

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Electromagnetic compatibility (EMC) –
Part 4-18: Testing and measurement techniques – Damped oscillatory wave
immunity test**

**Compatibilité électromagnétique (CEM) –
Partie 4-18: Techniques d'essai et de mesure – Essai d'immunité à l'onde
oscillatoire amortie**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –**Part 4-18: Testing and measurement techniques –
Damped oscillatory wave immunity test**

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International Standard IEC 61000-4-18 has been prepared by subcommittee 77B: High frequency phenomena, of IEC Technical Committee 77: Electromagnetic compatibility.

It forms Part 4-18 of the IEC 61000 series. It has the status of a basic EMC publication in accordance with IEC Guide 107.

This second edition cancels and replaces the first edition published in 2006 and its Amendment 1:2010. This edition constitutes a technical revision.

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

- a) addition of a mathematical modelling of damped oscillatory wave waveform;
- b) new Annex B on measurement uncertainty;
- c) addition high speed CDN;

- d) addition of calibration procedures for CDNs;
- e) addition of the use of the capacitive coupling clamp on interconnection lines for fast damped oscillatory waves;
- f) addition of a test procedure for DC/DC converters in case the CDN does not work;
- g) new Annex C on issues relating to powering EUTs having DC/DC converters at the input.

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

FDIS	Report on voting
77B/797/FDIS	77B/799/RVD

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

This document 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 document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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INTRODUCTION

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

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

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

Part 4: Testing and measurement techniques

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 damped oscillatory waves.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-18: Testing and measurement techniques – Damped oscillatory wave immunity test

1 Scope

This part of IEC 61000 focuses on the immunity requirements and test methods for electrical and electronic equipment, under operational conditions, with regard to:

- a) repetitive slow damped oscillatory waves occurring mainly in power, control and signal cables installed in high voltage and medium voltage (HV/MV) substations;
- b) repetitive fast damped oscillatory waves occurring mainly in power, control and signal cables installed in gas insulated substations (GIS) and in some cases also air insulated substations (AIS) or in any installation due to high-altitude electromagnetic pulse (HEMP) phenomena.

The object of this document is to establish a common and reproducible reference for evaluating the immunity of electrical and electronic equipment when subjected to damped oscillatory waves on supply, signal, control and earth ports. 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. ¹

The document defines:

- test voltage and current waveforms;
- ranges of test levels;
- test equipment;
- calibration and verification procedures of test equipment;
- test setups;
- test procedure.

2 Normative references

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

IEC 60050-161, *International Electrotechnical Vocabulary (IEV) – Part 161: Electromagnetic compatibility* (available at www.electropedia.org)

¹ TC 77 and its sub-committees are prepared to co-operate with product committees in the evaluation of the value of particular immunity tests for their products.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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

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

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

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

3.1.1

air insulated substation

AIS

substation which is made up with only air insulated switchgear

Note 1 to entry: This note applies to the French language only.

3.1.2

auxiliary equipment

AE

equipment necessary to provide the equipment under test (EUT) with the signals required for normal operation and to verify the performance of the EUT

Note 1 to entry: This note applies to the French language only.

3.1.3

burst

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

[SOURCE: IEC 60050-161:1990, 161-02-07]

3.1.4

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]

3.1.5

capacitive coupling clamp

device of defined dimensions and characteristics for common mode coupling of the disturbance signal to the circuit under test without any galvanic connection to it

3.1.6

coupling

interaction between circuits, transferring energy from one circuit to another

3.1.7

coupling network

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

3.1.8

decoupling network

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

3.1.9

degradation (in performance)

undesired departure in the operational performance of any device, equipment or system from its intended performance

Note 1 to entry: The term "degradation" can apply to temporary or permanent failure.

[SOURCE: IEC 60050-161:1990, 161-01-19]

3.1.10

gas insulated substation

GIS

substation which is made up with only gas insulated metal enclosed switchgear

Note 1 to entry: This note applies to the French language only.

[SOURCE: IEC 60050-605:1983, 605-02-14, modified – "metal-enclosed" has been removed from the term.]

3.1.11

high-altitude electromagnetic pulse

HEMP

electromagnetic pulse produced by a nuclear explosion outside the earth's atmosphere

Note 1 to entry: Typically above an altitude of 30 km.

3.1.12

electromagnetic compatibility

EMC

ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[SOURCE: IEC 60050-161:2018, 161-01-07]

3.1.13

immunity (to a disturbance)

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

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

3.1.14

port

particular interface of the EUT with the external electromagnetic environment

3.1.15**reference ground plane****RGP**

flat conductive surface that is at the same electric potential as reference ground, which is used as a common reference, and which contributes to a reproducible parasitic capacitance with the surroundings of the equipment under test (EUT)

Note 1 to entry A reference ground plane is needed for the measurements of conducted disturbances, and serves as reference for the measurement of unsymmetrical and asymmetrical disturbance voltages.

Note 2 to entry In some regions, the term 'earth' is used in place of 'ground'.

Note 3 to entry: This note applies to the French language only.

[SOURCE: IEC 60050-161:1990, 161-04-36]

3.1.16**rise time**

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

[SOURCE: IEC 60050-161:1990, 161-02-05, modified – The note has been included in the definition]

3.1.17**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 with the time-scale of interest

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

3.1.18**verification**

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

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

Note 2 to entry: The procedure of 6.2.1.3 and 6.2.2.3 is meant as a guide to ensure the correct operation of the test generator and other items making up the test setup so that the intended waveform is delivered to the EUT.

3.2 Abbreviated terms

AE	auxiliary equipment
AIS	air insulated substation
CDN	coupling/decoupling network
EFT/B	electrical fast transient/burst
EMC	electromagnetic compatibility
EUT	equipment under test
FDOW	fast damped oscillatory wave
FDOWG	fast damped oscillatory wave generator
GDT	gas discharge tube
GIS	gas insulated substation
HEMP	high-altitude electromagnetic pulse
HV	high voltage
MU	measurement uncertainty

MV	medium voltage
PE	protective earth
PWM	pulse width modulation
RGP	reference ground plane
SDOW	slow damped oscillatory wave
SDOWG	slow damped oscillatory wave generator

4 General

4.1 Types of damped oscillatory waves

The damped oscillatory wave phenomena are divided into two parts. The first part is referred to as the slow damped oscillatory wave and includes oscillation frequencies between 100 kHz and 1 MHz. The second part is referred to as the fast damped oscillatory wave, and it includes oscillation frequencies above 1 MHz.

The formula of the ideal waveform of Figure 1, $w(t)$ (open circuit voltage or short circuit current), is as follows:

$$w(t) = A \cdot K \cdot \frac{\left(\frac{t}{t_1}\right)^n}{1 + \left(\frac{t}{t_1}\right)^n} \cdot \exp\left(-\frac{t}{t_2}\right) \cdot \cos(2\pi f \cdot t + \phi)$$

The values of the parameters of $w(t)$ for the open circuit voltage are given in Table 1 for each standard oscillation period $T = 1/f$.

Table 1 – Values of the parameters of $w(t)$ for each standard oscillation frequency

Waveform	A	K	n	t_1	f	t_2	ϕ
Fast 30 MHz	Pk_1	1,19	1,67	2,26 ns	30 MHz	126 ns	$-\pi/2$
Fast 10 MHz	Pk_1	1,04	2,65	1,69 ns	10 MHz	377 ns	$-\pi/4$
Fast 3 MHz	Pk_1	1,07	2,30	2,89 ns	3 MHz	1,26 μ s	0
Slow 1 MHz	Pk_1	1,12	2,45	49,8 ns	1 MHz	3,77 μ s	$-\pi/4$
Slow 100 kHz	Pk_1	1,04	1,96	32,7 ns	100 kHz	37,7 μ s	0

The causes of these two types of damped oscillatory waves are described below.

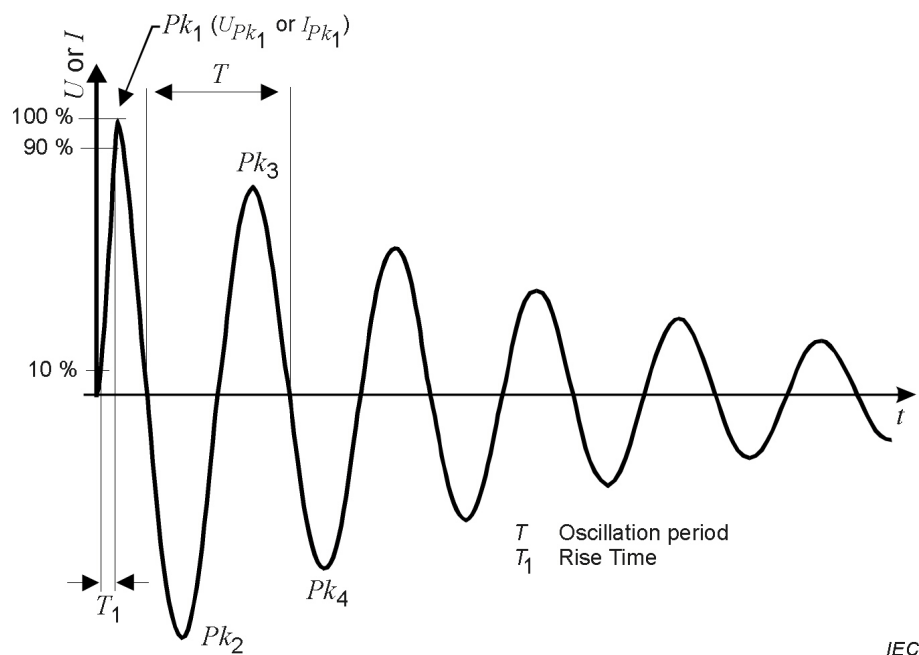


Figure 1 – Example of waveform of the damped oscillatory wave

4.2 Slow damped oscillatory wave phenomenon

This phenomenon is representative of the switching of disconnectors in HV/MV open-air substations, and is particularly related to the switching of HV busbars.

In substations, the opening and closing operations of HV disconnectors give rise to sharp front-wave transients, with rise times of the order of some tens of nanoseconds.

The voltage front-wave includes reflections due to the mismatch of the characteristic impedance of HV circuits involved. In this respect, the resulting transient voltage and current in HV busbars are characterized by a fundamental oscillation frequency that depends on the length of the circuit and on the propagation time.

The oscillation frequency ranges from about 100 kHz to a few megahertz for open-air substations, depending on the influence of the parameters mentioned above and the length of the busbars, which can vary from some tens of metres to hundreds of metres (400 m can occur).

In this respect, the oscillation frequency of 1 MHz can be considered representative of most situations, but 100 kHz has been considered appropriate for large HV substations.

The repetition frequency is variable between a few hertz and a few kilohertz depending on the distance between the switching contacts. For contacts in close proximity, the repetition frequency is at its maximum, while for contact distances close to allowing re-ignitions between the contacts, the repetition rate is at its minimum and is equivalent to twice the power frequency with respect to each phase (100/s per phase for 50 Hz grids and 120/s per phase for 60 Hz grids).

The repetition rates of 40/s and 400/s represent a compromise, taking into account the different durations of the phenomena, different frequencies considered and the energy to which the circuits under test are subjected.

Repetitive oscillatory transients can be generated by switching transients and the injection of impulsive currents in power systems (networks and electrical equipment).

4.3 Fast damped oscillatory wave phenomenon

4.3.1 General

The fast damped oscillatory wave immunity test should cover phenomena present in two specific environments:

- substations of the power network (produced by switchgear and controlgear);
- all installations exposed to high-altitude electromagnetic pulse (HEMP).

4.3.2 Disturbances produced by switchgear and controlgear

During opening or closing disconnecter operations, between both contacts of the operated device, a large number of restrikes take place due to the slow speed of the contacts. Therefore, disconnector switch operations generate very fast transients, which propagate as travelling waves in the busbars of the substation. The electrical length of conductors and busbars will determine the oscillation frequencies of the transient overvoltages.

For air insulated substations (AIS) these transients will radiate an electromagnetic field in the substation environment. Measurements have been performed in air insulated substations using instruments with a large frequency bandwidth [1]². These measurements have shown that transient phenomena with frequencies higher than 1 MHz can also take place in these substations.

For gas insulated substations (GIS), these transients propagate inside the metallic enclosure, which contains the SF₆ gas. Due to the skin effect, high frequency transients are confined inside the enclosure and cause no problems. Transient current is transferred to the external surface of the enclosure tube at any enclosure discontinuity. As a consequence, the enclosure potential rises and the current flowing on the enclosure surface radiates an electromagnetic field in the substation environment. The transient ground potential rise is a direct source of transient common mode currents in the secondary circuits. The radiated electromagnetic field also induces common mode currents in the secondary circuits.

Measurements have shown that the maximum frequency of significant components in the spectral density of these currents can be as high as 30 MHz to 50 MHz [2].

As summarized in [1], the oscillation frequency of transients occurring in HV substations has increased due to the reduction of the overall sizes of substations, the use of GIS and the installation of electronic equipment nearer to switching devices.

Therefore, the oscillation frequencies of 3 MHz, 10 MHz and 30 MHz for the fast damped oscillatory waves are suitable to represent the environment both in some AIS and in all GIS.

The repetition frequency varies between a few hertz and many kilohertz depending on the distance between the switching contacts. With close contacts, there will be a high repetition frequency, while as the distances increase as the contacts open further, the minimum repetition frequency, with respect to each phase, is twice the power frequency (100/s per phase for 50 Hz and 120/s per phase for 60 Hz HV systems).

The repetition rate of 5 000/s represents the higher repetition rates measured in GIS. This rate still represents a compromise, taking into account the different durations of the phenomena, the suitability of the different frequencies considered and the problem related to the energy to which the circuits under test are subjected.

² Numbers in square brackets refer to the Bibliography.

4.3.3 Disturbances produced by high-altitude electromagnetic pulse (HEMP)

HEMP as presented in IEC 61000-2-9 [4] describes an intense, plane wave electromagnetic pulsed field which has a rise time of 2,5 ns and a pulse width of approximately 25 ns. This field interacts with exposed transmission lines to produce an oscillating voltage and current which depends on the length of the line (see IEC 61000-2-10 [5]). Outdoor power and communication lines have sufficient length (longer than 1 km), so that the coupled currents and voltages are normally impulsive in nature.

For indoor power and communication lines the incident HEMP is partially attenuated. Even so, the field couples to short indoor cables, causing a threat to connected electronic equipment. The HEMP fields couple to these short lines and produce high-frequency damped oscillatory waveforms with frequencies up to 100 MHz. Frequencies below 30 MHz are the most commonly observed (see IEC 61000-2-10 [5]). The damping rate of the oscillatory wave is fast due to the presence of absorbing walls, and a resonance quality factor Q between 10 and 20 is typical.

Short outdoor wiring (for example control circuits in substations or power plants) will couple to HEMP fields. Damped oscillatory transients will be induced, which will have frequencies of 1 MHz to 100 MHz.

The HEMP event typically generates one or two pulses. A high repetition rate is not necessary to replicate the HEMP event. Due to reliability concerns with digital electronics, it is recommended that a repetition rate of 5 000/s similar to switchgear and controlgear generated disturbances be used. This will increase the probability of discovering any malfunction caused by the HEMP event.

This document also includes information on test levels, generator specification and test procedures that will enable tests to be carried out at voltages induced by HEMP. Many frequencies occur under realistic conditions, but tests are carried out with oscillation frequencies up to 30 MHz in line with the environment in substations.

5 Test levels

The preferred test levels for the damped oscillatory wave tests, applicable to power, signal and control ports of the equipment, are given in Table 2 and Table 3. The test level is related to the voltage of the first peak of the waveform (Pk_1 in Figure 1).

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

**Table 2 – Test levels for the slow damped oscillatory wave
(100 kHz or 1 MHz)**

Level	Open circuit test voltage	
	Line-to-line kV	Line-to-ground kV
1	0,25	0,5
2	0,5	1
3	1	2 ^a
4 ^b	---	---
X ^c	Special	Special
^a The value is increased to 2,5 kV for substation equipment. ^b This level is not applicable to slow damped oscillatory wave. ^c "X" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification.		

**Table 3 – Test levels for the fast damped oscillatory wave
(3 MHz, 10 MHz or 30 MHz)**

Level	Open circuit test voltage
	Line-to-ground kV
1	0,5
2	1
3	2
4	4
X ^a	Special
^a "X" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification.	

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

6 Test instrumentation

6.1 General

The generator output shall have the capability to operate under short circuit conditions.

The test generator produces a damped oscillatory wave with the following characteristics as it shall be applied to the EUT port. If applied via a coupling/decoupling network, the characteristics are specified at the output of that network.

The SDOWG output shall be floating. This condition is necessary to test the EUT control and signal ports in differential mode. A dual output generator is necessary. The FDOWG output has a single coaxial output. The test with this generator shall be made only in common mode.

6.2 Damped oscillatory wave generators

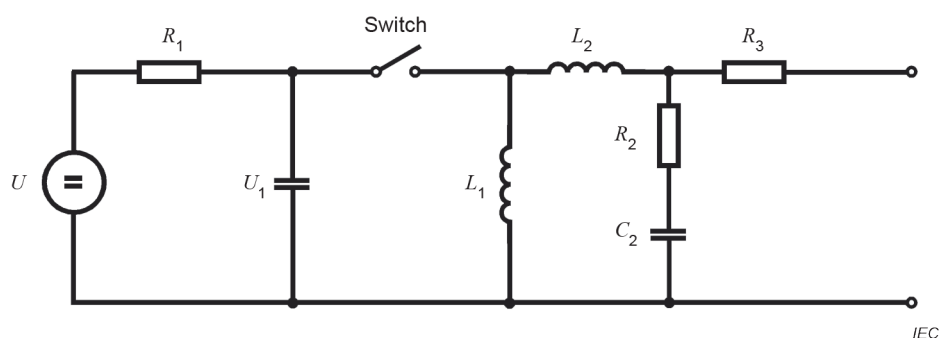
6.2.1 Slow damped oscillatory wave generator

6.2.1.1 General

The output impedance of the slow generator has been fixed at $200\ \Omega$ although the actual impedance of the cables (twisted pairs) is nearer to $150\ \Omega$. The reason for which the $200\ \Omega$ impedance has been selected is in order not to modify an existing general status that would involve the technical specifications of a family of equipment, with applications mainly in high voltage substations.

In addition, the cables in this category of electrical and industrial plants are mostly in the order of hundreds of meters in length, and therefore the impedance of the connections in the field is nearer the characteristic impedance of the cables, and not less than that value.

An example of a schematic circuit of the generator is given in Figure 2.



Key

U :	high voltage source	L_2 :	filter inductor
R_1 :	charging resistor	R_2 :	filter resistor
C_1 :	energy storage capacitor	C_2 :	filter capacitor
Switch:	high voltage switch	R_3 :	source resistor
L_1 :	oscillating circuit inductor		

Figure 2 – Example of schematic circuit of the generator for the slow damped oscillatory wave

6.2.1.2 Performance characteristics of the slow damped oscillatory wave generator

The specifications of the slow damped oscillatory wave generator are as follows:

- voltage rise time (T_1 in Figure 1): $75\text{ ns} \pm 20\%$;
- voltage oscillation frequencies (see Note 1): $(100\text{ kHz and } 1\text{ MHz}) \pm 10\%$;
- repetition rate: $40/\text{s}$ for $100\text{ kHz} \pm 10\%$ and $400/\text{s}$ for $1\text{ MHz} \pm 10\%$;
- voltage decaying (see Figure 1): Pk_5 shall be $> 50\%$ of the Pk_1 value and Pk_{10} shall be $< 50\%$ of the Pk_1 value; not less than 2 s ;
- burst duration:
- open circuit voltage (U_{Pk1} value, see Figure 1): $(250\text{ V to } 2,5\text{ kV}) \pm 10\%$;
- short circuit current (I_{Pk1} value): $(1,25\text{ A to } 12,5\text{ A}) \pm 20\%$;
- phase relationship with the power frequency: no requirement;
- polarity of the first half-period: positive and negative.

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

NOTE 2 The effective output impedance is the nominal open circuit voltage U_{Pk1} divided by the nominal short circuit current I_{Pk1} . The nominal value is 200 Ω .

Examples of the repetition rate and burst duration are shown in Figure 3.

The waveform of the slow damped oscillatory wave with peak points marked is given in Figure 1.

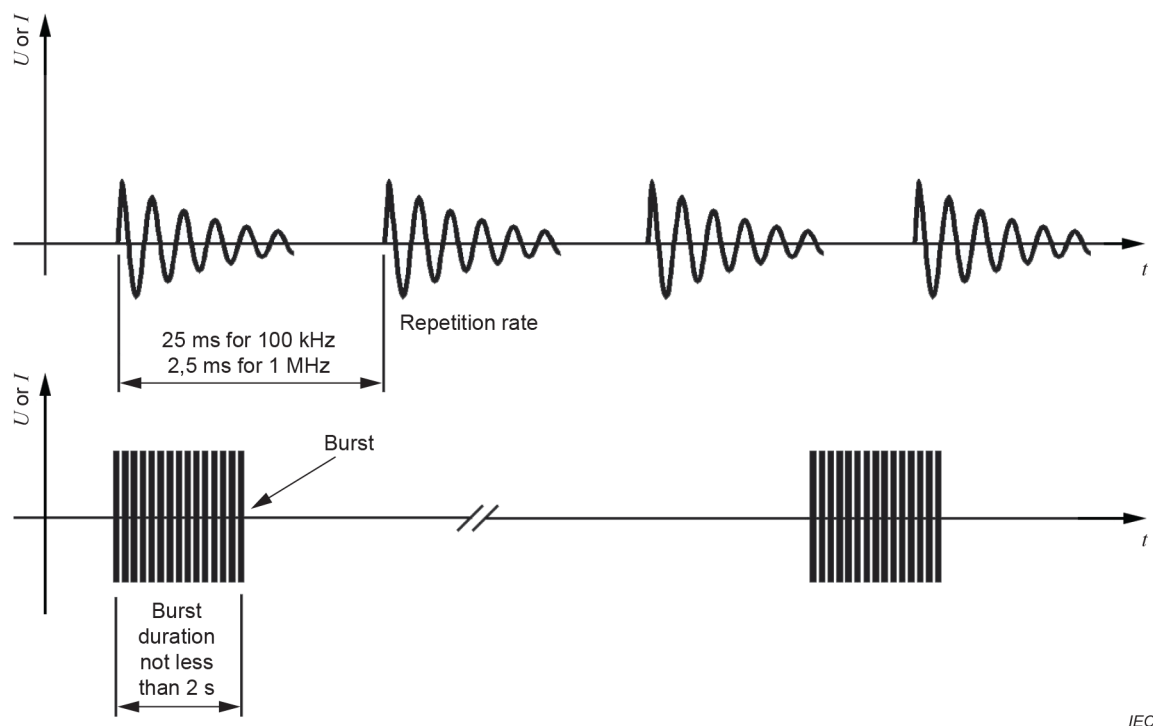


Figure 3 – Representation of a slow damped oscillatory wave

6.2.1.3 Calibration of the slow damped oscillatory wave generator

The test generator characteristics mentioned in 6.2.1.2 shall be calibrated in order to establish that they meet the requirements of this document. The following parameters are essential in order to compare different test generators:

- voltage rise time;
- oscillation frequency;
- repetition rate;
- decaying;
- burst duration;
- open circuit voltage U_{Pk1} (open circuit impedance: $Z_{oc} \geq 10 \text{ k}\Omega$);
- short circuit current I_{Pk1} (using a short circuit impedance: $Z_{sc} \leq 0,1 \Omega$).

The calibrations shall be carried out with voltage or current probes (as applicable) and with oscilloscopes or other equivalent measurement instrumentation with a minimum bandwidth of 40 MHz.

The waveform characteristics shall be verified directly at the output of the test generator with an open circuit impedance $\geq 10 \text{ k}\Omega$ and short circuit load impedances $\leq 0,1 \Omega$.

Calibrations shall be performed at those test levels which are applied to the EUT.

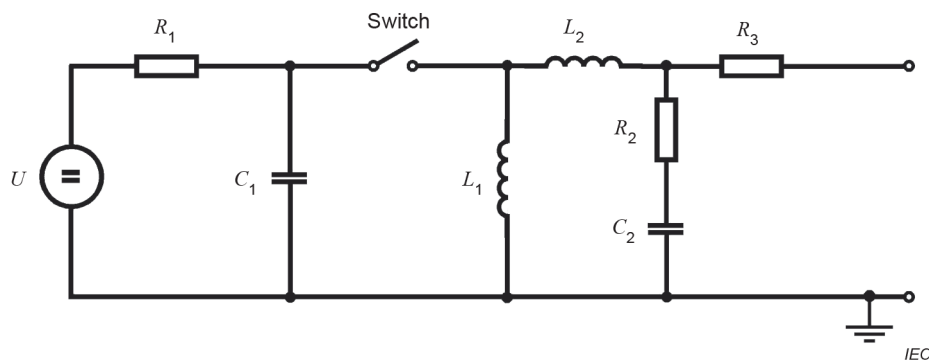
For measurement uncertainty see Annex B.

6.2.2 Fast damped oscillatory wave generator

6.2.2.1 General

The output impedance of the fast generator has been fixed at 50 Ω . The reason for which the 50 Ω impedance has been selected is to be consistent with the EFT/B generator as specified in IEC 61000-4-4 [15].

An example of a schematic circuit of the fast generator is given in Figure 4.



Key

U :	high voltage source	L_2 :	filter inductor
R_1 :	charging resistor	R_2 :	filter resistor
C_1 :	energy storage capacitor	C_2 :	filter capacitor
Switch:	high voltage switch	R_3 :	source resistor
L_1 :	oscillating circuit inductor		

Figure 4 – Example of schematic circuit of the test generator for the fast damped oscillatory wave

6.2.2.2 Performance characteristics of the fast damped oscillatory wave generator

The open circuit specifications of the fast damped oscillatory wave generator are as follows:

- voltage rise time (T_1 in Figure 1): 5 ns $\pm$ 30 %;
- voltage oscillation frequencies (see Note 1): (3 MHz, 10 MHz and 30 MHz) $\pm$ 10 %;
- repetition rate (see Figure 5): 5 000/s $\pm$ 10 %;
- decaying (see Figure 1): Pk_5 shall be > 50 % of the Pk_1 value and Pk_{10} shall be < 50 % of the Pk_1 value;
- burst duration (see Figure 5):
 3 MHz: 50 ms $\pm$ 20 %;
 10 MHz: 15 ms $\pm$ 20 %;
 30 MHz: 5 ms $\pm$ 20 %;
- burst period (see Figure 5): 300 ms $\pm$ 20 %;
- open circuit voltage (U_{Pk1} value, see Figure 1): (500 V to 4 kV) $\pm$ 10 %;
- phase relationship with the power frequency: no requirement;
- polarity of the first half-period: positive and negative.

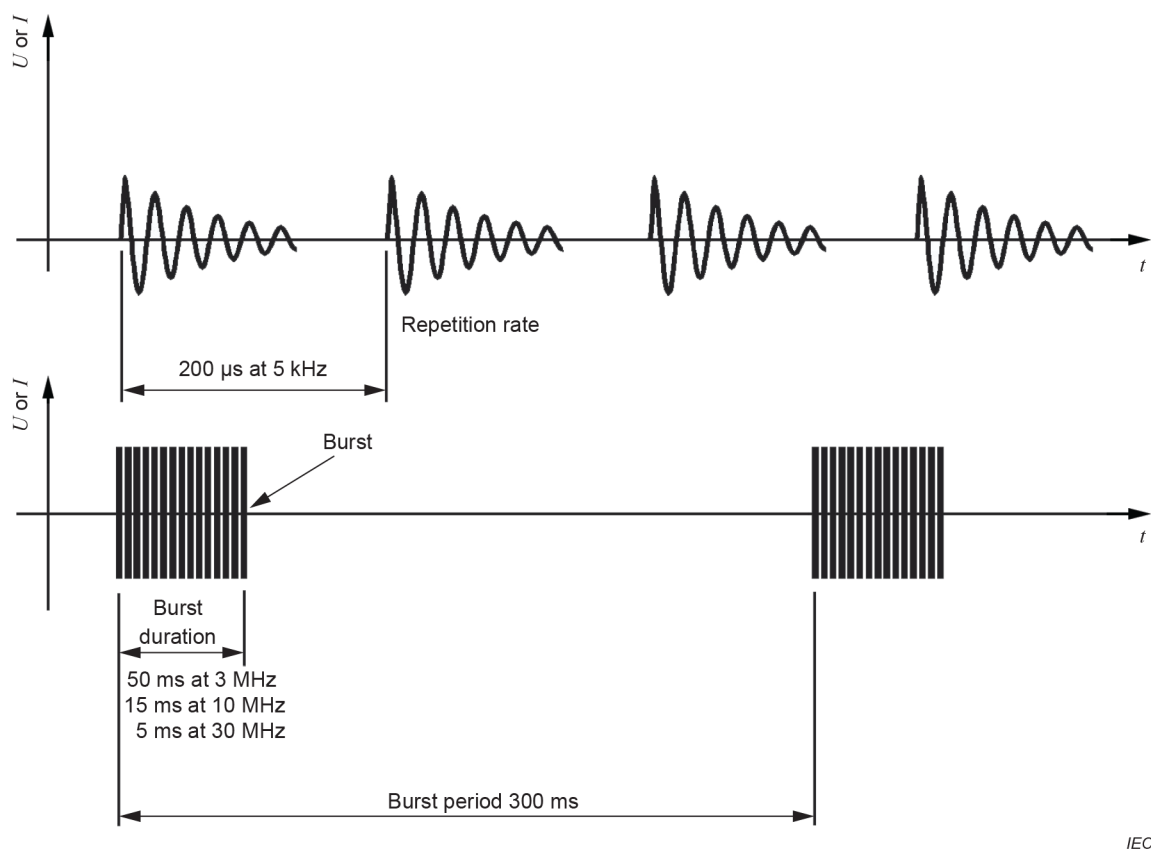
The short circuit specifications of the fast damped oscillatory wave generator are as follows:

- current rise time (T_1 in Figure 1):
 3 MHz: < 330 ns;
 10 MHz: < 100 ns;
 30 MHz: < 33 ns;
- current oscillation frequencies (Note 1): (3 MHz, 10 MHz and 30 MHz) $\pm$ 30 %;
- decaying (see Figure 1): Pk_5 shall be > 25 % of the Pk_1 value
 and Pk_{10} shall be < 25 % of the Pk_1 value;
- short circuit current (I_{Pk1} value): (10 A to 80 A) $\pm$ 20 %.

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

NOTE 2 The effective output impedance is the nominal open circuit voltage U_{Pk1} divided by the nominal short circuit current I_{Pk1} . The nominal value is 50 Ω .

The waveform of the fast damped oscillatory wave with peak points marked, is given in Figure 1.



IEC

Figure 5 – Representation of a fast damped oscillatory wave

6.2.2.3 Calibration of the fast damped oscillatory wave generator

The test generator characteristics mentioned in 6.2.2.2 shall be calibrated in order to establish that they meet the requirements of this document. The following parameters are essential in order to compare different test generators:

- rise time;
- oscillation frequency;
- repetition rate;

- voltage waveform decaying;
- burst duration;
- burst period;
- open circuit voltage U_{Pk1} (open circuit impedance: $Z_{oc} = 1 \text{ k}\Omega \pm 2 \%$);
- current rise time;
- current oscillation frequencies;
- current waveform decaying;
- short circuit current I_{Pk1} (short circuit impedance: $Z_{sc} = 0,10 \text{ }\Omega \pm 2\%$).

The calibrations shall be carried out with voltage or current probes (as applicable) and with oscilloscopes or other equivalent measurement instrumentation with a minimum bandwidth of 400 MHz.

The voltage probe used shall have the following characteristics:

- $1 \text{ k}\Omega \pm 2 \%$; this measurement is performed at DC.

The tolerance of the insertion loss of the test loads shall not exceed:

- $\pm 1 \text{ dB}$ up to 100 MHz;
- $\pm 3 \text{ dB}$ from 100 MHz up to 400 MHz.

The current probe used shall have the following characteristics:

- $0,1 \text{ }\Omega \pm 2 \%$; this measurement is performed at DC.

The tolerance of the insertion loss of the test loads shall not exceed:

- $\pm 3 \text{ dB}$ up to 400 MHz.

The waveform characteristics shall be verified directly at the output of the test generator with open circuit and short circuit load impedances.

The 30 MHz waveform may be distorted at the beginning between Pk_1 and Pk_3 . The following points shall be considered during the 30 MHz calibration:

- a) The Pk_1 amplitude should be higher than Pk_3 to clearly define the 100 % point for the rise time and the damping calculation.
- b) The Pk_2 amplitude may be higher than Pk_1 . In this case the Pk_1 is still relevant for the 100 % point.

Calibrations shall be performed at those test levels which are applied to the EUT.

For measurement uncertainty see Annex B.

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 given in 6.3.2 for slow and 6.3.3 for fast.

The CDN provides both the ability to apply the test voltage in either common (for both generators) or differential (only 100 kHz, 1 MHz) mode to the mains, signal and control ports of the EUT, and prevents the test voltage from affecting any auxiliary equipment needed to perform the test.

The 0,5 μF for the slow damped oscillatory wave or the 33 nF for the fast damped oscillatory wave coupling capacitors in the coupling networks shall give a coupling attenuation of less than 10 %.

The CDN shall have a dedicated earth terminal.

For I/O and communication lines, the series impedance of the decoupling network limits the available bandwidth for data transmission. The preferred coupling elements are capacitors. When coupling to interconnection lines, the waveform can be distorted by the coupling mechanisms described in 6.3.2.3.

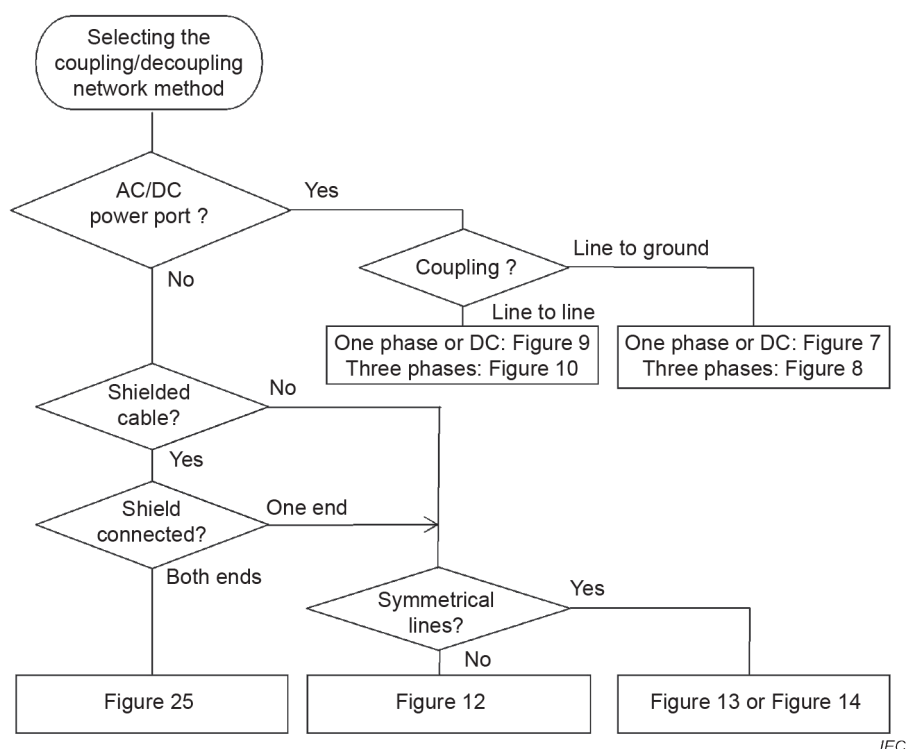
Each CDN shall satisfy the requirements of 6.3. and shall fulfil the calibration requirements in 6.4.

An RGP is used for a fast damped oscillatory wave setup. For a slow damped oscillatory wave setup, no RGP is necessary (an RGP is systematically required above 1 MHz).

6.3.2 Coupling/decoupling networks for slow damped oscillatory waves

6.3.2.1 Selection of coupling/decoupling networks

The use of CDNs is decided according to the following flowchart (see Figure 6):



IEC

Figure 6 – Selection of coupling/decoupling method for slow damped oscillatory waves

6.3.2.2 Coupling/decoupling networks for AC/DC power ports up to 32 A

For AC or DC power lines, the decoupling network provides a relatively high impedance to the slow damped oscillation 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 CDN. High voltage capacitors are used for coupling elements and rated to allow the complete waveform duration to be coupled to the EUT.

NOTE Currently, all equipment subject to this document have current ratings up to 32 A. Therefore CDNs with current ratings larger than 32 A have not been considered.

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.

Examples of CDNs for AC/DC power ports are shown in Figure 7 to Figure 10.

The residual damped oscillatory voltage (from Pk_1 to Pk_{10}) on the power supply inputs of the decoupling network when the EUT is disconnected shall not exceed 15 % of the applied test voltage or twice the rated peak voltage of the coupling/decoupling network, whichever is higher.

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

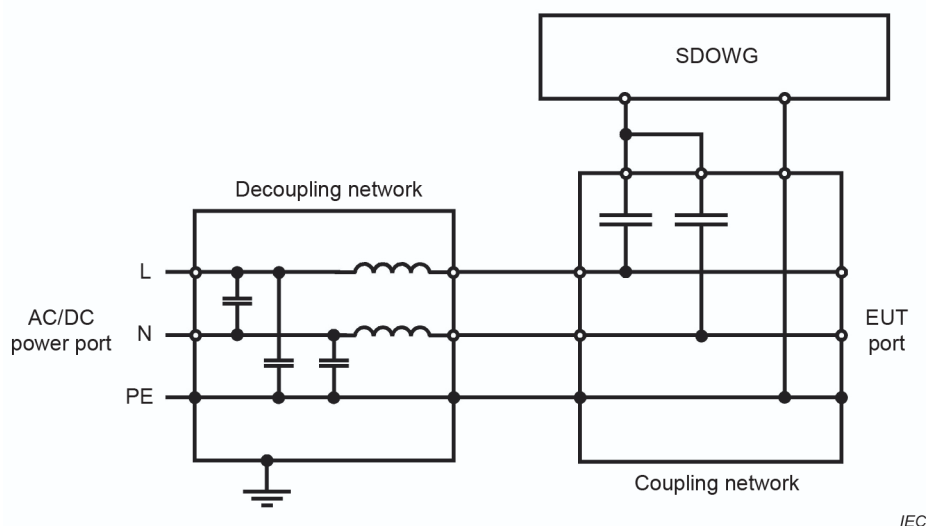


Figure 7 – Example of a CDN for capacitive coupling on AC/DC lines: line-to-ground coupling

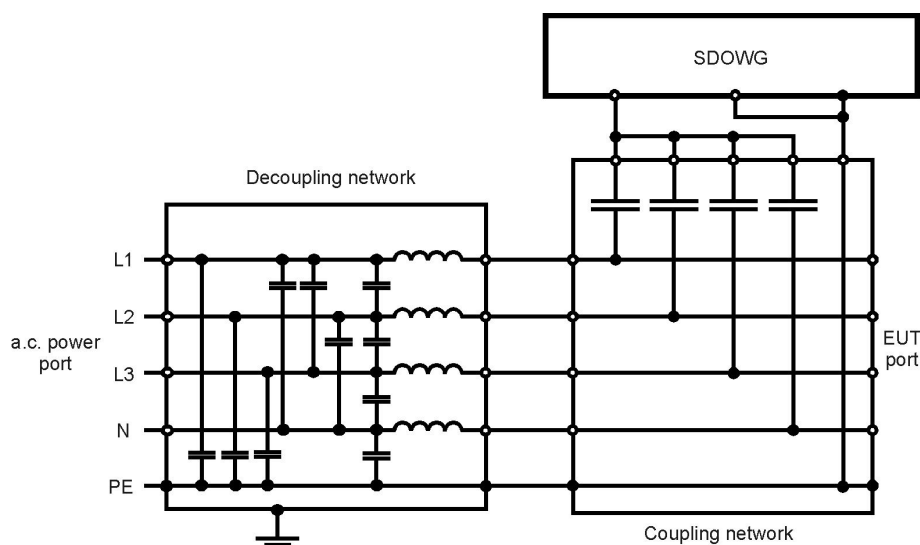


Figure 8 – Example of a CDN for capacitive coupling on AC lines (three phases): line-to-ground coupling

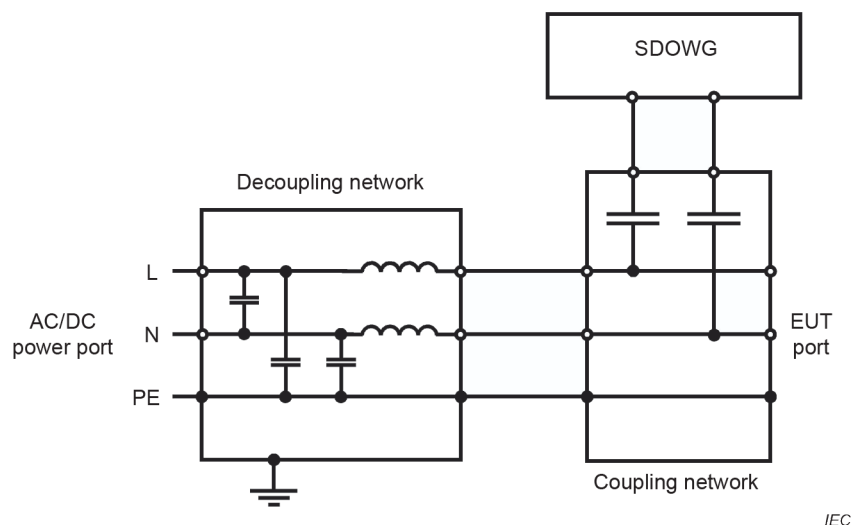


Figure 9 – Example of a CDN for capacitive coupling on AC/DC lines: line-to-line coupling

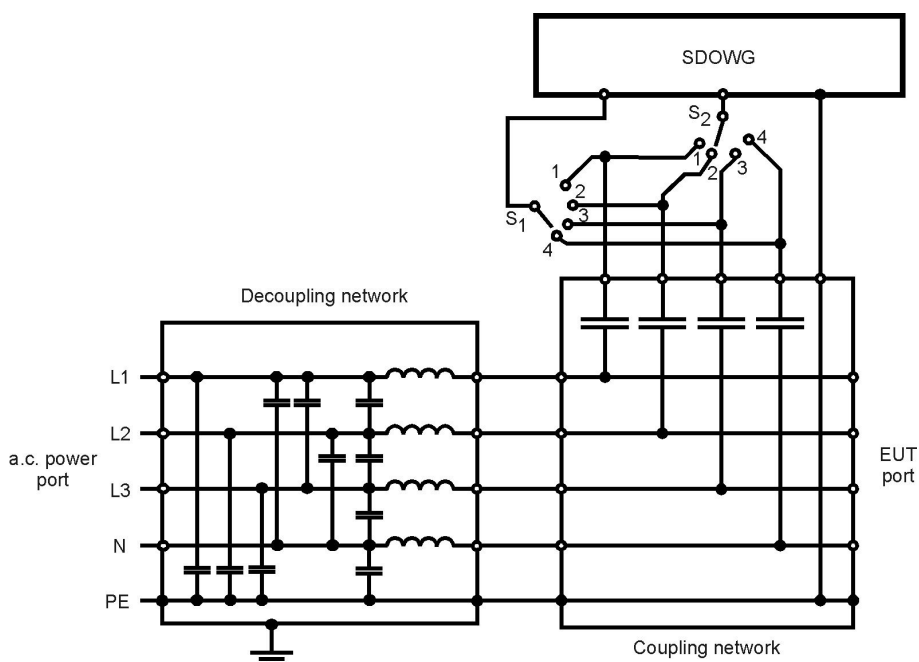


Figure 10 – Example of a CDN for capacitive coupling on AC lines (three phases): line L2-to-line N coupling

6.3.2.3 Coupling/decoupling networks for interconnection lines

6.3.2.3.1 General

The coupling method shall be selected based on the types or function of the interconnection cables, circuits and the operational conditions provided by the product specification. Figure 11 shows a typical CDN used for interconnection lines.

Coupling to unshielded lines requires 0,5 μF coupling capacitors that ensure sufficient insulation between the interconnection lines and the damped oscillatory generator but allow efficient transfer of the damped oscillatory wave.

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

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, gas discharge tubes (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.

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

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

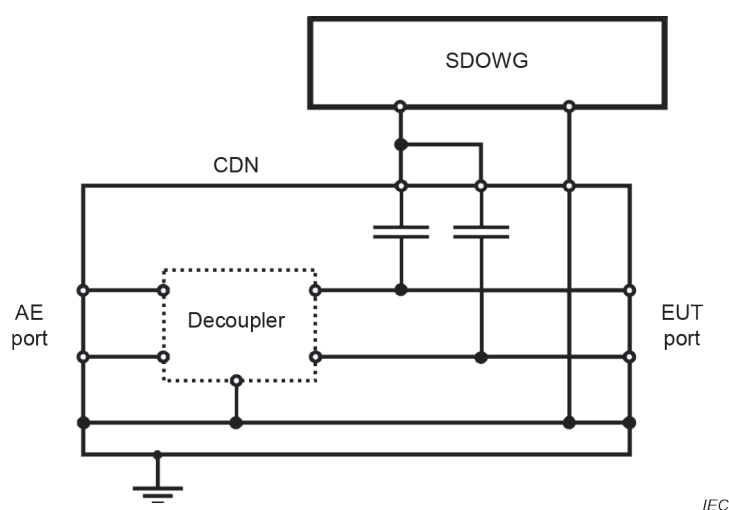


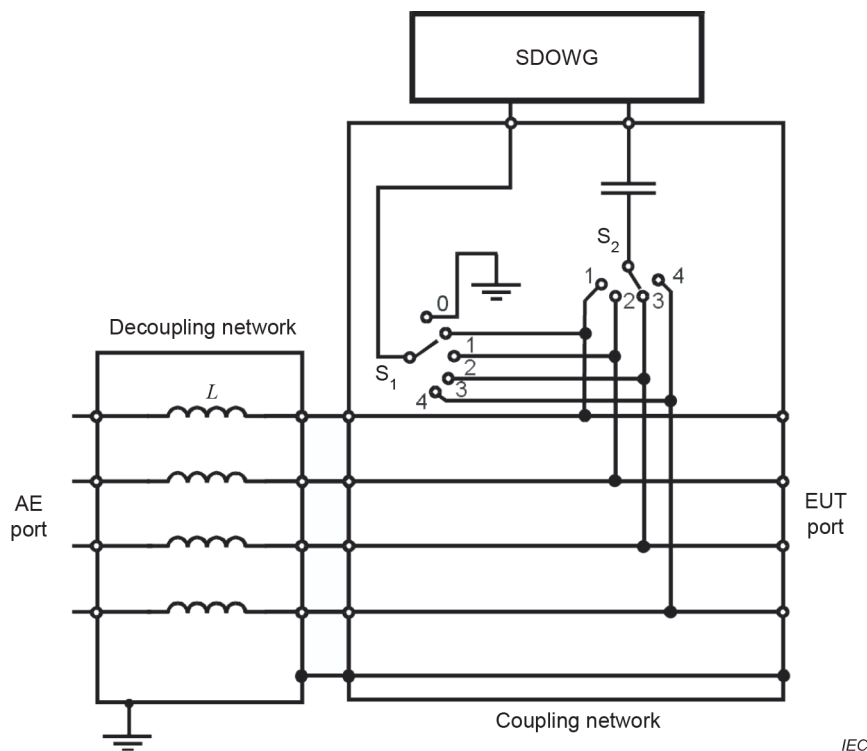
Figure 11 – Example of a CDN for interconnection lines: line-to-ground coupling

The decoupling section of the CDN consists generally of inductors greater than 1,5 mH.

6.3.2.3.2 Coupling/decoupling networks for unshielded, unsymmetrical interconnection lines

Coupling to unshielded unsymmetrical interconnection lines includes both line-to-line and line-to-ground coupling. The decoupling is provided with one decoupling choke per line.

An example of a CDN for unshielded unsymmetrical interconnection lines is shown in Figure 12.



- 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

Figure 12 – Example of a CDN for unshielded unsymmetrical interconnection lines: line-to-line and line-to-ground coupling

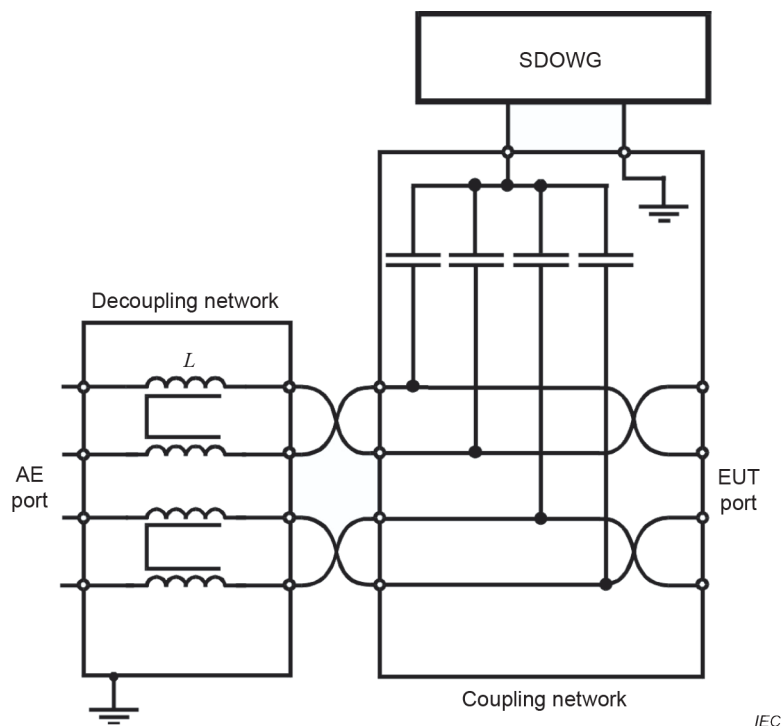
Coupling to unshielded unsymmetrical interconnection lines requires $0,5 \mu\text{F}$ capacitors. The decoupling section of the CDN generally consists of inductors greater than $1,5 \text{ mH}$.

6.3.2.3.3 Coupling/decoupling networks for 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.

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 13.



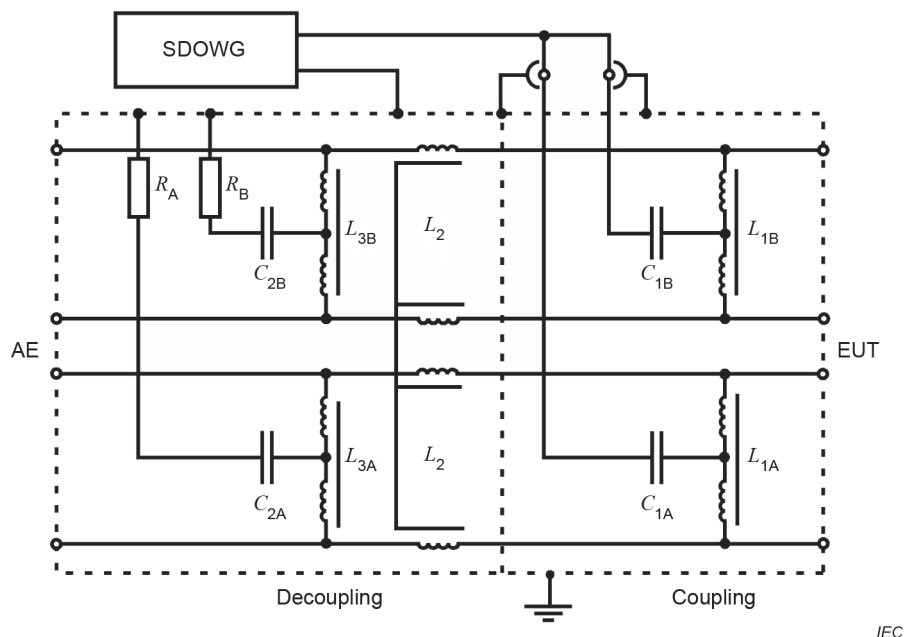
NOTE L with current compensation can include all four coils or only pairs – as shown – to be effective.

Figure 13 – Example of a CDN for unshielded symmetrical interconnection lines: line-to-ground coupling

For unshielded symmetrical interconnection lines, the examples given in Figure 13 and Figure 14 can be used. The value of the coupling capacitor in Figure 13 shall be $0,5 \mu\text{F}$.

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



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

Figure 14 – Example of a CDN for unshielded symmetrical interconnection lines: line-to-ground coupling via capacitors

6.3.3 Coupling/decoupling networks for fast damped oscillatory waves

6.3.3.1 Selection of CDNs for fast damped oscillatory waves

Different types of CDNs mentioned in 6.3.2 are used in combination with the FDOWG for applying fast damped oscillatory waves. The following methods apply:

- for AC/DC power ports, the examples shown in Figure 15 and Figure 16 are used;
- for interconnection lines, the example shown in Figure 17 is used.

NOTE Subclause 8.3 gives details in case the use of a CDN is not suitable.

6.3.3.2 Coupling/decoupling networks for AC/DC power ports up to 32 A for fast damped oscillatory waves

For AC or DC power lines, the decoupling network provides a relatively high impedance to the fast damped oscillation 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 CDN. High voltage capacitors are used for coupling elements and rated to allow the complete waveform duration to be coupled to the EUT.

NOTE Currently, all equipment subject to this document have current ratings up to 32 A. Therefore CDNs with current ratings larger than 32 A have not been considered.

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.

Examples of CDNs for AC/DC power ports are shown in Figure 15 and Figure 16.

The residual damped oscillatory voltage (from Pk_1 to Pk_{10}) on the power supply inputs of the decoupling network when the EUT is disconnected shall not exceed 15 % of the applied test voltage or twice the rated peak voltage of the coupling/decoupling network, whichever is higher.

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

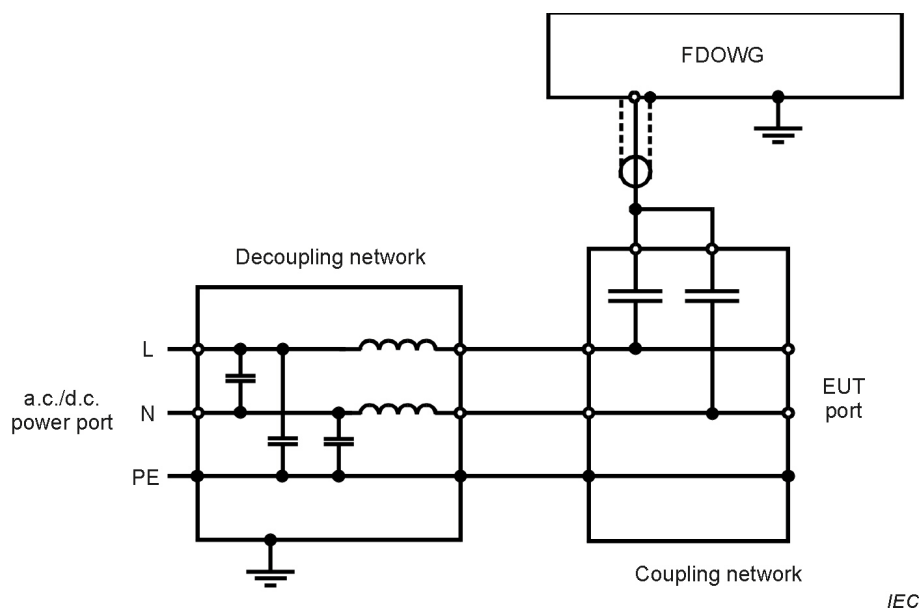


**Figure 15 – Example of CDN for AC/DC single-phase power supply:
line-to-ground coupling**

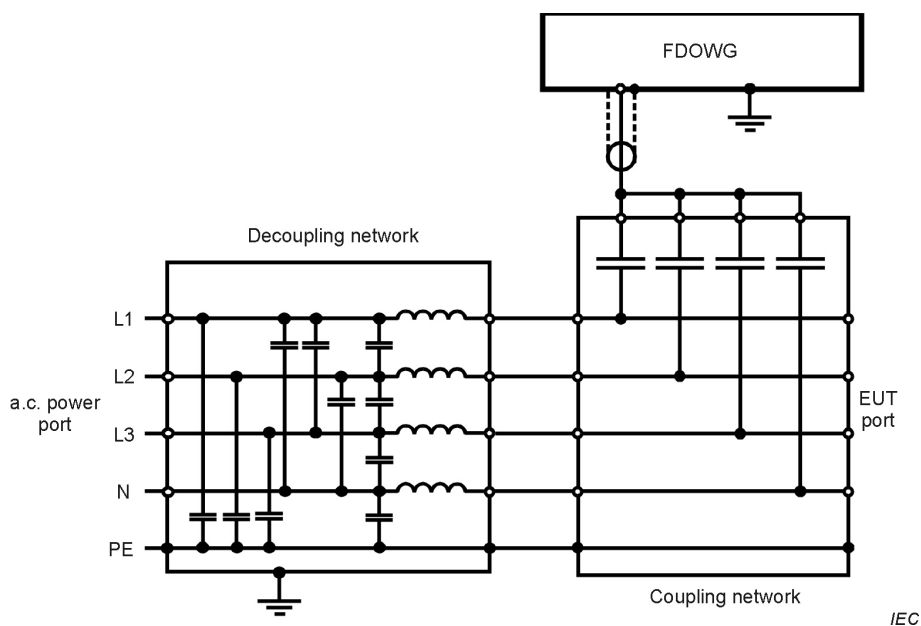


Figure 16 – Example of CDN for AC three-phase power supply: line-to-ground coupling

6.3.3.3 Coupling/decoupling networks for interconnection lines for fast damped oscillatory waves

The coupling method shall be selected based on the types or function of the interconnection cables, circuits and the operational conditions provided by the product specification. Figure 17 shows a typical CDN used for interconnection lines.

Coupling to unshielded lines requires 33 nF coupling capacitors that ensure sufficient insulation between the interconnection lines and the damped oscillatory generator but allow efficient transfer of the damped oscillatory wave.

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

The breakdown voltage of the coupling capacitor 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 fulfil the calibration requirements given 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.

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

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

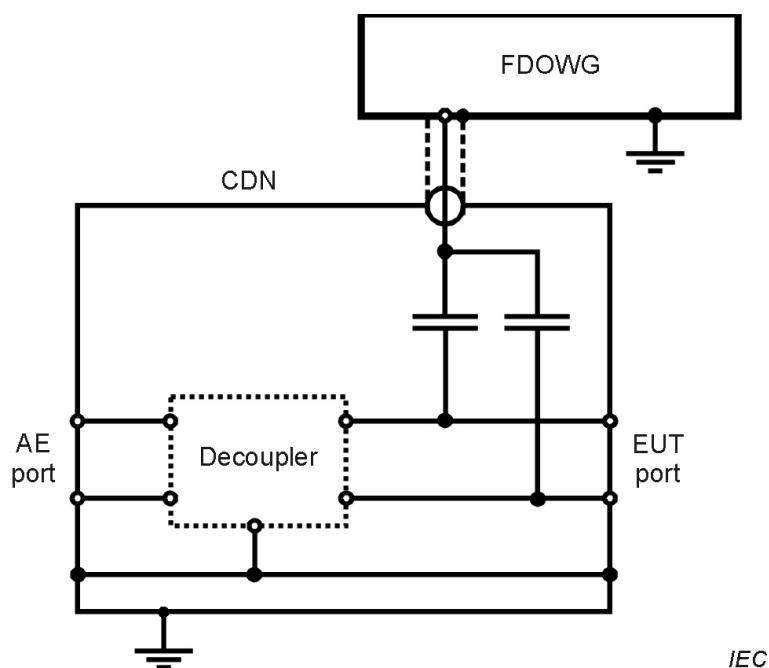


Figure 17 – Example of CDN for interconnection lines for fast damped oscillatory waves: line-to-ground coupling

The decoupling section of the CDN is built with $> 100 \mu\text{H}$ (for the fast damped oscillatory wave test) inductances.

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. Considerations of measurement uncertainties are given in Annex B. 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, therefore, can be different with various generators.

The measuring equipment used for the calibration of the CDN shall satisfy the same requirements applicable to the calibration of the generator (see 6.2.1.3 or 6.2.2.3 respectively)

Calibrations shall be performed at those test levels which are applied to the EUT or at minimum and maximum test levels.

The open circuit voltage U_{Pk1} , rise time and decay shall be measured under open circuit voltage conditions. Under short circuit conditions, the current I_{Pk1} shall be measured.

The residual damped oscillatory voltage measured between applied lines and ground on the AC/DC input 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 damped oscillatory voltage measured between non-applied lines and ground at the EUT port with EUT and mains supply not connected shall not exceed 15 % of the maximum applied test voltage (open circuit).

The residual damped oscillatory voltage measured between the applied lines and ground on the AE side of the CDN for interconnection lines, with the EUT and AE equipment disconnected, shall be measured and recorded so that users of the CDN can determine if the protection is sufficient for use with a particular AE.

NOTE Currently, there are no limits defined for the residual voltage for interconnection lines CDN.

6.4.2 Calibration of CDNs for slow damped oscillatory waves

Calibrations shall be made port by port with open circuit and short circuit for P_{k1} at the EUT port of the CDN. Both polarities (positive and negative) shall be calibrated.

The requirements stated in 6.4.1 and the characteristics in Table 4 shall be met at the output of the CDN with neither the AC/DC power port nor the AE port connected.

Table 4 – Damped oscillatory waveform specifications at the EUT port of CDNs for slow damped oscillatory waves

Selection of CDN	Voltage oscillation frequencies $\pm 10\%$	SDOWG Output voltage	U_{Pk1} at CDN EUT port $\pm 10\%$	Voltage rise time T_1 $\pm 20\%$	Voltage decaying U_{Pk5}	Voltage decaying U_{Pk10}	I_{Pk1} at CDN EUT port $\pm 20\%$
CDN (Figure 7, Figure 8) Common mode (line-to-ground)	100 kHz 1 MHz	0,5 kV	0,5 kV	75 ns	> 50 % of U_{Pk1}	< 50 % of U_{Pk1}	2,5 A
		1,0 kV	1,0 kV				5 A
		2,0 kV ^a	2,0 kV ^a				10 A ^a
CDN (Figure 9, Figure 10) Differential mode (line-to-line)	100 kHz 1 MHz	0,25 kV	0,25 kV	75 ns	> 50 % of U_{Pk1}	< 50 % of U_{Pk1}	1,25 A
		0,5 kV	0,5 kV				2,5 A
		1,0 kV	1,0 kV				5 A
CDN (Figure 11) Common mode (line-to-ground)	100 kHz 1 MHz	0,5 kV	0,5 kV	75 ns	> 50 % of U_{Pk1}	< 50 % of U_{Pk1}	2,5 A
		1,0 kV	1,0 kV				5 A
		2,0 kV ^a	2,0 kV ^a				10 A ^a
CDN (Figure 12) Differential mode (line-to-line)	100 kHz 1 MHz	0,25 kV	0,25 kV	75 ns	> 50 % of U_{Pk1}	< 50 % of U_{Pk1}	1,25 A
		0,5 kV	0,5 kV				2,5 A
		1,0 kV	1,0 kV				5 A
CDN (Figure 13, Figure 14) Common mode (line-to-ground)	100 kHz 1 MHz	0,5 kV	0,5 kV	75 ns	> 50 % of U_{Pk1}	< 50 % of U_{Pk1}	2,5 A
		1,0 kV	1,0 kV				5 A
		2,0 kV ^a	2,0 kV ^a				10 A ^a
The waveforms at the CDN output ports shall comply with the same tolerances than at the generator output port.							
^a The value is increased to 2,5 kV / 12,5 A for substation equipment.							

6.4.3 Calibration of CDNs for fast damped oscillatory waves

The calibration shall be performed for common mode coupling, that is, coupling the damped oscillatory waves to all lines simultaneously.

Calibrations shall be made port by port with short circuit for Pk_1 at the EUT port of the CDN. Both polarities (positive and negative) shall be calibrated.

For AC/DC power port CDNs, the calibration is performed with the generator output at those test levels which are applied to the EUT. The generator is connected to the input of the CDN. Each individual output of the CDN (L1, L2, L3, N normally connected to the EUT) is loaded with the 0,1 Ω shunt to the RGP while the other ports are open. The peak current and waveform are recorded for each polarity. Figure 18 shows one of the four calibration measurements, the calibration of L1 to the RGP.

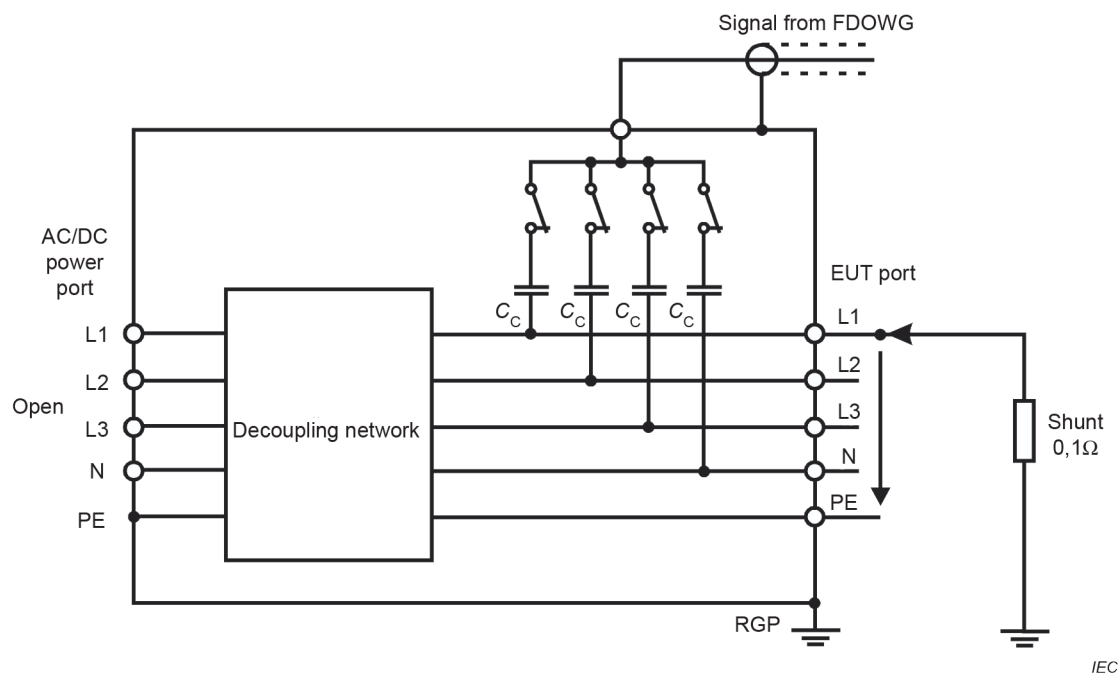


Figure 18 – Example of a calibration setup of CDNs for AC/DC power ports for fast damped oscillatory waves

For interconnection-line CDNs, the specifications given in Table 5 shall be individually calibrated for each coupling line at each EUT port terminal (SC1, SC2) of the CDN with a single $0,1\ \Omega \pm 2\%$ shunt to the RGP. Figure 19 shows one of the two calibration measurements, the calibration of SC1 to the RGP.

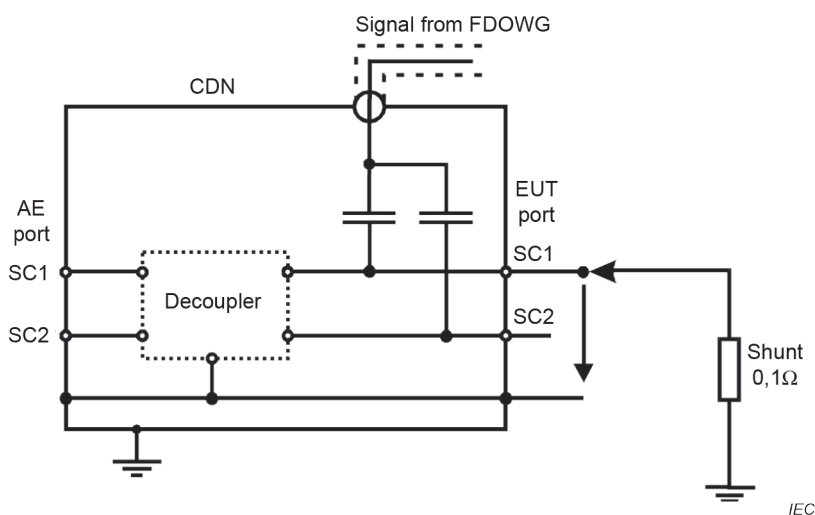


Figure 19 – Example of a calibration setup of CDNs for interconnection lines for fast damped oscillatory waves

NOTE 1 Verifying each coupling line separately is done to ensure that each line is properly functioning and calibrated.

NOTE 2 Care is taken to use coaxial adapters to interface with the output of the CDN.

The connection between the output of the CDN and the coaxial adapter should be as short as possible, but not exceed 0,1 m.

The requirements stated in 6.4.1 and the characteristics in Table 5 shall be met at the output of the CDN with neither the AC/DC power port nor the AE port connected.

Table 5 – Damped oscillatory waveform specifications at the EUT port of CDNs for fast damped oscillatory waves

Selection of CDN	FDOWG Output voltage	I_{Pk1} at CDN EUT port $\pm 20 \%$	Current oscillation frequencies $\pm 30 \%$	Current rise time T_1	Current decaying I_{Pk5}	Current decaying I_{Pk10}
CDN (Figure 18, Figure 19) Common mode (line-to-ground)	0,5 kV	10 A	3 MHz 10 MHz 30 MHz	< 330 ns < 100 ns < 33 ns	> 25 % of I_{Pk1}	< 25 % of I_{Pk1}
	1,0 kV	20 A				
	2,0 kV	40 A				
	4,0 kV	80 A				

6.5 Capacitive coupling clamp for fast damped oscillatory waves

6.5.1 Characteristics of the capacitive coupling clamp

The clamp provides the ability to couple the fast damped oscillatory waves to the circuit under test without any galvanic connection to the terminals of the EUT's ports, shielding of the cables or any other part of the EUT.

The coupling capacitance of the clamp depends on the cable diameter, material of the cables, and cable shielding (if any).

The device is composed of a clamp unit (made, for example, of galvanized steel, brass, copper or aluminium) for housing the cables (flat or round) of the circuits under test and shall be placed on an RGP. The RGP shall extend beyond the clamp by a least 0,1 m on all sides.

The clamp shall be provided at both ends with a high voltage coaxial connector for the connection of the test generator at either end. The generator shall be connected to that end of the clamp which is nearest to the EUT.

NOTE When the coupling clamp has only one HV coaxial connector, it is arranged so that the HV coaxial connector is closest to the EUT.

The clamp itself shall be closed as much as possible to provide maximum coupling capacitance between the cable and the clamp.

An example of the mechanical arrangement of the coupling clamp is given in Figure 20. The following dimensions shall be used:

- lower coupling plate height: (100 ± 5) mm
- lower coupling plate width: (140 ± 7) mm
- lower coupling plate length: $(1\,000 \pm 50)$ mm

NOTE The extensions of the lower coupling plate to accommodate the fixing (screws) to hold the top plate down are not part of the area given by the dimensions specified in the list above and shown in Figure 20.