BS EN 61881-1:2011

BSI Standards Publication

Railway applications — Rolling stock equipment — Capacitors for power electronics

Part 1: Paper/plastic film capacitors

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National foreword

This British Standard is the UK implementation of EN 61881-1:2011. It is identical to IEC 61881-1:2010. It supersedes BS EN 61881:1999, which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee GEL/9, Railway Electrotechnical Applications, to Subcommittee GEL/9/2, Railway Electrotechnical Applications - Rolling stock.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Railway applications -
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Part 1: Paper/plastic film capacitors
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Applications ferroviaires -
Matériel roulant -
Condensateurs pour électronique de puissance -
Partie 1: Condensateurs papier et film plastique
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European Committee for Electrotechnical Standardization
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Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of document 9/1405/FDIS, future edition 1 of IEC 61881-1, prepared by IEC TC 9, Electrical equipment and systems for railways, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61881-1 on 2011-01-02.

This European Standard supersedes EN 61881:1999.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2011-10-02
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2014-01-02

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61881-1:2010 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60077-1:1999	NOTE	Harmonized as EN 60077-1:2002 (modified).
IEC 60077-2:1999	NOTE	Harmonized as EN 60077-2:2002 (modified).
IEC 60110-1:1998	NOTE	Harmonized as EN 60110-1:1998 (not modified).
IEC 60146-1-1:2009	NOTE	Harmonized as EN 60146-1-1:2009 (not modified).
IEC 60384-14:2005	NOTE	Harmonized as EN 60384-14:2005 (not modified).
IEC 60664-1:2007	NOTE	Harmonized as EN 60664-1:2007 (not modified).
IEC 60831-1:1996	NOTE	Harmonized as EN 60831-1:1996 (not modified).
IEC 60831-2:1995	NOTE	Harmonized as EN 60831-2:1996 (not modified).
IEC 60871-1:2005	NOTE	Harmonized as EN 60871-1:2005 (not modified).
IEC 60931-1:1996	NOTE	Harmonized as EN 60931-1:1996 (not modified).
IEC 60931-2:1995	NOTE	Harmonized as EN 60931-2:1996 (not modified).
IEC 61071	NOTE	Harmonized as EN 61071.
IEC 61287-1:2005	NOTE	Harmonized as EN 61287-1:2006 (not modified).

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60068-2-14	-	Environmental testing - Part 2-14: Tests - Test N: Change of temperature	EN 60068-2-14	-
IEC 60068-2-20	-	Environmental testing - Part 2-20: Tests - Test T: Test methods for solderability and resistance to soldering heat of devices with leads	EN 60068-2-20	-
IEC 60068-2-21	-	Environmental testing - Part 2-21: Tests - Test U: Robustness of terminations and integral mounting devices	EN 60068-2-21	-
IEC 60068-2-78	-	Environmental testing - Part 2-78: Tests - Test Cab: Damp heat, steady state	EN 60068-2-78	-
IEC 60269-1	-	Low-voltage fuses - Part 1: General requirements	EN 60269-1	-
IEC 60695-2-11	-	Fire hazard testing - Part 2-11: Glowing/hot-wire based test methods - Glow-wire flammability test method for end-products	EN 60695-2-11	-
IEC 60695-11-5	-	Fire hazard testing - Part 11-5: Test flames - Needle-flame test method - Apparatus, confirmatory test arrangement and guidance	EN 60695-11-5	-
IEC 60721-3-5	-	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 5: Ground vehicle installations	EN 60721-3-5	-
IEC 61373	-	Railway applications - Rolling stock equipment - Shock and vibration tests	EN 61373	-
IEC 62491	-	Industrial systems, installations and equipment and industrial products - Labelling of cables and cores	EN 62491	-
IEC 62497-1	-	Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment	-	-

CONTENTS

RAILWAY APPLICATIONS – ROLLING STOCK EQUIPMENT – CAPACITORS FOR POWER ELECTRONICS –

Part 1: Paper/plastic film capacitors

1 Scope

This part of IEC 61881 applies to capacitors for power electronics intended to be used on rolling stock.

The rated voltage of capacitors covered by this part is limited to 10 000 V.

The operating frequency of the systems in which these capacitors are used is usually up to 15 kHz, while the pulse frequencies may be up to 5 to 10 times the operating frequency.

It distinguishes between AC and DC capacitors.

They are considered as components mounted in enclosures.

NOTE This standard covers an extremely wide range of capacitor technologies for numerous applications: overvoltage protection, DC and AC filtering, switching circuits, DC energy storage, auxiliary inverters, etc.

Examples are given in Clause 9.

The following are excluded from this standard:

- capacitors for induction heat-generating plants operating at frequencies between 40 Hz and 24 000 Hz (see IEC 60110-1 and 60110-2);
- capacitors for motor applications and the like (see IEC 60252-1 and IEC 60252-2);
- capacitors to be used in circuits for blocking one or more harmonics in power supply networks;
- small AC capacitors as used for fluorescent and discharge lamps (see IEC 61048 and IEC 61049);
- capacitors for suppression of radio interference (see IEC 60384-14);
- shunt capacitors for AC power systems having a rated voltage above 1 000 V (see IEC 60871-1 and IEC 60871-2);
- shunt power capacitors of the self-healing type for AC systems having a rated voltage up to and including 1 000 V (see IEC 60831-1 and IEC 60831-2);
- shunt power capacitor of the non self-healing type for AC systems having a rated voltage up to and including 1 000 V (see IEC 60931-1 and IEC 60931-2);
- series capacitors for power systems (see IEC 60143-1, IEC 60143-2 and IEC 60143-3);
- coupling capacitors and capacitors dividers (see IEC 60358);
- capacitors for applications requiring energy storage/high current discharge such as photocopiers and lasers;
- capacitors for microwave ovens;
- capacitors for power electronics (see IEC 61071).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2-14, *Environmental testing – Part 2-14: Tests. Test N: Change of temperature*

IEC 60068-2-20, *Environmental testing – Part 2-20: Tests. Test T: Test methods for solderability and resistance to soldering heat of devices with leads*

IEC 60068-2-21, *Environmental testing – Part 2-21: Tests. Test U: Robustness of terminations and integral mounting devices*

IEC 60068-2-78, *Environmental testing – Part 2-78: Tests. Test Cab: Damp heat, steady state*

IEC 60269-1, *Low-voltage fuses – Part 1: General requirements*

IEC 60695-2-11, *Fire hazard testing – Part 2-11: Glowing/hot-wire based test methods – Glow-wire flammability test method for end-products*

IEC 60695-11-5, *Fire hazard testing – Part 11-5: Test flames – Needle-flame test method – Apparatus, confirmatory test arrangement and guidance*

IEC 60721-3-5, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 5: Ground vehicles installations*

IEC 61373, *Railway applications – Rolling stock equipment – Shock and vibration tests*

IEC 62491, *Industrial systems, installations and equipment and industrial products – Labelling of cables and cores*

IEC 62497-1, *Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distance for all electrical and electronic equipment*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
capacitor element (or element)
indivisible part of a capacitor consisting of two electrodes separated by a dielectric

3.2
capacitor unit (or unit)
assembly of one or more capacitor elements in the same case with terminals brought out

3.3
capacitor bank
assembly of two or more capacitor units, electrically connected to each other

3.4
capacitor
general term used when it is not necessary to state whether reference is made to an element, a unit or a capacitor bank

3.5
capacitor equipment
assembly of capacitor units and their accessories intended for connection to a network

3.6
capacitor for power electronics
power capacitor intended to be used in power electronic equipment and capable of operating continuously under sinusoidal and non sinusoidal current and voltage

3.7
metal-foil capacitor (non self-healing)
capacitor in which the electrodes usually consist of metal foils separated by a dielectric, in the event of a breakdown of the dielectric; the capacitor does not restore itself

3.8
self-healing metallized dielectric capacitor
capacitor, the electrodes of which are metallized (usually by evaporation); in the event of dielectric breakdown, the capacitor restores itself

3.9
AC capacitor
capacitor essentially designed for operation with alternating voltage

NOTE AC capacitors may be used with DC voltage up to the rated voltage only when authorized by the capacitor manufacturer.

3.10
DC capacitor
capacitor essentially designed for operation with direct voltage

NOTE DC capacitors may be used with a specified AC voltage only where authorized by the capacitor manufacturer.

3.11
model capacitor
smaller unit which simulates a complete unit or element in an electrical test, without reducing the severity of the electrical, thermal or mechanical conditions

NOTE The combined sum of stresses should always be considered, for instance the sum of temperature, mechanical conditions and electrical stresses.

3.12
internal (element) fuse
device incorporated in the capacitor which disconnects an element or a group of elements in the event of breakdown

3.13
safety devices

3.13.1
overpressure disconnector
disconnecting device inside a capacitor, designed to interrupt the current path in case of capacitor failure

3.13.2
overpressure detector
device designed to detect abnormal increase of the internal pressure by an electrical switch/signal and indirectly interrupt the current path

3.13.3
segmented metallization design
design of the metal layer over the dielectric shaped in a way to allow a small part of it to be isolated in case of local short circuit or breakdown, in order to restore the full functionality of the unit with a negligible loss of capacitance

3.13.4
special unsegmented metallization design
design of the metal layer over the dielectric shaped in a way that safe self-healing features operating at a voltage up to U_s guarantee the full functionality of the unit with a negligible loss of capacitance

3.14
discharge device of a capacitor
a device which may be incorporated in a capacitor, capable of reducing the voltage between the terminals practically to zero, within a given time, after the capacitor has been disconnected from a network

3.15
rated AC voltage (U_N)
maximum operating peak recurrent voltage of either polarity of a reversing type waveform for which the capacitor has been designed

NOTE 1 The waveform can have many shapes. Examples are given in Annex A.

NOTE 2 The mean value of the waveform may be positive or negative.

NOTE 3 It is important to note that the rated AC voltage is not an r.m.s. value.

NOTE 4 Definitions used in this standard can be different from those of IEC 60077-1.

3.16
rated DC voltage (U_{NDC})
maximum operating peak voltage of either polarity but of a non-reversing type waveform, for which the capacitor has been designed, for continuous operation

Damping capacitors, for gate turn-off thyristor (GTO) can be regarded as DC capacitors with a ripple voltage equal to the rated DC voltage $U_{NDC} = U_r$.

In the case of reversal voltage, the use should be agreed between user and manufacturer.

NOTE If the reversal voltage is small (less than 10 %), the voltage waveform can be considered to be not reversing. For test purposes, U_{NDC} and U_r should be increased by U, the reversal voltage.

3.17
ripple voltage (U_r)
peak-to-peak alternating component of the unidirectional voltage

3.18
non-recurrent surge voltage (U_s)
peak voltage induced by a switching or any other disturbance of the system which is allowed for a limited number of times and for durations shorter than the basic period

3.19
insulation voltage (U_i)
r.m.s. value of the sine wave voltage designed for the insulation between terminals of capacitors to case or earth. If not specified, the r.m.s. value of the insulating voltage is equivalent to the rated voltage divided by $\sqrt{2}$.

3.20
maximum peak current ($\hat{I}$)
maximum peak current that can occur during continuous operation

3.21
maximum current (I_{max})
maximum r.m.s. current for continuous operation

3.22
maximum surge current ($\hat{I}_s$)
peak non-repetitive current induced by switching or any other disturbance of the system which is allowed for a limited number of times, for durations shorter than the basic period

3.23
pulse frequency (f_p)
repetition rate of periodic current pulses

3.24
current pulse width (τ)
time of current flow during charging or discharging from one voltage value to another, of the capacitor

NOTE Pulse current waveform examples are shown in Annex A.

3.25
resonance frequency (f_r)
lowest frequency at which the impedance of the capacitor becomes minimum

3.26
duty cycle

3.26.1
continuous duty
operation time such that a capacitor is at thermal equilibrium for most of the time

3.26.2
intermittent duty

discontinuous working or operation with variable loads which should be described in terms of ON/OFF or HIGH/LOW periods with their durations

3.27
operating temperature
temperature of the hottest point on the case of the capacitor when in thermal equilibrium

3.28
lowest operating temperature (θ_{min})
lowest temperature at which the capacitor may be energized

3.29
case temperature rise ($\Delta\theta_{case}$)
difference between the temperature of the hottest point of the case and the temperature of the cooling air

3.30
cooling-air temperature (θ_{amb})
temperature of the cooling air measured at the hottest position of the capacitor, under steady-state conditions, midway between two units

If only one unit is involved, it is the temperature measured at a point approximately 0,1 m away from the capacitor case and at two-thirds of the height from its base.

3.30.1
outlet fluid temperature for forced-cooled capacitors
temperature of the cooling fluid as it leaves the capacitor, measured at the hottest point

3.30.2
inlet fluid temperature for forced-cooled capacitors
temperature of the cooling fluid measured in the middle of the inlet fluid channel at a point not influenced by the heat dissipation of the capacitor

3.31
maximum operating temperature (θ_{max})
highest temperature of the case at which the capacitor may be operated

3.32
steady-state conditions
thermal equilibrium attained by the capacitor at constant output and at constant cooling-air temperature

3.33
capacitor losses
active power consumed by a capacitor

NOTE Unless otherwise stated, the capacitor losses are understood to include losses in fuses and discharge resistors forming an integral part of the capacitor.

At high frequency, the capacitor losses are predominantly due to losses in connections, contacts and electrodes.

3.34
tangent of the loss angle of a capacitor tan δ
ratio between the equivalent series resistance and the capacitive reactance of a capacitor at a specified sinusoidal alternating voltage, frequency and temperature

$$\tan \delta = R_{esr} \ \omega C = \tan_d + R_s \ \omega C$$

$$\tan_d = \text{dielectric loss factor}$$

3.35
equivalent series resistance of a capacitor R_{esr}
effective resistance which, if connected in series with an ideal capacitor of capacitance value equal to that of the capacitor in question, would have a power loss equal to active power dissipated in that capacitor under specified operating conditions

3.36
series resistance R_s
effective ohmic resistance of the conductors of a capacitor under specified operating conditions

3.37
maximum power loss (P_{max})
maximum power loss with which the capacitor may be loaded at the maximum case temperature

3.38
maximum frequency for maximum power loss and maximum current (f_2)
frequency at which the maximum current (I_{max}) produces the maximum power loss (P_{max}) in the capacitor. For explanation of (f_2) see Annex B.

4 Service conditions

NOTE See IEC 60077-1.

4.1 Normal service conditions

This standard gives requirements for capacitors intended for use in the following conditions:

4.1.1 Altitude

Not exceeding 1 400 m (IEC 62491 class A1).

NOTE The effect of altitude on convection cooling and external insulation should be taken into consideration, if the altitude exceeds 1400 m. In this case the derating or a proper design shall be agreed between manufacturer and user

4.1.2 Temperature

The climatic ambient temperatures are derived from IEC 60721-3-5 class 5k2 which has a range from –25 °C to +40 °C.

Where ambient temperature lies outside this range, it shall be agreed between the user and the manufacturer.

The upper limit of case temperature θ_{max} at which the capacitor may be operated, shall be chosen among the values 55 °C, 70 °C and 85 °C.

4.1.3 Operating temperature with forced ventilation

If capacitors are intended for forced cooling with a fluid medium, the operating temperature conditions specified in 4.1.2 shall be observed.

The following Table 1 of preferred temperatures of cooling fluid shall be applied.

Table 1 – Maximum temperature of cooling medium for unlimited time

Inlet temperature °C	Outlet temperature °C
35	40
45	50
55	60

The lowest inlet temperature for the cooling fluid may be –25 °C.

There are two methods of specifying the upper temperature limit of the cooling medium using either the inlet temperature or the outlet temperature.

Unless otherwise agreed, the choice of method shall be left to the capacitor manufacturer.

For the inlet method, the flow of cooling medium shall be specified.

4.2 Unusual service conditions

This standard does not apply to capacitors, whose service conditions are such as to be in general incompatible with its requirements, unless otherwise agreed between the manufacturer and the user.

Unusual service conditions require additional measurements, which ensure that the conditions of this standard are complied with even under these unusual service conditions.

If such unusual service conditions exist then they shall be notified to the manufacturer of the capacitor.

Unusual service conditions can include:

- unusual mechanical shocks and vibrations,
- cooling water with corrosive or obstructing particles (sea water, very hard water),
- corrosive and abrasive particles in the cooling air,
- dust in the cooling air, particularly if conductive,
- explosive dust or gas,
- oil or water vapour or corrosive substances,
- nuclear radiation,
- unusual storage or transport temperature,
- unusual humidity (tropical or subtropical region),
- excessive and rapid changes of temperature (more than 5 °C/h) or of humidity (more than 5 %/h),
- service areas higher than 1 400 m above sea level,
- superimposed electromagnetic fields,
- excessive overvoltages, as far as they exceed the limits given in Clause 6,
- airtight (poor change of air) installations.

5 Quality requirements and tests

5.1 Test requirements

5.1.1 General

This subclause gives the test requirements for capacitor units.

5.1.2 Test conditions

Unless otherwise specified for a particular test or measurement, the temperature of the capacitor dielectric shall be in the +5 °C to +35 °C range.

If corrections are necessary, the reference temperature shall be +20 °C, unless otherwise agreed between the manufacturer and the user.

NOTE It may be assumed that the dielectric temperature is the same as the ambient temperature, provided that the capacitor has been left in an unenergized state, in a constant ambient temperature, for an adequate period of time in order to reach thermal equilibrium.

The AC tests and measurements shall be carried out with a sinusoidal voltage of 50 Hz or 60 Hz, unless otherwise specified.

5.2 Classification of tests

The test are classified as routine test, type tests and acceptance tests as follows:

5.2.1 Routine tests

Routine tests are the following:

a) sealing test (5.8);
b) external inspection (5.14.2);
c) voltage test between terminals (5.5.2);
d) voltage test between terminals and case (5.6.1);
e) capacitance and tan δ measurements (5.3);
f) test of internal discharge device (5.7);

Routine tests shall be carried out by the manufacturer on every capacitor before delivery.

At his request, the user shall be supplied with a certificate detailing the results of such tests. The sequence of the tests is as indicated.

5.2.2 Type tests

Unless otherwise specified, every capacitor sample to which it is intended to apply the type test shall first have withstood satisfactorily the application of all the routine tests.

Type tests are the following:

a) voltage test between terminals (5.5.3);
b) voltage test between terminals and case (5.6.2);
c) surge discharge test (5.9);
d) self-healing test (5.11);
e) environmental testing (5.13);
f) mechanical testing (5.14);
g) capacitor tangent of the loss angle (tan δ) measurement (5.4);
h) thermal stability test (5.10);
i) test of internal discharge device (5.7);
j) resonance frequency measurement (5.12);
k) endurance test between terminals (5.15);
l) disconnection test on fuses (5.17);
m) destruction test (5.16).

Type tests are intended to prove the soundness of the design of the capacitor and its suitability for operation under the considerations detailed in this standard.

The type tests shall be carried out by the manufacturer, and the user shall, on request, be supplied with a certificate, detailing the results of such tests.

These tests shall be made upon a capacitor of a design identical to that of the capacitor under contract, or on a capacitor of a design that gives during the test the same or more severe test conditions.

It is not essential that all type tests be carried out on the same capacitor sample. The choice is left to the manufacturer.

5.2.3 Acceptance tests

The routine and/or type test, or some of them, may be carried out by the manufacturer, on agreement with the user.

The number of samples that may be subjected to such repeat tests, the acceptance criteria, as well as permission to deliver any of these units shall be subject to agreement between the manufacturer and the user, and shall be stated in the contract.

5.2.4 Summary of tests

Table 2 lists the type and routine test for capacitor units.

Table 2 – Summary of tests

	Test item	Type	Routine
1	Capacitance and tanδ measurements	-	5.3
2	Capacitor loss tangent (tanδ) measurement	5.4	-
3	Voltage test between terminals	5.5.3	5.5.2
4	Voltage test between terminals and case	5.6.2	5.6.1
5	Test of internal discharge device	5.7	5.7
6	Sealing test	-	5.8
7	Surge discharge test	5.9	-
8	Thermal stability test	5.10	-
9	Self-healing test	5.11	-
10	Resonance frequency measurement	5.12	-
11	Environmental testing	5.13	-
12	Mechanical testing	5.14	-
13	External inspection	-	5.14.2
14	Endurance test	5.15	-
15	Destruction test	5.16	-
16	Disconnecting test on fuses	5.17	

5.3 Capacitance and tan δ measurements (routine test)

5.3.1 Measuring procedure

The capacitance and tan δ shall be measured at a voltage and at a frequency chosen by the manufacturer.

The method used shall not include errors due to harmonics or to accessories external to the capacitor to be measured, such as reactors and blocking circuits in the measuring circuit.

The accuracy of the measuring method shall be given and shall be better than 0,2 % for capacitance and 10 % for tan δ but not necessarily better than 1×10^{-4} if the measurement is made at 50-60 Hz.

NOTE For capacitors in the milliFarad range a lower accuracy may be appropriate.

The capacitance measurement shall be carried out after the voltage test between terminals (see 5.5).

For capacitors with internal fuses, capacitance measurement shall also be made before the voltage tests.

5.3.2 Capacitance tolerances

If not otherwise specified, the capacitance measured shall not differ from the rated capacitance by more than –10 % to +10 %.

5.3.3 Loss requirements (tan δ)

The requirements regarding capacitor losses may be agreed upon between the manufacturer and the user.

NOTE The manufacturer should, on agreement, furnish curves or tables showing the capacitor losses under steady-state conditions at rated output as a function of ambient temperature within the temperature category.

5.4 Capacitor loss tangent (tan δ) measurement (type test)

5.4.1 Measurements

The following measurements shall be made:

5.4.1.1 AC capacitors

The capacitor losses (tan δ) shall be measured at the end of the thermal stability test (see 5.10).The measuring voltage end frequency may be agreed upon between the manufacturer and the user.

5.4.1.2 DC capacitors

The measurement shall be carried out at a frequency in the range of 50 Hz to 60 Hz at the ripple voltage (U_r) divided by $2\sqrt{2}$.

NOTE The losses in the electrodes, connections, leads and terminals are functions of the frequency and can be calculated.

5.4.2 Loss requirements

The value of tan δ measured in accordance with 5.4.1 shall not exceed the value declared by the manufacturer, or the value agreed upon between the manufacturer and the user.

5.5 Voltage test between terminals

5.5.1 General

Tests shall be carried out according to the following Table 3:

Table 3 – Test voltage between terminals

	AC capacitors	DC capacitors	
	All types	**Non-self-healing**	**Self-healing**
AC test voltage r.m.s. value	1,5 U_N	–	–
DC test voltage	2,15 U_N	2 U_{NDC}	1,5 U_{NDC}

The test voltage indicated in Table 3 can be reduced if capacitors are intended for intermittent duty (see 3.26.2) or for short service duration; the new values shall be agreed upon between the manufacturer and the user. For capacitors directly connected to the line supply, the test voltage between terminals may be increased on agreement between the manufacturer and the user.

NOTE The AC test voltage may be at 50 Hz or 60 Hz.

5.5.2 Routine test

Every capacitor shall be subjected for 10 s to either test of 5.5.1 at ambient temperature. The choice is left to the manufacturer. During the test, neither puncture nor flashover shall occur.

Self-healing breakdowns are permitted.

The duration may be reduced to 2 s provided the voltage is increased by 10 %.

This is to be agreed between the manufacturer and the user.

In the case of units with all elements in parallel, operation of internal element fuse(s) is permitted provided the capacitance tolerances are still met.

NOTE If necessary, this test can be repeated one more time only.

5.5.3 Type test

The capacitor shall be subjected for 1 min to either test of 5.5.1.

The choice is left to the manufacturer.

After the test voltage between terminals the capacitance and tan δ shall be measured.

5.6 AC voltage test between terminals and case

5.6.1 Routine test

Units having all terminals insulated from the case shall be subjected for 10 s to a voltage applied between the terminals (joined together) and the case.

The test voltage values are the following:

$$U_{\text{t, case}} = 2\ U_{\text{i}} + 1\ 000\ \text{V or } 2\ 000\ \text{V whichever is the highest value,}$$

where U_{i} is the insulation voltage.

The duration may be reduced to 2 s provided the voltage is increased by 10 %.

This is to be agreed between the manufacturer and the user

The insulating voltage of the capacitor shall be specified by the user. The insulation voltage is equal to the rated voltage of the capacitor, divided by $\sqrt{2}$, unless otherwise specified.

During the test, neither puncture nor flashover shall occur. The test shall be performed even if one of the terminals is intended to be connected to the case in service.

Units having one terminal permanently connected to the case shall not be subjected to this test.

NOTE 1 If the capacitor (with metal case) is equipped with an external overpressure detector, the terminals of the detector should be joined together and connected to the case.

NOTE 2 The voltage test between the overpressure detector and the case should be agreed between user and manufacturer.

NOTE 3 If necessary this test can be repeated once again only.

5.6.2 Type test

Units having all terminals insulated from the case shall be subjected to a test according to 5.6.1 with the same voltage value, but with a duration of 1 min. For capacitors directly connected to the line supply, the test voltage may be increased on agreement between the manufacturer and the user.

Capacitors with insulating case shall have a metal foil tightly wrapped all around them during the test.

5.7 Test of internal discharge device

The resistance of the internal discharge device, if any, shall be checked either by resistance measurement or by measuring the self-discharge rate.

The test shall be made after the voltage tests of 5.5.

5.8 Sealing test

Unenergized capacitor units shall be heated to a uniform temperature of at least their maximum operating temperature plus 5 °C and shall be maintained at this temperature for at least three times the thermal constant, but not less than 2 h.

No leakage shall occur. It is recommended that a suitable indicator be used.

Leakage source of the capacitor shall be detectable by visual inspection.

The test position of the capacitor unit shall be defined on agreement between the manufacturer and the user, taking into account the usual position of the device.

NOTE If the capacitor contains no liquid material, the choice to carry out this test or not and the test method is left to the manufacturer and it should be carried out by sampling.

5.9 Surge discharge test

The units shall be charged by means of a DC source and then discharged through a spark gap situated as close as possible to the capacitor. They shall be subjected to five such discharges within 10 min. For big units more than 10 min may be required.

The test voltage shall be equal to 1,1 U_N.

Within 5 min after this test, the units shall be subjected to a voltage test between terminals (see 5.5).

The capacitance shall be measured before the discharge test and after the voltage test.

The measurement shall not differ by more than an amount corresponding either to breakdown of an element or to blowing of an internal fuse.

For self-healing capacitors, the change of capacitance shall be less than ±1 %.

The following formula shall be checked: $\tan \delta \leq 1{,}2 \times \tan \delta_o + 1 \times 10^{-4}$.

Tan δ is the value after the test, tan δ_0 before the test.

If, however, a maximum surge current is specified, the discharge current shall be adjusted by variation of the charging voltage and the impedance of the discharge circuit to a value of:

$$\hat{I}_{test} = 1{,}1\ \hat{I}_s$$

5.10 Thermal stability test

5.10.1 General

This test is performed on both AC and DC capacitors and provides the following information about the capacitors subjected to it:

a) it determines the thermal stability of the capacitor under overload conditions;

b) it conditions the capacitor to enable a reproducible loss measurement to be made.

5.10.2 Measuring procedure

One capacitor unit shall be placed in an enclosure where the cooling temperature shall be:

a) for natural cooling, that indicated by the manufacturer (θ_{amb}) + 5 °C;

b) for forced cooling, the specified outlet cooling temperature + 5 °C.

After all parts of the capacitor have attained the temperature of the cooling medium, the capacitor shall be subjected for a period of at least 48 h to an AC voltage of substantially sinusoidal form.

The value of the voltage and frequency shall be kept constant through the test.

The current shall be 1,1 I_{max}.

The supply conditions are those indicated in Annex B with the power = 1,21 P_{max}.

During at least 6 h, the temperature of the case near the top shall be measured at least four times; throughout this period of 6 h, the temperature rise shall not increase by more than 1 °C.

Should a greater change be observed, the test may be continued until the above requirement is met for four consecutive measurements during a 6 h period.

Before and after the test, the capacitance shall be measured within the temperature range given in 5.1.2 for testing, and the two measurements shall be corrected to the same dielectric temperature.

The difference between the two measurements shall be less than an amount corresponding to either breakdown of an element or operation of an internal fuse. At the end of this test, the tan δ measurement is performed (see 5.4.1).

NOTE 1 When checking whether the capacitor losses or the temperature conditions are satisfied, fluctuations of voltage, frequency and cooling medium temperature during the test should be taken into account. For this reason, it is advisable to plot these parameters and the case temperature as a function of time.

NOTE 2 The test may be performed, on agreement between the manufacturer and the user, with a non-sinusoidal voltage, provided the values of current and power loss remain: 1,1 I_{max} and 1,21 P_{max}.

5.11 Self-healing test

This test may be carried out on a complete unit, on a separate element or on a group of elements that are part of the unit; provided the elements under test are identical to those used in the unit and their conditions are similar to those in the unit. The choice is left to the manufacturer. This test has to be done to demonstrate the self-healing properties and is only applicable to self-healing capacitors.

The capacitor or element shall be subjected for 10 s to a DC voltage: 1,1 times of the non-recurrent/surge voltage (U_s), or equal to the routine test voltage (2,15 U_N for AC capacitors, 1,5 U_{NDC} for DC capacitors) whichever is higher.

If fewer than five clearings occur during this time, the voltage shall be increased slowly until five clearings have occurred since the start of the test or until the voltage has reached 2,5 times the rated voltage.

If fewer than five clearings have occurred when the voltage has reached 2,5 $U_{N,}$ for a time of 10 s the test shall be finished.

Before and after the test, the capacitance and tan δ shall be measured. No change of the capacitance equal/higher than 0,5 % shall be permitted.

The following formula shall be checked: tan $\delta \leq 1{,}1 \tan \delta_o + 1 \times 10^{-4}$.

Tan δ is the value after the test, tan δ_o before the test.

5.12 Resonance frequency measurement

The resonance frequency shall be measured within the temperature range according to 5.1.2, using a method that minimizes errors due to connections and accessories.

The appropriate measuring method may be chosen from the two examples given in Annex C.

This measurement is not necessary for all applications.

NOTE The self-inductance is calculated from the resonance frequency and the value of self-inductance should not exceed the value agreed upon between the manufacturer and the user.

5.13 Environmental testing

5.13.1 Change of temperature

The change of temperature test shall be carried out in accordance with test Na or Nb of IEC 60068-2-14, on agreement between user and manufacturer with the upper and lower limit temperature of the capacitor.

Test Nb shall be carried out with a transition time of about 1 h (1 °C/min).

5.13.2 Damp heat, steady state

The damp heat steady-state test (see Table 4) shall be carried out in accordance with IEC 60068-2-78 with a degree of severity in accordance with location category of the capacitor.

Before the start of the long-term test, the capacitance shall be measured at room temperature. After completion of the steady-state test, the capacitor shall be subjected to a voltage test between terminals in accordance with 5.5.1, and dielectric strength between terminals and case in accordance with 5.6.1.

Finally a capacitance measurement shall be carried out in accordance with 5.3.1 at stable room temperature.

No test sample shall suffer puncturing or flashover. Self-healing clearings are permitted. The change in capacitance shall not exceed 2 %.

Table 4 – Damp heat test

Application class of capacitor	**Test**	**Test environment**	**Duration** days
	Ca	40/93	56
	Ca	40/93	21

5.14 Mechanical testing

5.14.1 Mechanical tests of terminals

The robustness of terminations shall be tested in accordance with Tables 5 and 6.

Table 5 – Testing the robustness of terminals

1	**2**	**3**		**4**
No.	**Tests or measurements**	**Performance**		**Test criteria**
1	Tensile strength of connecting cables and soldered connections	IEC 60068-2-21	Ua1	Individual with capacitor weight, at least 10 N
2	Flexural strength of connections		Ub1	Number of flexing cycles: 2
3	Flexural strength of soldering and flat plug lugs		Ub2	Number of bending cycles, for soldered lugs with connected wire also: 2
4	Torsion resistance of axial connections		Uc	Severity 2
5	Torque resistance of screwed and bolted elements		Ud	Severity 2
6	Solderability and heat resistance of soldered connections	IEC 60068-2-20		Soldering iron at 350 °C Size A

Table 6 – Example of current-carrying capacities of screw terminals and bolts

Maximum continuous r.m.s. current A	Bolt thread	Bolt material	Torque Nm	
			Max.	**Min.**
10	M 3,5	Brass	0,8	0,4
16	M 4		1,2	0,6
25	M 5		2,0	1,0
63	M 6		3,0	1,5
100	M 8		6,0	3,0
160	M 10		10,0	5,0
250	M 12		15,5	7,5
315	M 16		30,0	15,0
400	M 20		52,0	26,0
NOTE Materials other than brass are permitted under the condition that they are electrically and mechanically equivalent or better.				

5.14.2 External inspection

Capacitors are visually examined and checked for finish and marking.

5.14.3 Vibration and shocks

See IEC 61373. For specially specified non-standard capacitors the test conditions may be agreed between manufacturer and user,for instance testing on the complete application unit.

5.15 Endurance test

The purpose of the endurance test is to demonstrate the performance of the capacitor under the conditions which will actually occur in service.

The endurance test shall be performed on a complete unit or model capacitors.

5.15.1 Conditioning of the units before the test

The units shall be exposed to 1,1 times U_N in still air at a temperature of not less than +10 °C for 16 h to 24 h.

NOTE This procedure is left to the choice of the manufacturer.

5.15.2 Initial capacitance and loss factor measurements

The units shall be placed for at least 12 h in an unenergized state in a ventilated chamber, having a temperature of (30 ± 2) °C.

The measurements shall be performed as for 5.3 at the same ambient temperature, 5 min after the voltage application.

5.15.3 Endurance test

The test chamber shall be heated to a temperature close to the test temperature.

The test units shall be placed in the heated chamber and energized at the appropriate conditions as described in Table 7. AC and DC capacitors shall be subjected to the appropriate test as decided by the manufacturer. When the unit has achieved the test temperature, the cooling/heating conditions are adjusted so that stabilization is achieved at this test temperature. After this initial stabilization no changes in cooling/heating temperature are permitted.

The test temperature is the maximum case temperature (θ_{max}, see 3.31) during maximum continuous operating condition, i.e. excluding short time and exceptional conditions.

The test voltage U_t (pure DC or AC sinusoidal voltage with a peak voltage equal to U_{NDC} or U_N multiplied by the acceleration factor) shall be applied. A different acceleration factor/test duration can be selected according to Table 7.

The choice is left to the manufacturer. Half-way through the endurance test the capacitor shall be de-energized, cooled in still air at the ambient temperature, and subjected to 1 000 discharges as for 5.9, but with a peak current of 1,4 $\hat{I}$, where $\hat{I}$ is the maximum peak current (see 3.20).

The frequency of the discharges shall be decided by the manufacturer.

As soon as possible, the capacitors shall be energized again in order to complete the test.

Table 7 – Endurance test

Type of capacitor	U_t	Test steps	Temperature	Duration or number of discharges
DC	1,4 U_{NDC}	1,4 U_{NDC}	Test temperature	250 h
		1,4 $\hat{I}$	Room temperature	1 000 times
		1,4 U_{NDC}	Test temperature	250 h
	1,3 U_{NDC}	1,3 U_{NDC}	Test temperature	500 h
		1,4 $\hat{I}$	Room temperature	1 000 times
		1,3 U_{NDC}	Test temperature	500 h
AC	1,35 U_N (see note 1)	1,35 U_N	Test temperature	250 h
		1,4 $\hat{I}$	Room temperature	1 000 times
		1,35 U_N	Test temperature	250 h
	1,25 U_N (see note 1)	1,25 U_N	Test temperature	500 h
		1,4 $\hat{I}$	Room temperature	1 000 times
		1,25 U_N	Test temperature	500 h

NOTE 1 The conditions during this test may be different to the service conditions, e.g. 50 Hz or 60 Hz for all AC capacitors.

NOTE 2 Forced air liquid-bath cooling may be used if the temperature of the case exceeds θ_{max}.

NOTE 3 Damping capacitors for gate turn off thyristors (GTO) on agreement between the user and the manufacturer can be tested with a ripple voltage (unidirectional) $U_t = U_r$ = (1,25 or 1,35) U_N as for AC capacitors.

5.15.4 Final capacitance and tan δ measurement

The measurement shall be performed as indicated in Clause 5 within two days after completing the endurance test.

5.15.5 Acceptance criteria

The capacitance measurement performed in Clause 5 shall differ by not more than 3 % of the initial values. For capacitors intended to be used as filter capacitors directly supplied by the supply line, more stringent tolerances may be agreed upon between the user and the manufacturer.

The losses shall be reported.

If one capacitor has failed, the test is repeated and no more failures are permitted.

5.16 Destruction test

5.16.1 General

This test is performed to give an indication of the behaviour of the capacitor at the end of life and to prove the proper work of the safety system within the specification limits.

This test shall be applied only to protected capacitors (see 7.1) with any safety system e.g. self-healing. However, the following notes should be taken into account.

NOTE 1 The non-self-healing capacitors protected by internal fuses should comply with 5.17. For this kind of capacitors complying with 5.17 is considered as equivalent to 5.16.

NOTE 2 Capacitors without disconnection device but with, or intended for service with, an overpressure detector should be subjected to this test, and should be marked "Safe operation only with overpressure detector".

NOTE 3 Self-healing capacitors with internal fuses should be subjected to this test and should not be subjected to the test in 5.17.

NOTE 4 As the actual conditions can be significantly different in service, the behaviour at the end of life may also be different. Stored energy, expected short-circuit current, duration of failure current (and so on) should be considered in the application. Compliance with 5.16 minimizes the risk of dramatic failure but does not guarantee 100 % safe end of life of the capacitor.

The destruction test shall be carried out related to the type of safety system and to the main application of capacitors, according to Table 8. Performing of the test by applying DC - AC cycles or AC - DC cycles is at the choice of the manufacturer. After a failure the time to switch off the capacitor from the power supply shall be given by the manufacturer.In case of self-healing capacitors other methods to demonstrate the behaviour of the capacitor at the end of life and to prove the proper work of the safety system may be agreed between user and manufacturer

Table 8 – Destruction test as a function of type of safety system

Type of unit	Safety system	Main application	Test clause
Self-healing	1. Overpressure detector	AC	5.16.2
		DC	5.16.3
	2. Overpressure disconnector	AC	5.16.2
		DC	5.16.3
	3. Segmented and special unsegmented metallization design	DC/AC	5.16.3
Non-self-healing	1. Overpressure detector	AC	5.16.2
		DC	5.16.3
	2. Internal fuses	AC	5.17

5.16.2 Test sequence for AC capacitors

The test shall be carried out on a capacitor unit.

When specified by the manufacturer, a capacitor which has passed the endurance test may be used.

The principle of the test is to promote failures in the element(s) by a high internal impedance DC power supply, and subsequently to check the behaviour of the capacitor when an AC voltage is applied. The failure of non-self-healing capacitors without internal fuses may be promoted according to the procedures of 5.17.5. The choice is left to the manufacturer. The capacitor shall be mounted in a circulating air oven having a temperature equal to the maximum ambient air temperature of the temperature category of the capacitor.

When all the capacitor parts have reached the temperature of the oven, the following test sequence shall be performed with the circuit given in Figure 1. Instead of the fuse in Figure 1, if the capacitor is protected by the overpressure detector, a circuit breaker is used which is controlled by the overpressure detector.

a) With the selector switches H and K in position 1 and "a" respectively, the AC voltage source N is set to 1,3 U_N and the capacitor current is recorded.
b) The DC voltage source T is set at the voltage and short-circuit current value stated by the manufacturer; the switch H is then set to position 2.
c) Switch H is set to position 3 and switch K to position "b" in order to apply the DC test voltage to the capacitor which is maintained for a given period, as stated by the manufacturer.
d) Switch K is then set to position "a" again in order to apply the AC test voltage to the capacitor for a period of 5 min when the current is again recorded.

The following conditions may be obtained:

1) The ammeter I and the voltmeter U both indicate zero: in this case the fuse or the status of the overpressure detector shall be checked. If the fuse has blown, it shall be replaced. Then the voltage "N" is applied to the capacitor and if the fuse blows again or the overpressure detector has worked, the procedure is interrupted.

   If the fuse does not blow or the overpressure detector has not worked, the procedure consisting in applying to the capacitor T and N voltage as prescribed in items c) and d) continues using only the switch K.
2) The current indicated by the ammeter I is zero and the voltmeter U indicates 1,3 U_N.

   In this case the procedure is interrupted.
3) The current indicated by the ammeter I is higher than zero. In this case the procedure continues as per items b), c), and d).

If, after repeating this procedure several times, the remaining capacitance is higher than zero, or 10 % of the initial value in case of self-healing capacitors with segmented or special unsegmented design, another sample may be used, and/or test voltage and test time may be increased, or the unit has to be subjected to an externally operated overpressure until the disconnector or the overpressure detector has worked. The value of this pressure shall be given by the manufacturer.

When the procedure is interrupted, the capacitor is cooled to ambient temperature and the voltage test between terminals and terminals and case is carried out according to 5.5 and 5.6. In case of operation of an overpressure detector, no voltage test terminal to terminal is required. The status of the detector after cooling down to ambient temperature shall be reported.

The short-circuit current of the N voltage source at the capacitor terminals should be higher than 5 I_{max}.

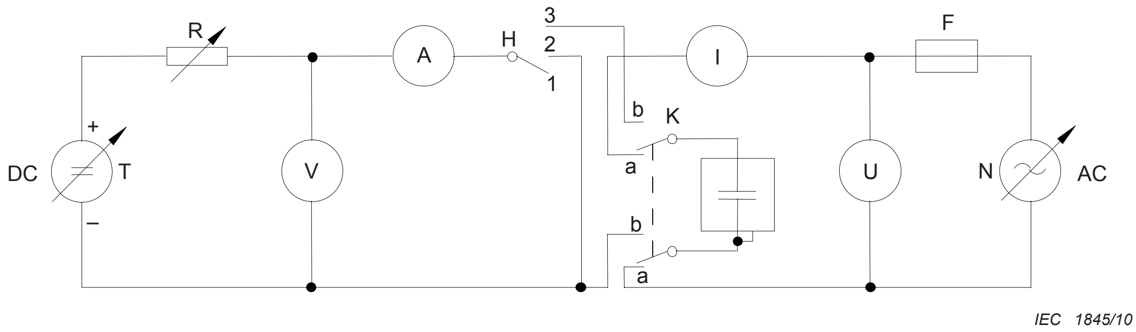


Figure 1 – Destruction test arrangement

The rated current I of the fuse shall be not less than 2 I_{max}.

Fuse according to IEC 60269-1 shall be used.

NOTE 1 If the capacitor unit is used in parallel connection with other units, the test should be performed by putting a corresponding capacitance in parallel with the N source.

NOTE 2 If the capacitor unit is too large or too small to comply with the test parameters, the test should be performed on agreement between the manufacturer and user.

NOTE 3 For unprotected capacitors, the risk of explosion is related to the duration of the short-circuit current.

The user can give theoretical information, while the manufacturer can declare the I^2t, these informations can reasonably help the designer to estimate the risk of explosion.

5.16.3 Test sequence for DC capacitors

The test shall be carried out on a capacitor unit. When specified by the manufacturer, a capacitor which has passed the endurance test may be used. The principle of the test is to promote failures in the element(s) by a high internal impedance DC power supply, and subsequently to check the behaviour of the capacitor when high DC voltage with superposed AC or DC low voltage with low internal impedance is applied.

The failure of non-self-healing capacitors without internal fuses may be promoted according to the procedures of 5.17.5. The choice is left to the manufacturer.

The capacitor shall be mounted in a circulating air oven having a temperature equal to the maximum ambient air temperature for the temperature category of the capacitor.

When all the capacitor parts have reached the temperature of the oven, the following test sequence shall be performed with the circuit given in Figure 1: the N source is a DC generator with a superposed ripple voltage (AC component).

An example of N generator is given in Figure 2.

The rated current of the fuse shall be not less than 2 I_{max}. Fuse according to IEC 60269-1 shall be used. Instead of the fuse shown in Figure 2, if the capacitor is protected by an overpressure detector, a circuit breaker is used which is controlled by the overpressure detector.

a) With the selector switches H and K in position 1 and "a", the voltage source N is set to 1,3 U_N and to 1,1 I_N.
b) The DC voltage source T is set at the value stated by the manufacturer; the switch H is then set to position 2.
c) Switch H is set to position 3 and switch K to position "b" in order to apply the DC test T to the capacitor which is maintained for a given period, stated by the manufacturer.

d) Switch K is then set to the position "a" again in order to apply the superimposed test voltage N to the capacitor for a period of 5 min while the current is recorded.

The following conditions may be obtained:

1) The ammeter I and the voltmeter U both indicate zero.

   In this case the fuse or the status of the overpressure detector shall be checked. If the fuse has blown it shall be replaced. The voltage N is then applied to the capacitor and if the fuse blows again or the overpressure detector has operated, the procedure is interrupted. If the fuse does not blow or the overpressure detector has not operated, the procedure consisting in the application to the capacitor of T and N voltage as prescribed in items c) and d) is continued using only the switch K.

2) The current indicated by the ammeter I is zero and the voltmeter U indicates 1,3 U_N.

   In this case the procedure is interrupted and the capacitance is checked.

   If the capacitance is higher than zero, the procedure is continued as per items b), c) and d).

3) The current indicated by the ammeter I is higher than zero.

   In this case the procedure continues as per items b), c) and d).

If, after repeating this procedure several times, the remaining capacitance is higher than zero, or 10 % of the initial value in case of self-healing capacitors with segmented or special unsegmented design, another sample may be used, and/or test voltage and test time may be increased, or the unit has to be subjected to an externally operated overpressure until the disconnector or the overpressure detector has worked. The value of this pressure shall be given by the manufacturer.

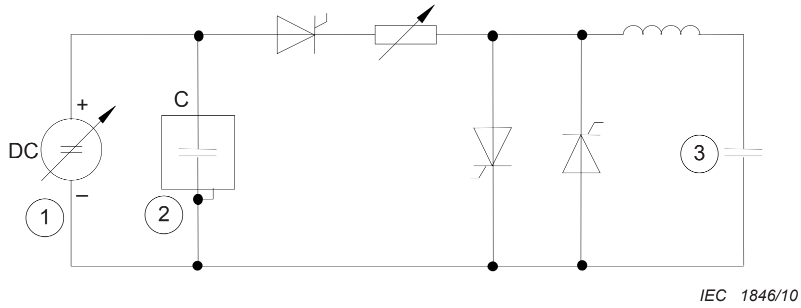
When the procedure is interrupted, the capacitor is cooled to the ambient temperature, and the voltage test between terminals and terminals and case shall be carried out according to 5.5 and 5.6.

In case of operation of an overpressure detector, no voltage test between terminals shall be performed.

If a device according to Figure 2 is not available, a N source according to Figure 3 can be used. In this case a high DC current is generated by a diode bridge. The DC and AC generators shall be adjustable.

Subclause 5.16.3 a) shall be modified as follows: "with the selector switches H and K in position 1 and "a" respectively, the voltage source N shall be set to 1,3 U_N".

The short-circuit current of the N voltage source at the capacitor terminals should be higher than 5 I_{max}.



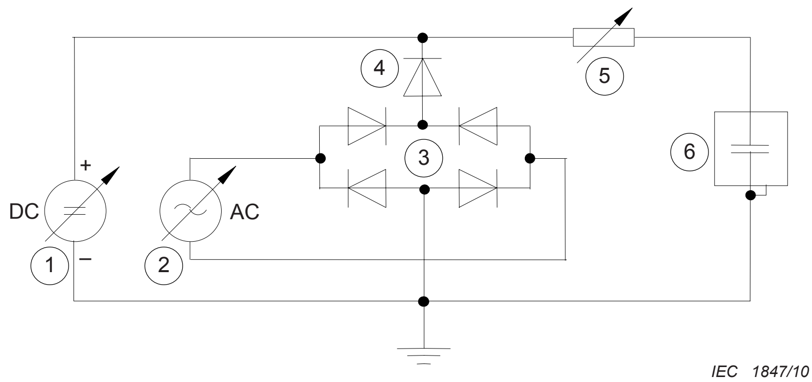
Key

1 High-voltage, high-current DC generator

2 Specimen under test

3 Inverter device

Figure 2 – N source DC – type 1



Key

1 High-voltage, low-current (300 mA) DC generator

2 Low-voltage, high-current AC generator

3 Low-voltage rectifier bridge

4 Blocking HV rectifier

5 Short-circuit current adjustment

6 Specimen under test

Figure 3 – N source DC – type 2

NOTE 1 If the capacitor unit is used in parallel connection with other units, the test should be performed by putting a corresponding capacitance in parallel with the N source.

NOTE 2 The AC voltage should be selected in such way to allow a circulation of the short-circuit current.

NOTE 3 If the capacitor unit is too large or too small to comply with the test parameters, the test should be performed on agreement between the manufacturer and user.

In case of self-healing capacitors with segmented or special unsegmented design, other methods to demonstrate the ability of capacitor to loose more than 90 % of its capacitance may be agreed between manufacturer and user.

5.17 Disconnecting test on internal fuses

5.17.1 General

This test applies to non-self-healing capacitors fitted with internal current fuses.

The fuse is connected in series with the element(s) which the fuse is intended to isolate if the element(s) becomes faulty. The range of currents and voltages for the fuse is therefore dependent on the capacitor design and, in some cases, also on the bank in which it is connected.

The operation of an internal fuse is generally determined by one or both of the following factors:

– the discharge energy from elements or units connected in parallel with the faulty element or unit;
– the available fault current.

NOTE If the unit is protected by an external fuse, the test is carried out with the external fuse suggested by the capacitor manufacturer.

5.17.2 Disconnecting requirements

The fuse shall enable the faulty element to be disconnected when electrical breakdown of elements occurs in a voltage range, in which u_1 is the lowest and u_2 the highest value of the voltage between the terminals of the unit at the instant of fault.

The recommended values for u_1 and u_2 are the following:

$$u_1 = 0{,}8\ U_N$$

$$u_2 = U_t$$

where U_t is the test voltage according to Table 3.

NOTE The u_1 and u_2 values above are based on the voltage that may normally occur across the capacitor unit terminals at the instant of electrical breakdown of the element. The user should specify if the u_1 and u_2 values differ from the standard ones.

5.17.3 Withstand requirements

After operation, the fuse assembly shall withstand full element voltage, plus any unbalanced voltage due to fuse action, and any short-time transient overvoltage normally experienced during the life of the capacitor.

The internal fuses during the life of the capacitor shall be able to

– carry continuously a maximum unit current of 1,1 I_{max};
– withstand the unit surge current ($\hat{I}_s$);
– carry the discharge currents due to the breakdown of element(s);
– withstand the discharge test.

NOTE Guidance for fuse and disconnector protection is given in 9.13.

5.17.4 Test procedure

The disconnecting test on fuses is carried out as follows. The upper DC test voltage u_2 (see 5.17.2) is applied until at least one fuse has failed. Then, immediately, the voltage is reduced to 0,8 U_N until a further fuse fails.

The voltage across the unit shall be monitored. The voltage across the unit shall be measured throughout the test. If the voltage immediately before the fuse operates and the voltage immediately after the fuse operates differ by more than 10 %, the test shall be repeated, with extra capacitance connected in parallel to the unit under test. This test may be repeated on a new unit at the manufacturer's discretion.

The tests of fuses are performed either on one complete capacitor unit or on two units, if there is only one fuse inside.

One of the following test procedures a), b), c), d) or an alternative method shall be used. The choice is left to the manufacturer.

It is preferred to use a method where the tests can be carried out on a standard unit.

a) Mechanical puncture of the element

   Mechanical puncture of the element is made by a nail, which is forced into the element through a pre-drilled hole in the case.

   NOTE 1 Puncture of only one element cannot be guaranteed.

   NOTE 2 In order to limit the possibility of a flashover to the case along the nail, or through the hole caused by the nail, a "nail" made of insulating material may be used and/or the punctures may be performed in the element connected permanently, or during the test, to the case.

b) Electrical breakdown of the element (first method)

   Some elements in the test unit are provided with, for example, a tab, inserted between the dielectric layers. Each tab is connected to a separate terminal.

   To obtain breakdown of an element thus equipped, a surge voltage of sufficient amplitude is applied between the tab and one of the foils of such a modified element.

   Capacitor current and/or voltage shall be recorded during the test.

c) Electrical breakdown of the element (second method)

   Certain elements in the test unit are provided with a short fusible wire connected to two extra tabs and inserted between the dielectric layers, each tab being connected to a separate insulated terminal.

   To obtain breakdown of an element equipped with this fusible wire, a separate capacitor charged to a sufficient energy is discharged into the wire in order to blow it.

   Capacitor current and/or voltage shall be recorded during the test.

d) Electrical breakdown of the element (third method)

   A small part of an element (or of several elements) in a unit is removed at the time of manufacture and replaced with a weaker dielectric. For example: 10 cm^2 to 20 cm^2 of a film-paper-film dielectric is cut out and replaced with two thin papers.

   At the upper voltage limit, one additional fuse (or one-tenth of the fused elements directly in parallel) connected to a sound element(s) is allowed to be damaged.

   The test voltage shall be maintained for several seconds (minimum 10 s) after a breakdown to ensure the fuse has disconnected correctly unaided by disconnection of the power supply.

   In special cases, it may be necessary to extend the tests until two or more breakdowns of capacitor elements have occurred. The number of breakdowns at each voltage limit in such cases should be subject to agreement between the manufacturer and the user. If the number of breakdowns is exceeded, the voltages stated in 5.17.7 may have to be increased.

NOTE 3 Precautions should be taken when performing this test against the possible explosion of a capacitor unit.

NOTE 4 It is recommended to discharge all the series element groups after each test if the capacitor has internal element series connections.

5.17.5 Capacitance measurement

After the test, capacitance shall be measured to prove that the fuse(s) has (have) blown.

A measuring method shall be used that is sufficiently sensitive to detect the capacitance change caused by one blown fuse.

5.17.6 Visual checking

After the disconnecting test, no significant deformation of the case shall be apparent.

5.17.7 Voltage test

The unit shall withstand for 10 s, without further operation of fuses, a withstand test voltage. This withstand test voltage should normally be equal to the test voltage specified in Table 3, unless otherwise agreed by the manufacturer and the user in accordance with the provisions of 5.17.4 d).

5.18 Partial discharge measurements (optional type tests)

On agreement between the user and the manufacturer, a test may be performed to determine that the level of partial discharges does not affect the life performance of the capacitors.

6 Overloads

Capacitor units shall be suitable for operation at voltage levels and duration according to Table 9 without any failure. It should be recognised that any significant period of operation at voltage above the rated one will reduce the useful life.

Table 9 – Maximum permissible voltage

Overvoltage	Maximum duration within one day	Observation
1,1 U_N	30 % of on-load duration	System regulation
1,15 U_N	30 min	System regulation
1,2 U_N	5 min	System regulation
1,3 U_N	1 min	System regulation

NOTE An overvoltage equal to 1,5 U_N for 30 ms is permitted 1 000 times during the life of the capacitor.

The amplitudes of the overvoltages that may be tolerated without significant reduction in the life-time of the capacitor depend on their duration, the number of application, and the capacitor temperature.

In addition these values assume that the overvoltages may appear when the internal temperature of the capacitor is less than 0 °C but within the temperature category.

7 Safety requirements

7.1 Discharge device

The use of discharge resistors is not suitable for certain power electronic capacitors. When required by the user, each capacitor unit or bank shall be provided with means for discharging each unit in 3 min to 60 V or less, from an initial voltage U_N or U_{NDC}.

For capacitors having U_N or $U_{NDC} \geq 1\,000$ V, the discharging time shall be not more than 10 min.

NOTE Capacitors with energy above 100 J should be protected by a short circuit between terminals and terminals to case before delivery.

There shall be no switch, fuse cut-out, or any other isolating device between the capacitor unit and this discharge device.

A discharge device is not a substitute for short-circuiting the capacitor terminals together and to earth before handling.

Capacitors connected directly to other electrical equipment providing a discharge path shall be considered properly discharged, provided that the circuit characteristics are such as to ensure the discharge of the capacitor within the time specified above.

Discharge circuits shall have adequate current-carrying capacity to discharge the capacitor from the peak of the maximum overvoltage.

7.2 Case connections

To enable the potential of the metal case of the capacitor to be fixed, and to be able to carry the fault current in the event of a breakdown to the case, the case shall be provided with a connection suitable to carry the fault current, or with an unpainted non-corrodible metallic region suitable for a connecting clamp.

7.3 Protection of the environment

When the capacitor is impregnated with materials that shall not be dispersed into the environment, precautions shall be taken. In some countries, there exist legal requirements in this respect.

The user shall specify any special requirements for labelling which apply to the country of installation (see 8.1.2).

7.4 Fire hazard

According to IEC 60695-2-11 or IEC 60695-11-5. The choice of the test method may be decided by the agreement between user and manufacturer.

If IEC 60695-2-11 is chosen, test severity (see Clause 6) shall be 850 °C. For evaluation of test result, see Clause 12.

If IEC 60695-11-5 is chosen, test severity may be decided by the agreement between user and manufacturer.

7.5 Other safety requirements

The user shall specify at the time of enquiry any special requirements with regard to the safety regulations that apply to the country in which the capacitor is to be installed.

8 Markings

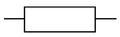
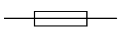
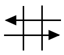
8.1 Marking of the units

8.1.1 Rating plate

The following information shall be given on the rating plate of each capacitor unit:

– Manufacturer
– Identification number and manufacturing date
– The date of manufacturing may be a part of identification number or be in code form.
– C = µF
– Tol = %
– U_{NDC} or U_N = V
– U_i = V AC (if specified, see 3.19)
– P_{max} = W (optional)
– f_2 = Hz (optional)
– I_{max} = A (optional)
– $\hat{I}_s$ = A (if any)
– θ_{min} = °C
– θ_{max} = °C
– maximum tightening torque = Nm (see note 2)
– type of cooling medium and temperature (only for forced cooling – see Clause 4)
– IEC 61881-1

The following signs shall be added if applicable:

– for internal discharge device 
– for internal fuse or disconnector 
– for self-healing capacitors SH or 
– for unprotected capacitors unprotected

NOTE 1 The location of the markings on the capacitor unit should be defined on agreement between the manufacturer and the user.

NOTE 2 For small units where it is impracticable to indicate all the above items on the rating plate, certain items may be stated in an instruction sheet.

NOTE 3 Additional data can be added to the rating plate on agreement between the manufacturer and the user.

8.1.2 Data sheet

Informations shall be provided by the manufacturer to enable correct operation of the capacitor. If the capacitor unit contains material that may pollute the environment or may be hazardous in any other way, these materials and their mass shall be declared in the data sheet according to the relevant laws of the country of the user who shall inform the manufacturer of such law(s).

9 Guide to installation and operation

9.1 General

Overstressing and overheating shorten the life of a capacitor, and therefore the operating conditions (i.e. temperature, voltage, current and cooling) should be strictly controlled.

Because of the different types of capacitors and the many factors involved, it is not possible to cover, using simple rules, installation and operation in all possible cases.

The following information is given with regard to the more important points to be considered. In addition, the instructions of the manufacturer and the power supply authorities shall be followed.

There are seven major applications:

a) internal overvoltage protection: snubber capacitors, loaded with part of sinusoidal voltages; both voltages may alternate with a certain amount of superimposed direct voltage;
b) DC harmonic filter capacitors generally loaded with a direct voltage superimposed with a non-sinusoidal alternating voltage;
c) switching circuit: commutating capacitors, generally loaded with trapezoidal voltages;
d) external AC overvoltage protection;
e) External DC overvoltage protection;
f) internal AC harmonic filter;
g) DC energy storage: auxiliary capacitors. Generally supplied with direct voltage and periodically charged and discharged with high peak current.

9.2 Choice of rated voltage

The rated voltage of the capacitor shall be equal to the recurrent peak voltage.

Most of the applications in power electronics show varying loads. Therefore it is necessary that the manufacturer and the user discuss the rated voltage and the true voltage stresses extensively.

Only in case of emergency should capacitors be operated at maximum permissible voltage and maximum operating temperature simultaneously, and then only for short periods of time (see Table 8).

NOTE The manufacturer may give the diagram of applicable voltage as a function of frequency and ambient temperature (θ_{amb}).

9.3 Operating temperature

Attention should be paid to the operating temperature of the capacitor, because this has a great influence on its life.

Temperature in excess of θ_{max} accelerates electrochemical degradation of the dielectric.

Temperature below θ_{min} or very rapid changes from hot to cold may initiate partial discharge degradation in the dielectric.

9.3.1 Installation

Capacitors shall be so placed that there is adequate dissipation by convection and radiation of the heat produced by the capacitor losses.

The ventilation of the operating room and the arrangement of the capacitor units shall provide good air circulation around each unit. This is of importance for units mounted in rows, one above the other.

The temperature of capacitors subjected to radiation from the sun or from any high temperature surface will be increased.

After installation it is necessary to verify that the temperature of the case is lower than θ_{max} with the maximum service conditions (voltage, current and cooling temperature).

Depending on the cooling air temperature, the efficiency of the cooling and the intensity and duration of the radiation, it may be necessary to adopt one of the following precautions:

– protect the capacitor from radiation;
– choose a capacitor designed for higher service air temperature or employ capacitors with rated voltage higher than that laid down in Clause 4;
– capacitors installed at high altitudes (above 1 400 m) will be subjected to decrease heat dissipation; this should be considered when determining the power of the units.

9.3.2 Unusual cooling conditions

In exceptional cases, the inlet temperature (see Table 1) may be higher than 55 °C maximum and capacitors of special design or with a higher rated voltage shall be used.

9.4 Special service conditions

Apart from high ambient temperature, other adverse conditions of use are liable to be encountered in tropical countries. When the user is aware of such conditions, the manufacturer should be informed when the capacitors are ordered.

This information should also be given to the suppliers of all associated equipment for the capacitor installation.

9.5 Overvoltages

Overvoltage factors are specified in 6.1.

With the manufacturer's agreement, the overvoltage factor may be increased if the estimated number of overvoltages is lower, or if the temperature conditions are less severe.

Capacitors that are liable to be subjected to high lightning overvoltages should be adequately protected. If lightning arresters are used, they should be located as near as possible to the capacitors.

Transient overvoltages during unusual service conditions may enforce the choice of higher rated capacitors.

When overvoltages are higher than those permitted in Table 9 (i.e. capacitors directly connected to the line) a higher voltage test may be required, on agreement between the manufacturer and the user.

9.6 Overload currents

Capacitors should never be operated with currents exceeding the maximum values defined in 3.20, 3.21 and 3.22.

Transient overcurrents of high amplitude and frequency may occur when capacitors are switched into the circuit or the equipment is switched. It may be necessary to reduce these transient overcurrents to acceptable values in relation to the capacitor and to the equipment.

If the capacitors are provided with fuses (internal or external), the peak value of the over-currents due to switching operations shall be limited to the value of $\hat{I}_s$.

9.7 Switching and protective devices

Switching and protective devices and connections shall be capable of withstanding the electrodynamics and thermal stresses caused by the transient overcurrents of high amplitude and frequency that may occur when switching on, or otherwise.

If consideration of electrodynamic and thermal stress would lead to excessive dimensions, special precautions, for the purpose of protection against overcurrents, should be taken.

NOTE Fuses in particular, should be chosen with an adequate thermal capacity.

9.8 Choice of creepage distance and clearance

According to IEC 62497-1.

9.9 Connections

The current leads into the capacitor are capable of dissipating heat from the capacitor. Equally they are capable of transferring heat generated in outer connections into the capacitor.

Therefore it is necessary to keep the connections leading to the capacitors always cooler than the capacitor itself.

Any bad contacts in capacitor circuits may give rise to arcing, causing high-frequency oscillations that may overheat and overstress the capacitors.

Regular inspection of all capacitor equipment contacts and capacitor connections is therefore recommended.

9.10 Parallel connections of capacitors

Special care is necessary when designing circuits with capacitors connected in parallel, because there are two possible dangers:

a) the current splitting depends on slight differences in resistance and inductance in the current paths, so that one of the capacitors may be easily overloaded;
b) because of the high frequencies often encountered in power electronics, interconnections should usually be designed for low inductance and resistance.

As a consequence, when one capacitor fails by a short circuit, the complete energy of the parallel capacitors will be rapidly dissipated at the point of breakdown.

Usually, it is impossible to disconnect the units by a current limiting fuse.

Special precautions have to be taken in this case.

9.11 Series connections of capacitors

Because of variations in the insulation resistance of units, the correct voltage sharing between units should be ensured by resistive voltage dividers.

AC voltages and intermittent DC application having long OFF periods need no special dividers, as the integral discharge devices will discharge any residual charge.

The insulation voltage of the units shall be appropriate for the series arrangement.

9.12 Magnetic losses and eddy currents

The strong magnetic fields of conductors in power electronics may induce alternating magnetization of magnetic cases and eddy currents in any metal part and thereby produce heat. It is therefore necessary to situate capacitors at a safe distance from heavy current conductors and to avoid the use as far as possible of magnetic materials.

9.13 Guide for internal fuse and disconnector protection in capacitors

The fuse is connected in series with the element that the fuse is designated to isolate, if the element becomes faulty.

After the breakdown of an element the fuse connected to it will blow and isolate it from the remaining part of the capacitor, which allows the unit to continue in service. The blowing of one or more fuses will cause voltage changes within the bank when series connections are used.

The voltage across sound unit(s) shall not exceed the value given in 5.17.

Depending on the internal connection of the units, the blowing of one or more fuses may also cause a change of voltage within the unit.

The remaining elements in a series group will have an increased working voltage and the manufacturer shall, on request, give details of the voltage rise caused by blown fuses.

Because of the self-healing properties of the capacitors, breakdowns are not dangerous and do not increase the current significantly. But, in the event of rising pressure (e.g. caused by thermal instability, which may occur at the end of the capacitor life or, in some cases, by an excessive number of self-healing breakdowns, caused by extreme overloads) the self-healing power capacitor shall be protected by an overpressure disconnector or overpressure detector.

These devices are not intended to protect against internal short circuits.

9.14 Guide for unprotected capacitors

For power electronics capacitors the user has to ensure by qualified installation that no danger appears due to a failing capacitor. The requirement applies in particular to unprotected capacitors.

Annex A
(informative)

Waveforms

For power electronic capacitors waveform definitions are explained through the example of a trapezoidal voltage.

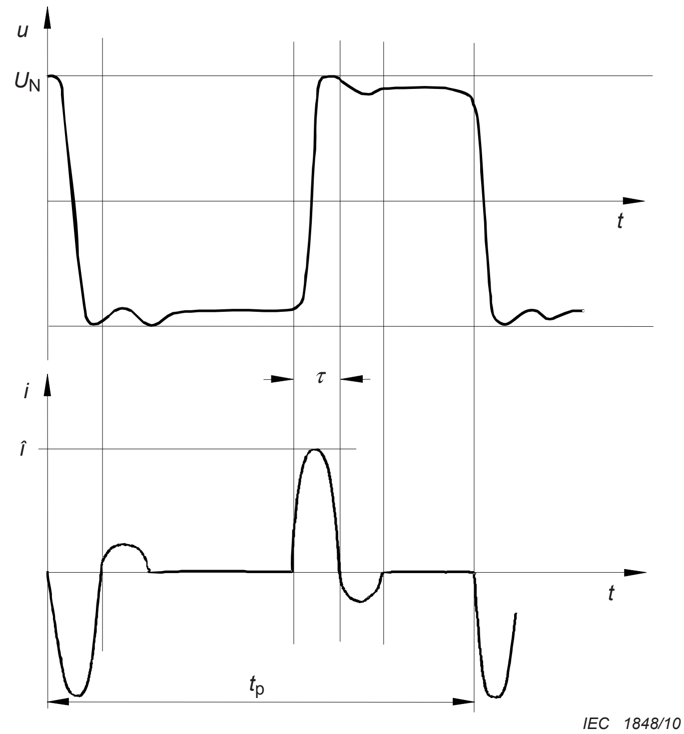


Figure A.1a – Commutating waveform

$$f_p = \frac{1}{t_p} \qquad \tau = \pi \times \sqrt{L \times C}$$

Key

τ	capacitor current pulse width
t_p	system pulse duration
f_p	system pulse frequency
U_N	peak recurrent voltage
$\hat{I}$	peak current
L	capacitor equivalent series inductance
C	capacitor capacitance

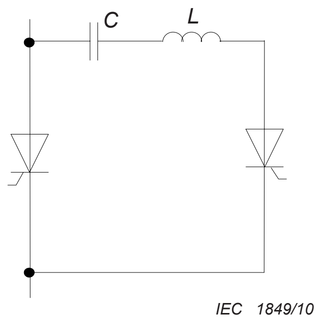


Figure A.1b – Commutating circuit example

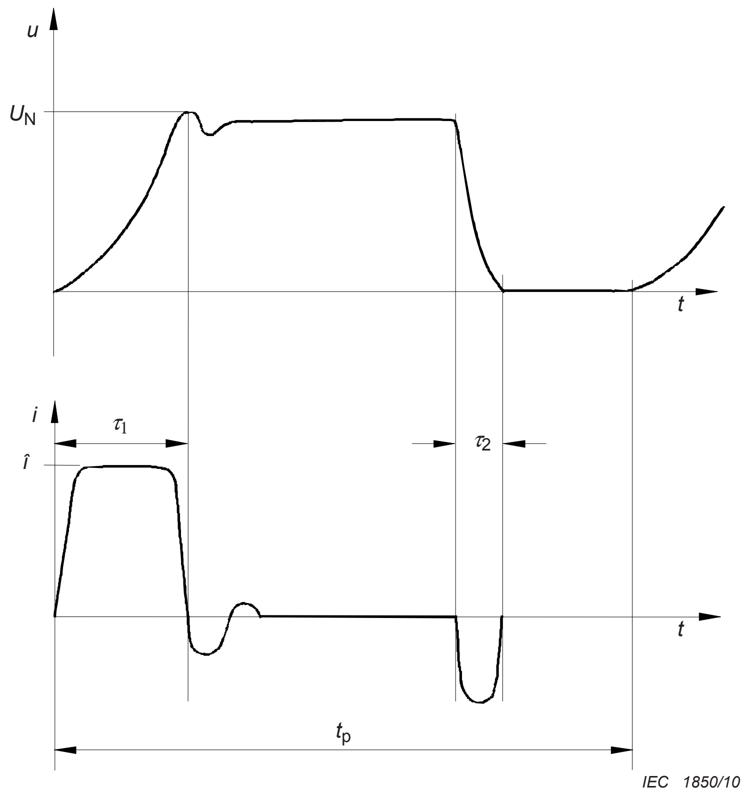


Figure A.1c – Damping capacitor for gate turn-off thyristors waveform

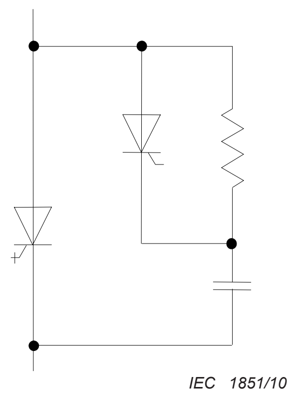


Figure A.1d – Damping circuit example

Figure A.1 – Waveforms and circuits

Annex B
(normative)

Operational limits of capacitors with sinusoidal voltages as a function of frequency and at maximum temperature (θ_{max})

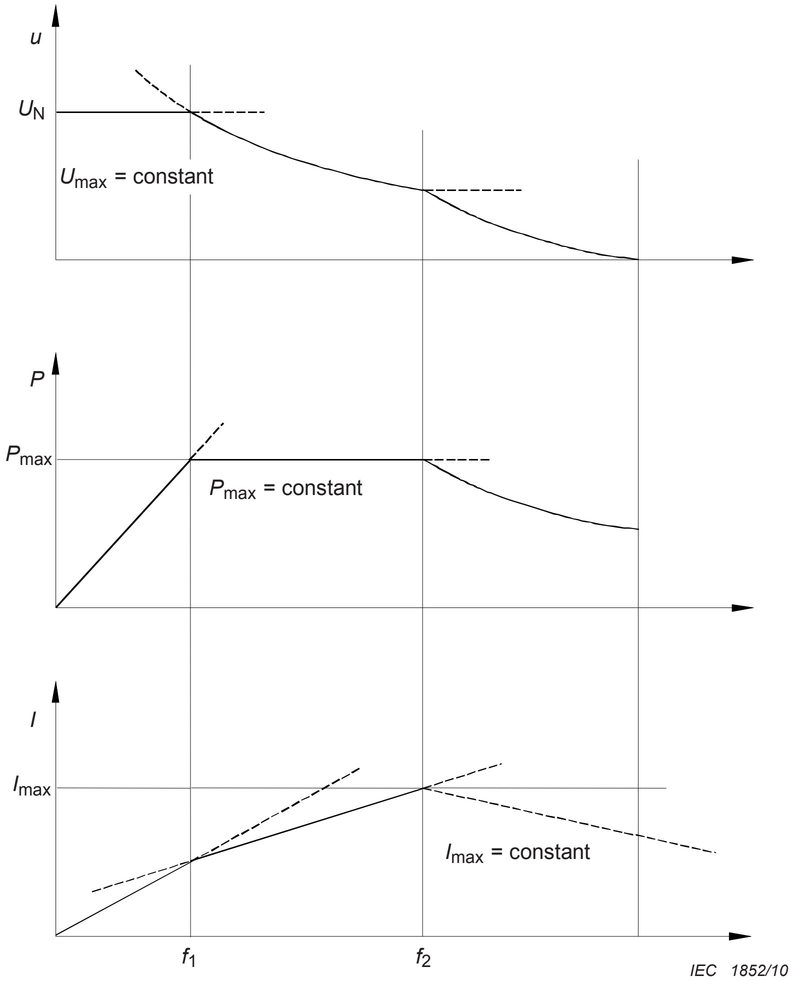


Figure B.1 – Supply conditions

The maximum voltage is in general a function of dielectric thickness (*a*), intrinsic field strength (E_D) and temperature (θ)

$$U_{max} = f\,(E_D,\ a,\ \theta)$$

For the frequency range $f \leq f_1$ the following is valid:

$$U_{max} = U_N$$

f_1 is the frequency at which the power loss of the capacitor is maximum.

$$P_{max} = \frac{U_N^2}{2}\ \ \omega \times C\ \tan\delta_1 \qquad \omega = 2\pi f_1$$

f_2 is the frequency at which the maximum current (I_{max}) produces the maximum power loss (P_{max}) in the capacitor.

For the frequency range f_1 to f_2

$$P_{max} = \text{constant}$$

and f_2 is the frequency at which the effective current reaches its maximum:

$$I = I_{max}$$

Above the maximum frequency the maximum current shall be reduced due to skin effect, etc.

The characteristic values of the capacitors are the following:

U_{max}	maximum voltage
P_{max}	maximum power loss
$\tan \delta_1$	capacitor loss tangent at the frequency f_1
$\tan \delta_2$	capacitor loss tangent at the frequency f_2
f_2	maximum frequency for full power loss and maximum current
I_{max}	maximum current r.m.s. value

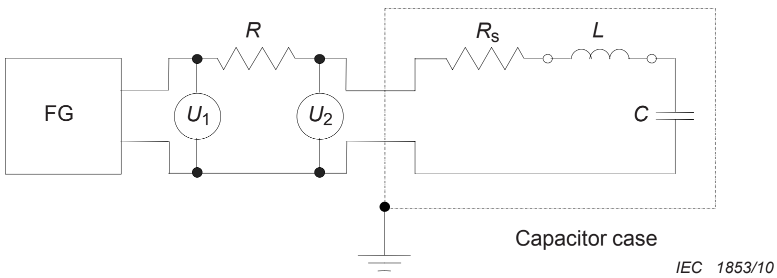
NOTE The suggested thermal stability test conditions are the following:

$$1{,}21\ P_{max} = \frac{U^2}{2} \times \omega_2 \times C \times \tan \delta_2 = 1{,}21 \times \frac{I_{max}^2}{\omega_2 \times C} \times \tan \delta_2 \qquad \omega_2 = 2\pi f_2$$

Annex C
(normative)

Resonance frequency measuring methods – Examples

C.1 Method 1



Key

FG variable frequency generator

R non-inductive load resistance directly connected to the tested capacitor terminals

R_s capacitor equivalent series resistance

L capacitor equivalent series inductance

C capacitor capacitance

U_1 U_2 electronic voltmeters

Figure C.1 – Measuring circuit

By changing a frequency and keeping U_1 constant, it is possible to plot a graph which shows the relation between the voltage across the capacitor and the supply frequency. The minimum value of U_2 corresponds to the resonance frequency (f_r).

The connections shall be as short as possible.

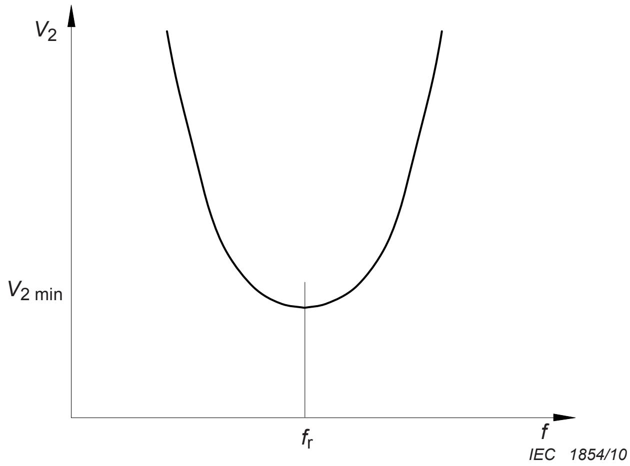


Figure C.2 – Relation between the voltage across the capacitor and the supply frequency

NOTE This frequency is equal to self resonance frequency if the external inductance of the connections is negligible in comparison with that of internal connections.

C.2 Method 2

The unit shall be charged by means of DC and then discharged through a gap situated directly at the capacitor terminals.

The discharge current wave shape is recorded by an oscilloscope.

f_r is evaluated by computation of the number of intersections of the time axis.

The shape of the discharge waveform is a function of the equivalent series resistance and the stray inductance.

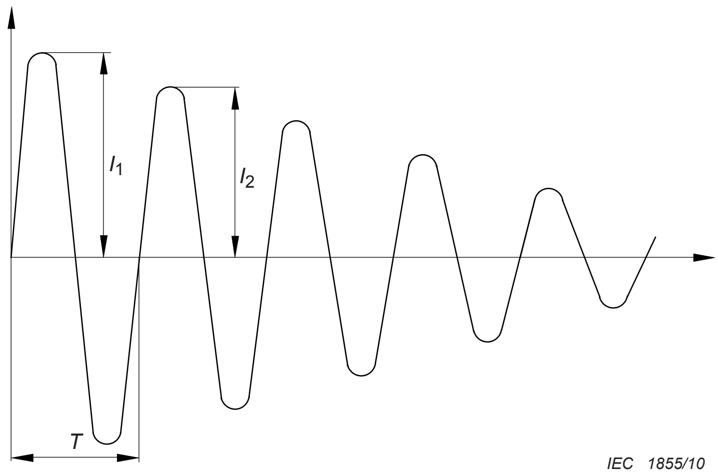


Figure C.3 – Discharge current wave shape

NOTE With the second method the discharge frequency is measured. This is equal to self-resonance frequency if the damping factor is low and if the external inductance of the connections is negligible in comparison with that of internal connections.

In any case the damping factor can be taken into account to calculate the self-inductance.

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