is usually much lower than the voltage amplitude of the surge impulse, then a change of the vertical scale of the oscilloscope (volt per division) is likely to be needed when performing the two measurements. The uncertainty contribution due to the oscilloscope vertical scale switching is negligible if a modern digital storage oscilloscope is used. However, the traceable calibration of the vertical scale of the oscilloscope is recommended, so that vertical scale inaccuracy can be evaluated according to the chosen volt-per-division setting.

G.4   Impulse measuring system for short-circuit current (8/20 μs, 5/320 μs)

A current step signal is applied at the input of the current divider and the step response is recorded by using a digital storage oscilloscope. A simplified circuit diagram of a suitable current step generator is given in Figure G.1. The current step generator should meet the requirements in G.1.
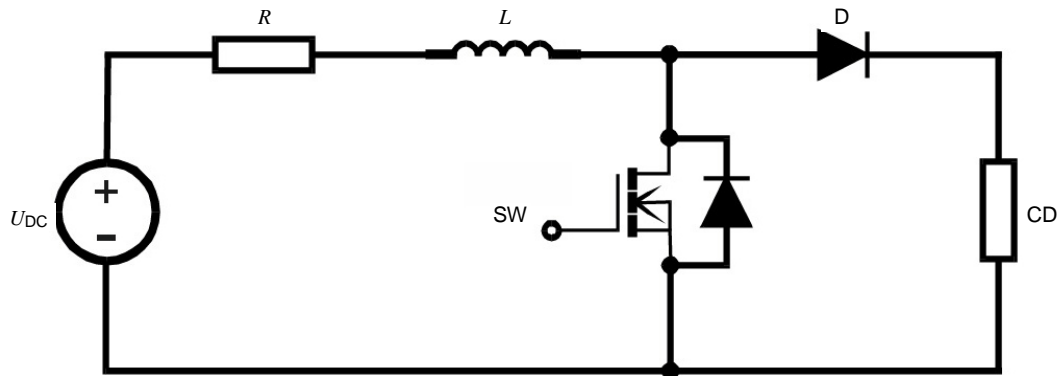
U_{DC} stabilized, adjustable d.c. voltage source

R current limiting resistor

L energy storage inductor

SW fast power switch

D fast power diode

CD current divider

Figure G.1 – Simplified circuit diagram of the current step generator

The recorded step response is then normalized so that the steady-state level becomes unity. The measuring system (current divider plus oscilloscope) response $I_{out}(t)$ to the standardized short-circuit current can be calculated as:

$$I_{out}(t) = \frac{d}{dt} \int_0^t I_{in}(\tau) \cdot g_i(t - \tau) d\tau \tag{G.4}$$

where

$g_i(t)$ is the normalized experimental step response of the current measurement system

$I_{in}(\tau)$ is the standardized short-circuit current waveform

The systematic error introduced by the measuring system is evaluated by comparing $I_{in}(\tau)$ with $I_{out}(t)$. The surge calibration result is then corrected for the systematic error.

A calibrated current shunt or current transformer should be used for the purpose of short-circuit current calibration. In order to reduce measurement uncertainty the same oscilloscope may be used both for recording the step response of the measuring system and for the calibration of the surge generator. Since the voltage amplitude of the step is usually much lower than the voltage amplitude of the surge impulse then a change of the vertical scale of the oscilloscope (volt per division) is likely to be needed when performing the two measurements. The uncertainty contribution due to the oscilloscope vertical scale switching is negligible if a modern digital storage oscilloscope is used. However, the traceable calibration of the vertical scale of the oscilloscope is recommended so that vertical scale inaccuracy can be evaluated according to the chosen volt-per-division setting.

Annex H
(informative)

Coupling/decoupling surges to lines rated above 200 A

H.1   General

As high current EUTs have low impedances which might load the surge generator so that most of the surge energy gets absorbed in the surge generator output impedance, an initial assessment might be carried out in order to determine:

- if the surge test makes sense,
- if sub-assemblies can be tested individually,
- whether the EUT can be tested in a mode consuming lower current (see 6.3).

Usually high current EUTs are tested in-situ.

Consideration of the action of built-in SPDs should be made. The SPDs have a good performance when the applied surge is high enough to make them operate. SPDs generally absorb most of the surge. If the surge voltage is lower than the SPD firing threshold, the full surge flows into the EUT.

H.2   Considerations of coupling and decoupling

To test high current EUTs for which no commercial CDNs are available, the following setup can be used:

- The coupling network as shown in Figures 7 and 8 shall be used.
- The decoupling network may consist of single chokes or a long enough supply cable to provide sufficient inductance, assuming that a straight 1 m length of wire represents about 1 μH. The recommended inductance values are given in Table H.1. A single choke or wire should be used per line in order to ensure proper differential mode decoupling.

Decoupling elements like capacitors or MOVs or combinations of both may not be necessary in the decoupling network.

Table H.1 – Recommended inductance values for decoupling lines (> 200 A)

EUT rated current	Recommended decoupling inductance
200 A < current rating ≤ 400 A	200 μH to 100 μH
400 A < current rating ≤ 800 A	100 μH to 50 μH
800 A < current rating ≤ 1 600 A	50 μH to 25 μH
I [Ampere] < current rating ≤ 2 × I	Inductance reduces by a factor of 2

H.3   Additional precautions

When testing on 3-phase power systems, where the EUT has a rated voltage of more than 415 V per phase, the supply voltage may damage the surge generator.

The coupling components shall have at least the same voltage rating as the EUT.

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