# IEC 61071

Edition 2.0 2017-08
REDLINE VERSION

# INTERNATIONAL STANDARD



colour inside

## Capacitors for power electronics

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## Capacitors for power electronics

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# CAPACITORS FOR POWER ELECTRONICS

## FOREWORD

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**This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.**

International Standard IEC 61071 has been prepared by IEC technical committee 33: Power capacitors and their applications.

This second edition cancels and replaces the first edition published in 2007. This edition constitutes a technical revision.

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

- Introduction of new terms and definitions
- clarifications for surge discharge test
- indications for measuring procedure during thermal stability test
- clarifications for self-healing test
- clarifications for endurance test
- clarifications for destruction test
- update of normative references
- general editorial review

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

| FDIS | Report on voting |
|---|---|
| 33/610/FDIS | 33/612/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.

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- withdrawn,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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# CAPACITORS FOR POWER ELECTRONICS

## 1 Scope

This International Standard applies to capacitors for power electronics applications.

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.

The document distinguishes between AC and DC capacitors which are considered as components when mounted in enclosures.

This document covers an extremely wide range of capacitor technologies for numerous applications, e.g. overvoltage protection, DC and ~~a.c.~~ filtering, switching circuits, ~~d.c.~~ energy storage, auxiliary inverters, etc.

The following are excluded from this document:

- capacitors for induction heat-generating plants operating at frequencies ~~between 40 Hz and 24 000 Hz~~ range up to 50 kHz (see IEC 60110-1 and IEC 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~~ the IEC 60871 standards);
- 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~~ the IEC 60931 standards);
- electronic capacitors not used in power circuits;
- series capacitors for power systems (see IEC 60143);
- coupling capacitors and capacitors dividers (see IEC 60358);
- capacitors for microwave ovens (see IEC 61270-1);
- capacitors for railway applications (see IEC 61881).

Examples of applications are given in 9.1.

## 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 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

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: ~~Soldering~~ 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 60071-1, *Insulation coordination – Part 1: Definitions, principle and rules*~~

~~IEC 60071-2, *Insulation coordination – Part 2: Application guide*~~

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

IEC 60664-1, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

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

IEC 60695-2-12, *Fire hazard testing – Part 2-12: Glowing/hot-wire based test methods – Glow-wire flammability index (GWFI) test method for materials*

IEC 60947-1:2007, *Low-voltage switchgear and controlgear – Part 1: General rules*

## 3 Terms and definitions

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

**3.1**
**capacitor element (or element)**
device consisting essentially of two electrodes separated by a dielectric

[SOURCE: IEC 60050-436:1990, 436-01-03]

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

[SOURCE: IEC 60050-436:1990, 436-01-04]

**3.3**
**capacitor bank**
number of capacitor units connected so as to act together

[SOURCE: IEC 60050-436:1990, 436-01-06]

**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 in power electronic equipment

**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

Note 1 to entry: In the event of a breakdown of the dielectric, the capacitor does not restore itself.

**3.8**
**self-healing metallized dielectric capacitor**
capacitor, of which at least one electrode consists of a metallic deposit on the dielectric

Note 1 to entry: In the event of local breakdown of the dielectric, the electric properties of the capacitor are rapidly and essentially self-restored.

**3.9**
**AC capacitor**
capacitor essentially designed for operation with alternating voltage

Note 1 to entry: 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 1 to entry: DC capacitors may be used with a specified AC voltage only where authorized by the capacitor manufacturer.

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

Note 1 to entry: The model unit may be of a different size from the complete unit.

Note 2 to entry: The combined sum of stresses should always be considered, for instance the sum of temperature and mechanical conditions as well as electrical stresses.

**3.12**
**internal (element) fuse**
fuse connected inside a capacitor unit, in series with an element or a group of elements

[SOURCE: IEC 60050-436:1990, 436-03-16]

**3.13**
**safety devices**

**3.13.1**
**overpressure disconnector**
disconnecting device inside a capacitor, designed to interrupt the current path in case of abnormal increase of internal overpressure

**3.13.2**
**overpressure detector**
device designed to detect abnormal increase of the internal pressure, usually used to operate an electrical switch and indirectly interrupt the current path

**3.13.3**
**segmented metallization design**
pattern 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 Us guarantee the full functionality of the unit with a negligible loss of capacitance.

**3.14**
**safety protection**
**protected capacitor**
capacitor that can be submitted to the destruction test as described at 5.16

Note 1 to entry: protected capacitors alone are not sufficient to prevent all possible dangers in case of malfunction.

**3.15**
**unprotected capacitor**
capacitor that don't meet the destruction test as described at 5.16

**3.16**
**discharge device of a capacitor**
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

[SOURCE: IEC 60050-436:1990, 436-03-15, modified ("to a given value" replaced by "practically to zero")]

**3.17**
**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 to entry: The waveform can have many shapes. Examples are given in Annex A.

Note 2 to entry: The mean value of the waveform may be positive or negative.

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

**3.18**
**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

Note 1 to entry: 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 ($U_{rev}$), the use should be agreed between user and manufacturer.

Note 2 to entry: If the reversal voltage is small (less than 10 %), the voltage waveform can be considered to be non- reversing. For test purposes, $U_{NDC}$ and $U_r$ should be increased by Urev, the reversal voltage.

**3.19**
**ripple voltage**
$U_r$
peak-to-peak alternating component of the unidirectional voltage

**3.20**
**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

**3.21**
**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

**3.22**
**maximum peak current**
$\hat{I}$
maximum repetitive peak current that can occur during continuous operation

**3.23**
**maximum current**
$I_{max}$
maximum r.m.s. current for continuous operation

**3.24**
**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

**3.25**
**pulse frequency**
$f_p$
repetition rate of periodic current pulses

**3.26**
**current pulse width**
$\tau$
time of current flow during charging or discharging from one voltage value to another, of the capacitor

Note 1 to entry: Pulse current waveform examples are shown in Annex A.

**3.27**
**resonance frequency**
$f_r$
lowest frequency at which the impedance of the capacitor becomes minimum

**3.28**
**duty cycle**

**3.28.1**
**continuous duty**
operation time such that a capacitor is at thermal equilibrium for most of the time

**3.28.2**
**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**~~
~~**highest operating temperature**~~
~~temperature of the hottest point on the case of the capacitor when in thermal equilibrium~~

**3.29**
**thermal equilibrium**
state of a capacitor when the temperature measured anywhere on its case or internally is less than 3K above or below that temperature which would be reached after waiting an infinitely long time under fixed conditions of ambient temperature, cooling, and internal power loss

**3.30**
**thermal time constant**
measure of the time required for a capacitor to reach thermal equilibrium after a change in ambient temperature, cooling, or internal power loss

**3.31**
**lowest operating temperature**
$\theta_{min}$
lowest temperature of the dielectric at which the capacitor may be energized

**3.32**
**container temperature rise**
$\Delta\theta_{case}$
difference between the temperature of the hottest point of the container and the temperature of the cooling air

**3.33**
**cooling-air temperature**
$\theta_{amb}$
temperature of the cooling air measured at the hottest position of the capacitor, under steady-state conditions, midway between two units

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

**3.33.1**
**outlet fluid temperature for forced-cooled capacitors**
temperature of the cooling fluid as it leaves the capacitor, measured at the hottest point

**3.33.2**
**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

**3.34**
**maximum operating temperature**
$\theta_{max}$
highest temperature of the case at which the capacitor may be operated under steady state condition

**3.35**
**hotspot temperature**
the highest temperature present inside the capacitor dielectric

**3.36**
**steady-state conditions**
thermal equilibrium attained by the capacitor at constant output and at constant cooling ~~air temperature~~ conditions

**3.37**
**capacitor losses**
active power dissipated in the capacitor

Note 1 to entry: 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.

[SOURCE: IEC 60050-436:1990, 436-04-10]

**3.38**
**tangent of the loss angle of a capacitor**
**tan $\delta$**
ratio between the equivalent series resistance and the capacitive reactance of a capacitor at a specified sinusoidal alternating voltage, frequency and temperature

Note 1 to entry: $\tan\delta = R_{esr}\,\omega C = \tan\delta_d + R_s\,\omega C$

$\tan\delta_d$ = dielectric loss factor

[SOURCE: IEC 60050-436:1990, 436-04-11]

**3.39**
**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

**3.40**
**series resistance**
$R_s$
effective ohmic resistance of the conductors of a capacitor under specified operating conditions

**3.41**
**maximum power loss**
***P*_max_**
maximum power loss at which the capacitor may be operated at the maximum case temperature

**3.42**
**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

Note 1 to entry: For explanation of $f_2$, see ~~Annex B~~ Figure B.1.

# 4 Service conditions

## 4.1 Normal service conditions

### 4.1.1 General

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

### 4.1.2 Altitude

Altitude shall not exceed 1 000 m unless the effects on cooling and external insulation are taken into account.

NOTE The effect of altitude on convection cooling and external insulation ~~should~~ has to be taken into consideration, if the altitude exceeds 1 000 m.

### 4.1.3 Operating temperature ($\theta_{max}$)

The upper limit of the case temperature $\theta_{max}$ at which the capacitor may be operated, shall normally be chosen from the values 45 °C, 55 °C, 70 °C and 85 °C. A different maximum operating temperature shall be subject to agreement between manufacturer and user.

### 4.1.4 Operating temperature with forced cooling

If capacitors are intended for use with forced cooling using a fluid medium, the operating temperature conditions specified in 4.1.~~2~~3 shall be observed. The lowest inlet temperature for the cooling fluid should be defined, taking into account the viscosity of the fluid.

There are two methods for specifying the upper temperature limit of the cooling medium, using either the inlet or the outlet cooling fluid 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 such unusual service conditions.

If such unusual service conditions exist then they ~~must~~ 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 1 000 m above sea level.
- superimposed electromagnetic fields.
- excessive overvoltages, as far as they exceed the limits given in Clause 6.

# 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 range of +5 °C to +35 C. If corrections are necessary, the reference temperature shall be +20 C, unless otherwise agreed between the manufacturer and the user.

NOTE It is 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 substantially sinusoidal voltage at a frequency specified by the manufacturer.

## 5.2 Classification of tests

### 5.2.1 General

The tests are classified as routine tests and type tests.

### 5.2.2 Routine tests

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 $\delta$ 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 above.

#### 5.2.3 Type tests

a) Mechanical tests (5.14).
b) Voltage test between terminals (5.5.3).
c) Voltage test between terminals and case (5.6.2).
d) Surge discharge test (5.9).
e) Self-healing test (5.11).
f) Environmental testing (5.13).
g) Measurement of the tangent of the loss angle (tan $\delta$) (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.

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.

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.



### 5.3 Capacitance and tan δ measurements (routine test)

#### 5.3.1 Measuring procedure

The capacitance and tan $\delta$ shall be measured at a voltage and 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 $\delta$.

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 $\delta$)

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

### 5.4 Measurement of the tangent of the loss angle (tan $\delta$) of a capacitor (type test)

#### 5.4.1 Measurements

##### 5.4.1.1 General

The following measurements shall be made.

##### 5.4.1.2 AC capacitors

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

##### 5.4.1.3 DC capacitors

The measurement shall be carried out at the end of thermal stability test at an AC voltage appropriate to capacitor rating, subject to this voltage being a maximum of $U_r$ divided by $2\sqrt{2}$.

#### 5.4.2 Loss requirements

The value of tan $\delta$ 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 Table 1.

**Table 1 – 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 1 can be reduced if capacitors are intended for intermittent duty (see 3.27) or for short service duration; the new values shall be agreed upon between the manufacturer and the user.

NOTE The AC test voltage ~~may~~ has to be at a frequency of 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 %.

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 The routine test is intended to be applied once. If repeated it ~~should~~ has to be carried out at 90 % of the original value unless agreed ~~differently~~ otherwise ~~by~~ with the manufacturer.

### 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 voltage test between terminals the capacitance and tan $\delta$ shall be measured.

## 5.6 AC voltage test between terminals and case

### 5.6.1 Routine test

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

The test voltage values are the following:

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

where $U_{\text{i}}$ is the insulation voltage.

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

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 container in service.

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

Units having insulated containers shall not be subjected to this test.

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

NOTE 2 The voltage test between the overpressure detector and the container ~~should~~ has to be be agreed between user and manufacturer.

NOTE 3 This test can be carried out a maximum of two times on the same capacitor.

### 5.6.2 Type test

Units having all terminals insulated from the container shall be subjected to a test according to 5.6.1 with the same voltage value, but with a duration of 1 min. Capacitors with insulating container shall have a metal foil tightly wrapped all around them during the test. The foil shall be connected to one terminal of the test supply.

## 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

The unit (in a non-painted state) shall be exposed to a test that will effectively detect any leak of the container and terminals. The test procedure is left to the manufacturer who shall describe the method concerned.

If no procedure is stated by the manufacturer the following test procedure shall apply.

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 by agreement between the manufacturer and the user, taking into account the use position of the device.

NOTE If the capacitor contains no liquid material, the choice to carry out this test or not is left to the manufacturer and it ~~should~~ has to be 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 short-circuiting device situated as close as possible to the capacitor. They shall be subjected to five such discharges ~~within 10 min~~.

~~The test voltage shall be equal to 1,1~~ ~~$U_{NDC}$~~

~~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 (surge) discharge test and after the voltage test.

The two measurements shall not differ 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 $\delta$ is the value after the test, tan $\delta_o$ before the test.

For capacitors without specified surge current limitation (short-circuit-proof capacitors), the test voltage for the surge discharge test shall be equal to 1,1 $U_N$ or 1,1 $U_{NDC}$.

Test voltages higher than 1,1 $U_N$ or 1,1 $U_{NDC}$ have to be agreed between manufacturer and user.

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

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

NOTE Be aware of the energy stored in the capacitor during surge-discharge testing.

### 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 ($\theta_{amb}$) + 5 °C~~ 5 degrees above the highest temperature of the ambient ($\theta_{amb}$) at which the capacitor can operate under steady state condition at $P_{max}$;
b) for forced cooling, 5 degrees above the specified outlet cooling temperature at which the capacitor can operate under steady state condition at $P_{max}$ + 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 supply conditions are those indicated in ~~Annex B~~ Figure B.1 with the equal power to 1,21 $P_{max}$.

For pure AC capacitors of single frequency the maximum reactive power is the base for the determination of the test conditions and the calculations. The thermal stability test should be performed with a reactive power of $Q_{test}$ = 1,21 $Q$ [$Q_{test}$ = 1,21 $(U_N)^2$ / 2 x $\omega$ C] which is equivalent to 1,21 $P_{max}$.

During the last 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 K.

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 for non-self-healing capacitors 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 $\delta$ measurement is performed (see 5.4.1).~~

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

At the end of this test, the tan $\delta$ measurement is performed (see 5.4.1).

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

Tan $\delta$ is the value after the test, tan $\delta_o$ before the test.

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~~ has to be 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~~ can be performed, on agreement between the manufacturer and the user, with a non-sinusoidal voltage, provided the value of power loss remains at 1,21 $P_{max}$.

NOTE 3 The test is not intended to be representative of the final application

### 5.11 Self-healing test

The purpose of the test is to confirm the presence of self-healing technology. This test is applicable only to self-healing capacitors and 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.

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 (~~1,5~~ 2,15 $U_N$ for a.c. 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 or more 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 $\delta$ 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 $\delta$ is the value after the test, tan $\delta_o$ is the value 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~~ Figures C.1, C.2 and C.3.

This measurement is not necessary for all applications.

NOTE 1 The self inductance is calculated from the resonance frequency and the value of self inductance ~~should~~ has not to exceed the value agreed upon between the manufacturer and the user.

NOTE 2 Modern equipments can require the capacitor to have very low self inductance for correct operation.

## 5.13 Environmental testing

### 5.13.1 Change of temperature

The ~~change~~ test of temperature ~~test~~ change 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 K/min).

### 5.13.2 Damp heat, steady state

The damp heat steady-state test (test Cab) 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~~ test condition as described at 5.1.2. After completion of the steady-state test, the capacitor shall be subjected to a voltage test between terminals in accordance with 5.5.~~1~~2, and a voltage test between terminals and container in accordance with 5.6.1.

Finally a capacitance measurement shall be carried out in accordance with 5.3.1 at stable ~~room temperature~~ at test condition as described at 5.1.2.

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

## 5.14 Mechanical testing

### 5.14.1 Mechanical tests of terminals

The robustness of terminations shall be tested in accordance with Table 2.

**Table 2 – Testing the robustness of terminals**

| 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<br>Size A |

### 5.14.2 External inspection

Capacitors are visually examined and checked for finish, marking and overall dimensions.

### 5.14.3 Vibration and shocks

This test shall be performed only at the request of the user and agreed with the manufacturer.

a) Vibration, in accordance with IEC 60068-2-6.

   1) For capacitors of weight not exceeding 3 kg:

$f$ = 10 Hz to 55 Hz

$a$ = ±0,35 mm

Test duration per axis = 10 frequency cycles (3 axes offset from each other by 90°), 1 octave/min.

2) For capacitors whose weight exceeds 3 kg: the choice of the test condition shall be agreed between the manufacturer and user.

b) Impacts: the choice of the test condition shall be agreed between the manufacturer and user.

Before and after the mechanical tests, the capacitance shall be measured. No change of the capacitance equal to/higher than 0,5 % shall be permitted.

### 5.15 Endurance test

#### 5.15.1 General

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 capacitor.

#### 5.15.2 Conditioning of the units before the test

The unit 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. The unit shall be allowed to cool down and reach thermal equilibrium at room temperature after conditioning.

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

#### 5.15.3 Initial capacitance and loss factor measurements

~~The unit 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.~~

The unit shall be tested for capacitance and tan δ per 5.3 at test condition as described at 5.1.2. The ambient temperature during this measurement shall be recorded.

#### 5.15.4 Endurance test

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

The test unit shall be placed in the heated chamber and energized at the appropriate conditions as described in Table 3. AC and D.C. 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 ($\theta_{max}$) during maximum continuous operating condition, i.e. excluding short time and exceptional conditions.

The test voltage $U_t$ (pure d.c. voltage equal to $U_{NDC}$ or a.c. 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 3. 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~~21).

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

~~As soon as possible~~ Following the 1 000 surge-discharges, the capacitor~~s~~ shall be energized again in order to complete the test.

**Table 3 – 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 (see 5.1.2) | 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 (see 5.1.2) | 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 (see 5.1.2) | 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 (see 5.1.2) | 1 000 times |
| | | 1,25 $U_N$ | Test temperature | 500 h |
| The conditions during this test may be different to the service conditions, e.g. 50 Hz or 60 Hz for all a.c. capacitors.<br><br>Additional cooling has to be used if the temperature of the case exceeds $\theta_{max}$.<br><br>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 a.c. capacitors. | | | | |

Due to the length of this test, voltage interruptions are allowed. During these interruptions, the unit has to remain in the controlled ambient. If power is lost to the chamber, the ambient test temperature shall be established for 12h prior to re-energization of the units.

NOTE The purpose of the tests is not to predict the capacitor lifetime but to show the capability of the capacitor to work under stringent conditions.

### 5.15.5 Final capacitance and tan $\delta$ measurement

The measurement shall be performed as indicated in 5.3 within two days after completing the endurance test. The ambient temperature during the final measurements shall not differ more than ±2 °K from the temperature recorded during the initial measurements.

### 5.15.6 Acceptance criteria

The capacitance measurement performed in Clauses 5.15.3 and ~~7~~ 5.15.5 shall differ by not more than 3 % of the initial values. The losses shall be reported.

If the unit/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 and to prove the proper work of the safety system within the specification limits. Completely safe failure during this test cannot be guaranteed.

This test shall be applied ~~only~~ to protected capacitors (see 8.1.1 ~~with any safety system~~). However, the following notes should be taken into account.

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

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

NOTE 1 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~~ has to be considered in the application. Compliance with 5.16 does not guarantee safe end of life of a capacitor.

NOTE 2 successful completion of the test is not sufficient to guarantee the total safe failure of the components in service. For this reason, there is a residual risk of fire and/or explosions that has to be carefully taken in consideration.

The destruction test shall be carried out related to the type of safety system and to the main application of capacitors, according to Table 4. Performing of the test by applying DC-AC cycles or DC-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.

**Table 4 – Destruction test as a function of type of safety system**

| Type of unit | Safety system | Main application | Test subclause |
|---|---|---|---|
| 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 or 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 a.c. 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 5.17.4. 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 operating temperature 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 F or the status of the overpressure detector shall be checked. If the fuse F 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 F 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 fused 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~~ shall 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 $I_{max}$.

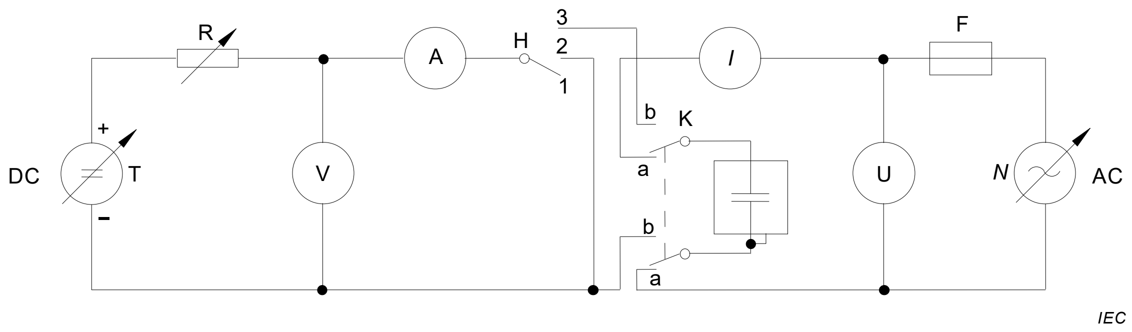



**Figure 1 – Destruction test arrangement**

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~~ has to 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~~ has to 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 $I^2t$, this information can reasonably help the designer to estimate the risk of explosion.

### 5.16.3 Test sequence for d.c. 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 ~~d.c.~~, as an alternative, when AC or DC low voltage with low internal impedance is applied.

The failure of non-self-healing capacitors with internal fuses may be promoted according to the procedures of 5.17.4. 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 operating temperature 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 F shall be not less than 2 $I_{max}$. A 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 $U_{NDC}$ 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 F 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 F 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 $U_{NDC}$.

   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 fused segmented ~~or special unsegmented~~ design, another sample may be used, and/or test voltage and test time may be increased, or the unit shall be subjected to an externally operated overpressure until the disconnector or the overpressure detector has operated. The value of this pressure shall be given by the manufacturer.

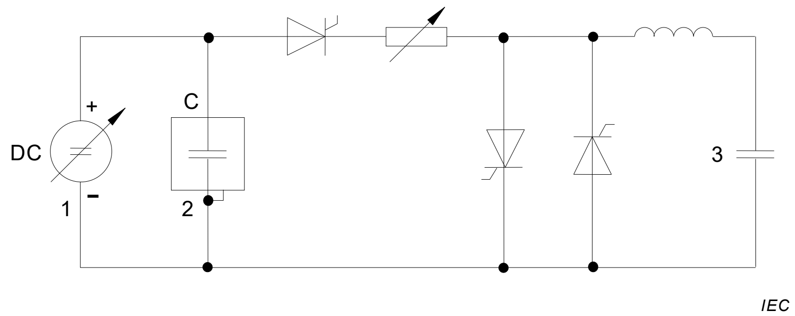
When the procedure is interrupted, the capacitor is cooled to the ambient temperature, and the voltage test between terminals and terminals and case shall be carried out according to 5.5 and 5.6.

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 d.c. current is generated by a diode bridge. The d.c. and a.c. generators shall be adjustable.

Item a) of 5.16.3 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 $I_{max}$.



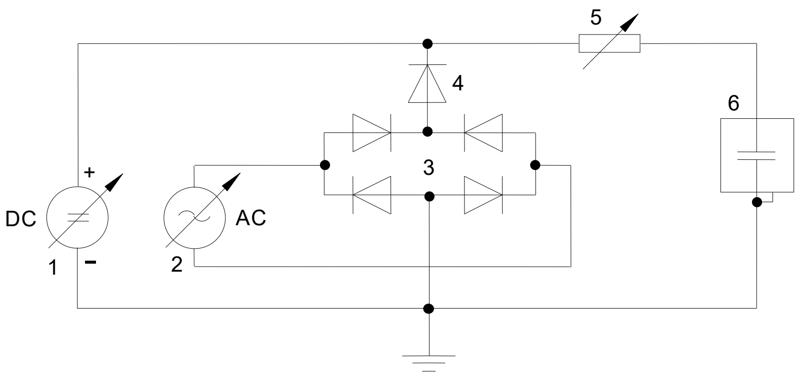

**Key**

1 high-voltage, high-current DC generator

2 specimen under test

3 inverter device, thyristors, inductor

**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~~ has to be performed by putting a corresponding capacitance in parallel with the *N* source.

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

NOTE ~~3~~ 2 If the capacitor unit is too large or too small to comply with the test parameters, the test ~~should~~ has to be performed on agreement between the manufacturer and user.

The AC voltage shall be selected in such way as to allow a circulation of the short-circuit current.

In case of protected self-healing capacitors ~~with segmented or special unsegmented design,~~ other methods to demonstrate the ability of a capacitor to lose 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 determinated 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:

$$u_1 = 0{,}8 \cancel{\sqrt{2}}\ U_N$$

$$u_2 = \cancel{\sqrt{2}}\ U_t$$

where $U_t$ is the test voltage according to Table 1.

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~~ has to 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 at the upper and at the lower voltage limits. The upper d.c. 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 measured throughout the test. If the voltage immediately before and 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 container.

NOTE 1 Puncture of only one element cannot be guaranteed.

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

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 1 Precautions ~~should~~ has to be taken when performing this test against the possible explosion of a capacitor unit.

NOTE 2 In case of internal element series connections it is recommended ~~to discharge~~ that all the series element groups be discharged 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 container shall be apparent.

### 5.17.7 Voltage test

The unit shall withstand for 10 s, without further operation of fuses, a voltage test. This withstand test voltage should normally be equal to the test voltage specified in Table 1, unless otherwise agreed by the manufacturer and the user in accordance with the provisions of item d) of 5.17.4.

# 6 Overloads

## 6.1 Maximum permissible voltages

Capacitor units shall be suitable for operation at voltage levels and duration according to Table 5 without any failure. It should be recognised that any significant period of operation at voltages above the rated one will reduce overall life

**Table 5 – Maximum permissible voltages**

| 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 |
| An overvoltage equal to 1,5 $U_N$ for 30 ms is permitted 1 000 times during the life of the capacitor.<br><br>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.<br><br>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.<br><br>The average applied voltage shall not be higher than the specified voltage. | | |



# 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 10 min to 75 V or less, from an initial voltage $U_N$ or $U_{NDC}$.

Capacitors without discharge resistors and with energy above 100 J shall 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 container 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)~~.

Products of combustion shall be environmentally acceptable. Self extinguishing materials are necessary for the terminals (test temperature 750 °C: see IEC 60695-2-11 or IEC 60695-2-12.

### 7.4 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

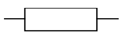
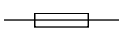
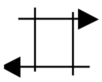
### 8.1 Marking of the units – Rating plate

~~**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.
- Capacitance (µF)
- Tolerance (%)
- $U_{NDC}$ or $U_N$ (volts)
- $U_i$ (volts, a.c.) (if specified, see 3.~~19~~20)
- ~~$P_{max}$ (optional) (watts)~~
- ~~$f_2$ (optional) (Hz )~~
- $I_{max}$ (optional) (A)
- $\hat{I}_s$ (if any) (A)
- $\theta_{min}$ ( °C)
- $\theta_{max}$ ( °C)
- Maximum tightening torque (Nm) (see note 2)
- Type of cooling medium and temperature (only for forced cooling – see Clause 4)
- Reference to this standard.

The following signs shall be added if applicable:

- for internal discharge device 
- for internal fuse or disconnector 
- for self-healing capacitors SH or 
- type of protection: protected / unprotected

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

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 given in an instruction sheet.~~

NOTE ~~3~~ 2 Additional data can be added to the rating plate, or additional warning plate, on agreement between the manufacturer and the user.

## 9 Guidance on 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 capacitor 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 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 shaped 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, not so much because of the intrinsic stress, but because the high values of d$V$/d$t$ in power electronics may induce partial discharge and losses which affect the capacitor life.

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 5).

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

## 9.3 Operating temperature

### 9.3.1 General

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

Temperature in excess of $\theta_{max}$ accelerates electrochemical degradation of the dielectric.

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

### 9.3.2 Installation

Capacitors shall be so placed that there is adequate dissipation by convection, conduction and radiation of the heat produced by the capacitor losses. The losses generated by associated equipment shall be taken into account.

The cooling of the operating enclosure and the arrangement of the capacitor units shall provide adequate cooling of 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 be lower than $\theta_{max}$ with the maximum service conditions (voltage, current and cooling temperature).

Depending on 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 and 9.2;
- capacitors installed at altitudes above 1 000 m will be subjected to decrease heat dissipation; this should be considered when determining the power of the units.

### 9.3.3 Unusual cooling conditions

In exceptional cases, the inlet temperature 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. 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.

The most important conditions are the following:

a) Frequent occurrence of periods of high relative humidity

It may be necessary to use insulators of special design. Attention is drawn to the possibility of external fuses being shunted by a deposit of moisture on their surfaces.

b) Rapid mould growth

Metals, ceramic materials and some paints and lacquers do not support mould growth. When fungicidal materials are used, they do not retain their poisoning property for more than several months; in any case, mould may develop in an installation on places where dust etc. can settle.

c) Corrosive atmospheres are found in industrial and coastal areas

It should be noted that in climates of higher temperature the effects of such atmospheres may be more severe than in temperate climates. Highly corrosive atmospheres may be present even in indoor application.

d) Pollution

When capacitors are mounted in a location with a high degree of pollution, special precautions shall be taken.

e) Altitude exceeding 1 000 m

Capacitors used at altitudes exceeding 1 000 m are subject to special conditions. The choice of the type shall be made by agreement between the user and the manufacturer (see 4.2).

### 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 5 (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 Overcurrents

Capacitors should never be operated with currents exceeding the maximum values of the parameters defined in ~~3.20,~~ 3.21, 3.22 and 3.23.

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.

### 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~~ has to be chosen with an adequate thermal capacity.

### 9.8 Choice of creepage distance and clearance

#### 9.8.1 Creepage distance

The recommendations given in IEC 60664-1 shall apply. The user shall specify which one of the pollution levels, or specific creepage distance, is applicable. Table 15 of IEC 60947-1:2007 gives specific creepage distances for different pollution levels.

#### 9.8.2 Air clearances

Guidelines for selection of air clearance distance are found in IEC 60947-1. Table 13 of IEC 60947-1:2007 gives specific clearance distances for different impulse voltages.

### 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

In d.c. capacitors, because of variations in the insulation resistance of units, the correct voltage sharing between units should be ensured by resistive voltage dividers for safety reasons. The lifetime of the resistor must not be shorter than the lifetime of the equipment.

NOTE Interruption in a resistor leads to overcharging of the affected capacitor.

AC voltages and intermittent d.c. 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 Guidance 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 electronics capacitor shall be protected by an overpressure disconnector or overpressure detector.

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

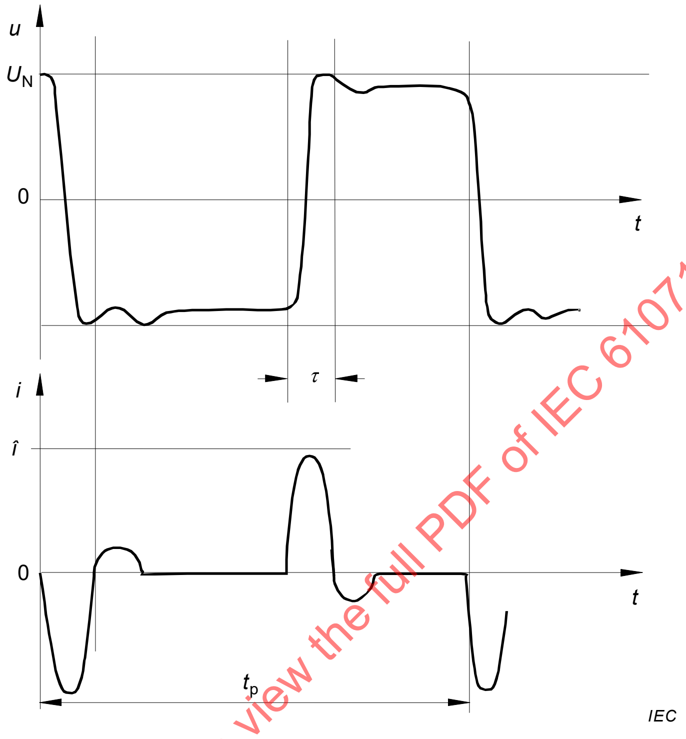
### 9.14 Guidance for unprotected capacitors

For power electronics capacitors, the user has to assure by qualified installation, that no danger appears due to a failing capacitor. This 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, as shown in Figure A.1.




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

**Key**

$\tau$ capacitor current pulse width

$t_p$ system pulse duration

$f_p$ system pulse frequency

$U_N$ peak recurrent voltage

$\hat{\imath}$ peak current

$L$ inductance of the inductor connected in series with the capacitor

$C$ capacitor capacitance

**Figure A.1a – Commutating waveform**

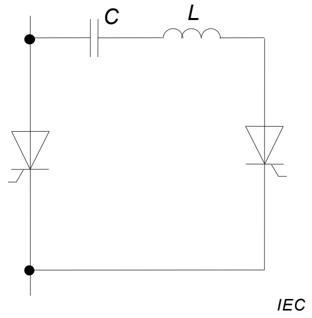



Figure A.1b – Commutating circuit example

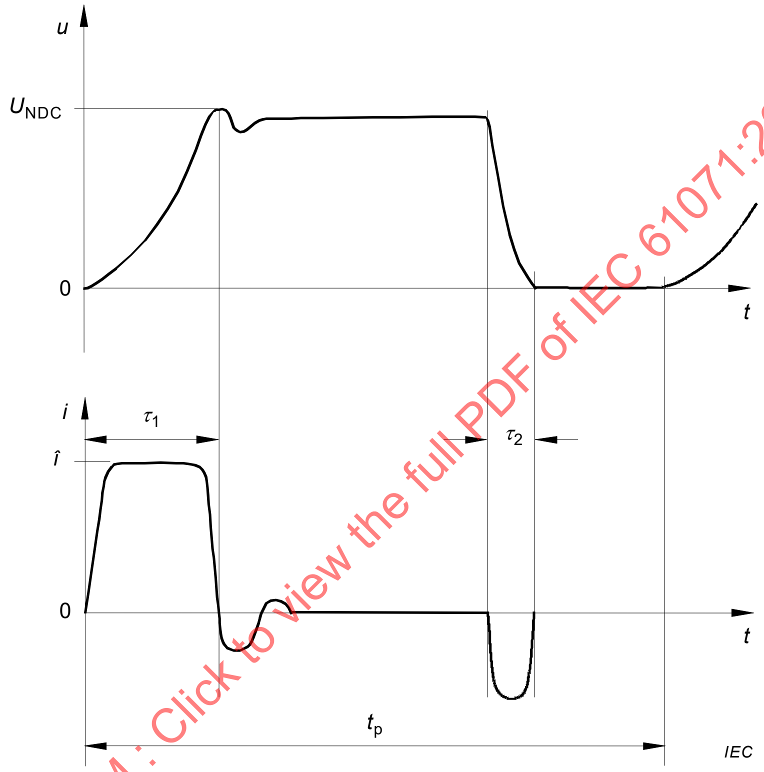



Figure A.1c – Damping capacitor for gate turn-off thyristors waveform

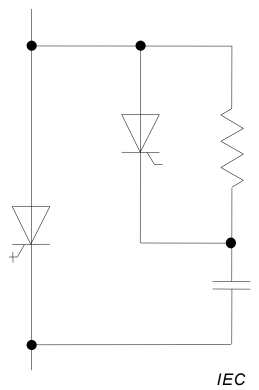



Figure A.1d – Damping circuit example

Figure A.1 – Example of waveforms and their circuits

# Annex B
(normative)

## Operational limits of capacitors with sinusoidal voltages as a function of frequency and at maximum temperature (θmax)

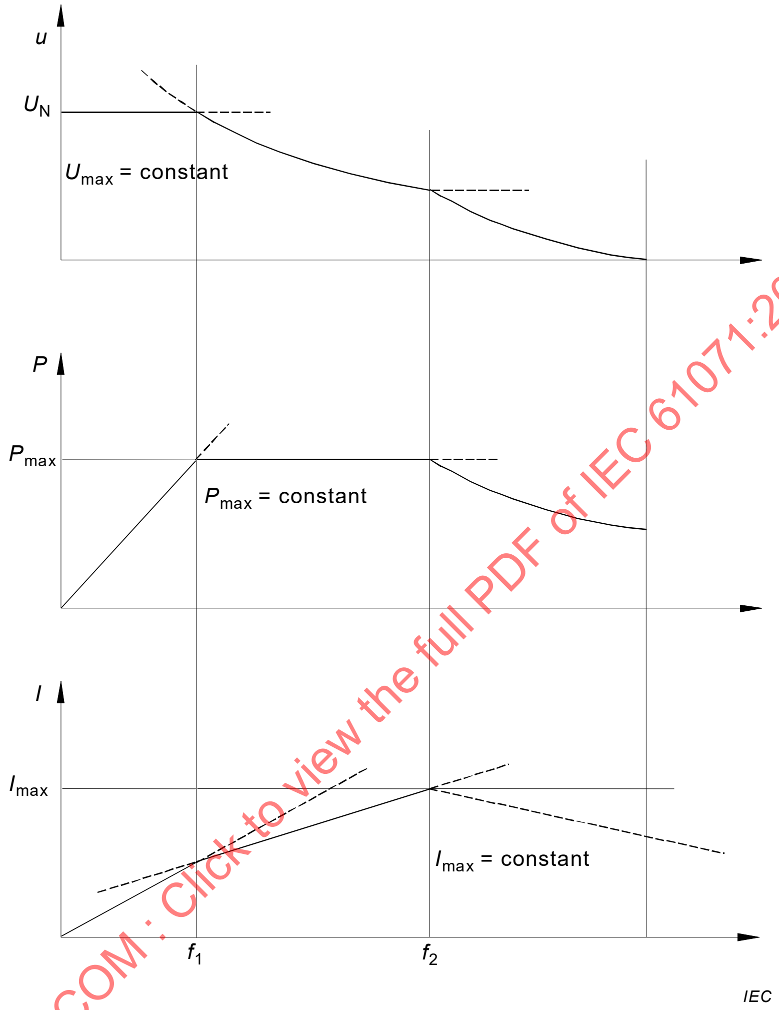





**Figure B.1 – Supply conditions**

The maximum voltage is in general a function of dielectric thickness ($a$), intrinsic field strength ($E_D$) and temperature ($\theta$).

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

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:

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

$f_2$ 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

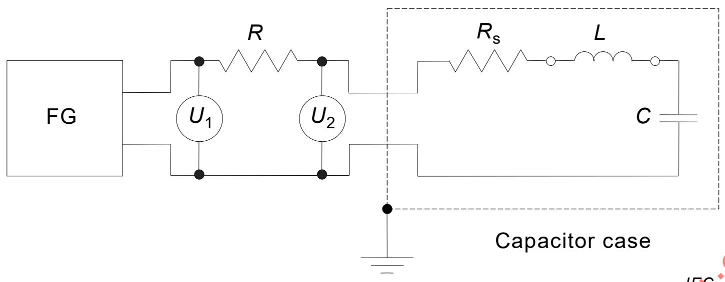
NOTE The suggested thermal stability test conditions are the following:

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

# Annex C
(normative)

## Resonance frequency measuring methods – Examples

### C.1 Method 1




where

| | |
|---|---|
| FG | is the variable frequency generator; |
| $R$ | is the non-inductive load resistance directly connected to the tested capacitor terminals; |
| $R_s$ | is the capacitor equivalent series resistance; |
| $L$ | is the capacitor equivalent series inductance; |
| $C$ | is the capacitor capacitance; |
| $U_1$ $U_2$ | are the 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.

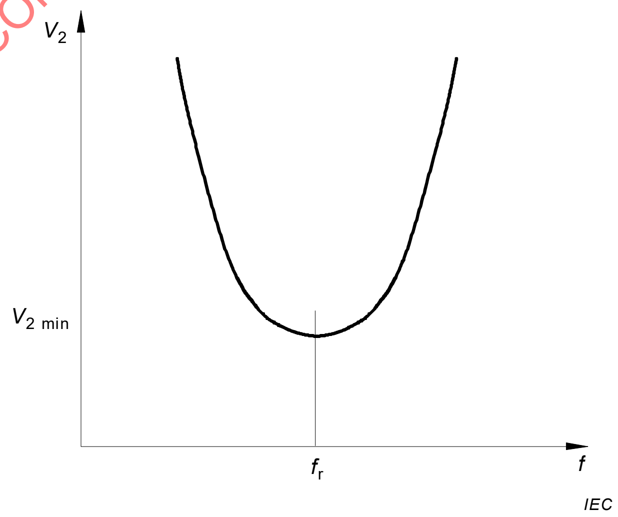



**Figure C.2 – Relation between the voltage across the capacitor and the supply frequency**

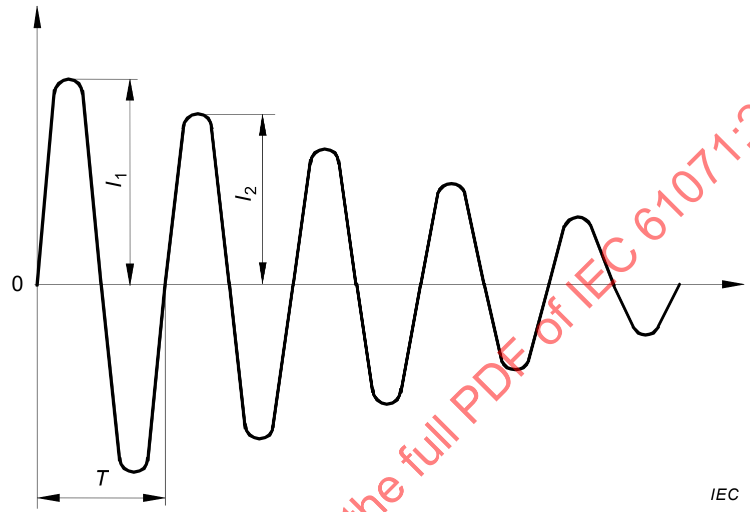
## C.2 Method 2

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.




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.

**Figure C.3 – Discharge current wave shape**

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IEC 61071

Edition 2.0 2017-08

# INTERNATIONAL STANDARD

# NORME INTERNATIONALE

## Capacitors for power electronics

## Condensateurs pour électronique de puissance



IEC 61071:2017-08(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

___________

# CAPACITORS FOR POWER ELECTRONICS

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International Standard IEC 61071 has been prepared by IEC technical committee 33: Power capacitors and their applications.

This second edition cancels and replaces the first edition published in 2007. This edition constitutes a technical revision.

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

- Introduction of new terms and definitions
- clarifications for surge discharge test
- indications for measuring procedure during thermal stability test
- clarifications for self-healing test
- clarifications for endurance test
- clarifications for destruction test
- update of normative references
- general editorial review

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

| FDIS | Report on voting |
|---|---|
| 33/610/FDIS | 33/612/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.

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.

# CAPACITORS FOR POWER ELECTRONICS

## 1 Scope

This International Standard applies to capacitors for power electronics applications.

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.

The document distinguishes between AC and DC capacitors which are considered as components when mounted in enclosures.

This document covers an extremely wide range of capacitor technologies for numerous applications, e.g. overvoltage protection, DC and filtering, switching circuits, energy storage, auxiliary inverters, etc.

The following are excluded from this document:

- capacitors for induction heat-generating plants operating at frequencies range up to 50 kHz (see IEC 60110-1 and IEC 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 the IEC 60871 standards);
- 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 the IEC 60931 standards);
- electronic capacitors not used in power circuits;
- series capacitors for power systems (see IEC 60143);
- coupling capacitors and capacitors dividers (see IEC 60358);
- capacitors for microwave ovens (see IEC 61270-1);
- capacitors for railway applications (see IEC 61881).

Examples of applications are given in 9.1.

## 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 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

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 60664-1, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

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

IEC 60695-2-12, *Fire hazard testing – Part 2-12: Glowing/hot-wire based test methods – Glow-wire flammability index (GWFI) test method for materials*

IEC 60947-1:2007, *Low-voltage switchgear and controlgear – Part 1: General rules*

## 3 Terms and definitions

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

**3.1**
**capacitor element (or element)**
device consisting essentially of two electrodes separated by a dielectric

[SOURCE: IEC 60050-436:1990, 436-01-03]

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

[SOURCE: IEC 60050-436:1990, 436-01-04]

**3.3**
**capacitor bank**
number of capacitor units connected so as to act together

[SOURCE: IEC 60050-436:1990, 436-01-06]

**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 in power electronic equipment

**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

Note 1 to entry: In the event of a breakdown of the dielectric, the capacitor does not restore itself.

**3.8**
**self-healing metallized dielectric capacitor**
capacitor, of which at least one electrode consists of a metallic deposit on the dielectric

Note 1 to entry: In the event of local breakdown of the dielectric, the electric properties of the capacitor are rapidly and essentially self-restored.

**3.9**
**AC capacitor**
capacitor essentially designed for operation with alternating voltage

Note 1 to entry: 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 1 to entry: DC capacitors may be used with a specified AC voltage only where authorized by the capacitor manufacturer.

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

Note 1 to entry: The model unit may be of a different size from the complete unit.

Note 2 to entry: The combined sum of stresses should always be considered, for instance the sum of temperature and mechanical conditions as well as electrical stresses.

**3.12**
**internal (element) fuse**
fuse connected inside a capacitor unit, in series with an element or a group of elements

[SOURCE: IEC 60050-436:1990, 436-03-16]

**3.13**
**safety devices**

**3.13.1**
**overpressure disconnector**
disconnecting device inside a capacitor, designed to interrupt the current path in case of abnormal increase of internal overpressure

**3.13.2**
**overpressure detector**
device designed to detect abnormal increase of the internal pressure, usually used to operate an electrical switch and indirectly interrupt the current path

**3.13.3**
**segmented metallization design**
pattern 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 Us guarantee the full functionality of the unit with a negligible loss of capacitance.

**3.14**
**safety protection**
**protected capacitor**
capacitor that can be submitted to the destruction test as described at 5.16

Note 1 to entry: protected capacitors alone are not sufficient to prevent all possible dangers in case of malfunction.

**3.15**
**unprotected capacitor**
capacitor that don't meet the destruction test as described at 5.16

**3.16**
**discharge device of a capacitor**
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

[SOURCE: IEC 60050-436:1990, 436-03-15, modified ("to a given value" replaced by "practically to zero")]

**3.17**
**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 to entry: The waveform can have many shapes. Examples are given in Annex A.

Note 2 to entry: The mean value of the waveform may be positive or negative.

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

**3.18**
**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

Note 1 to entry: 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 ($U_{rev}$), the use should be agreed between user and manufacturer.

Note 2 to entry: If the reversal voltage is small (less than 10 %), the voltage waveform can be considered to be non- reversing. For test purposes, $U_{NDC}$ and $U_r$ should be increased by Urev, the reversal voltage.

**3.19**
**ripple voltage**
$U_r$
peak-to-peak alternating component of the unidirectional voltage

**3.20**
**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

**3.21**
**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

**3.22**
**maximum peak current**
$\hat{I}$
maximum repetitive peak current that can occur during continuous operation

**3.23**
**maximum current**
$I_{max}$
maximum r.m.s. current for continuous operation

**3.24**
**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

**3.25**
**pulse frequency**
$f_p$
repetition rate of periodic current pulses

**3.26**
**current pulse width**
$\tau$
time of current flow during charging or discharging from one voltage value to another, of the capacitor

Note 1 to entry: Pulse current waveform examples are shown in Annex A.

**3.27**
**resonance frequency**
$f_r$
lowest frequency at which the impedance of the capacitor becomes minimum

**3.28**
**duty cycle**

**3.28.1**
**continuous duty**
operation time such that a capacitor is at thermal equilibrium for most of the time

**3.28.2**
**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

**3.29**
**thermal equilibrium**
state of a capacitor when the temperature measured anywhere on its case or internally is less than 3K above or below that temperature which would be reached after waiting an infinitely long time under fixed conditions of ambient temperature, cooling, and internal power loss

**3.30**
**thermal time constant**
measure of the time required for a capacitor to reach thermal equilibrium after a change in ambient temperature, cooling, or internal power loss

**3.31**
**lowest operating temperature**
$\theta_{min}$
lowest temperature of the dielectric at which the capacitor may be energized

**3.32**
**container temperature rise**
$\Delta\theta_{case}$
difference between the temperature of the hottest point of the container and the temperature of the cooling air

**3.33**
**cooling-air temperature**
$\theta_{amb}$
temperature of the cooling air measured at the hottest position of the capacitor, under steady-state conditions, midway between two units

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

**3.33.1**
**outlet fluid temperature for forced-cooled capacitors**
temperature of the cooling fluid as it leaves the capacitor, measured at the hottest point

**3.33.2**
**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

**3.34**
**maximum operating temperature**
$\theta_{max}$
highest temperature of the case at which the capacitor may be operated under steady state condition

**3.35**
**hotspot temperature**
the highest temperature present inside the capacitor dielectric

**3.36**
**steady-state conditions**
thermal equilibrium attained by the capacitor at constant output and at constant cooling conditions

**3.37**
**capacitor losses**
active power dissipated in the capacitor

Note 1 to entry: 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.

[SOURCE: IEC 60050-436:1990, 436-04-10]

**3.38**
**tangent of the loss angle of a capacitor**
**tan $\delta$**
ratio between the equivalent series resistance and the capacitive reactance of a capacitor at a specified sinusoidal alternating voltage, frequency and temperature

Note 1 to entry: $\tan \delta = R_{esr}\ \omega C = \tan\delta_d + R_s\ \omega C$

$\tan\delta_d$ = dielectric loss factor

[SOURCE: IEC 60050-436:1990, 436-04-11]

**3.39**
**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

**3.40**
**series resistance**
$R_s$
effective ohmic resistance of the conductors of a capacitor under specified operating conditions

**3.41**
**maximum power loss**
$P_{max}$
maximum power loss at which the capacitor may be operated at the maximum case temperature

**3.42**
**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

Note 1 to entry: For explanation of $f_2$, see Figure B.1.

# 4 Service conditions

## 4.1 Normal service conditions

### 4.1.1 General

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

### 4.1.2 Altitude

Altitude shall not exceed 1 000 m unless the effects on cooling and external insulation are taken into account.

NOTE The effect of altitude on convection cooling and external insulation has to be taken into consideration, if the altitude exceeds 1 000 m.

### 4.1.3 Operating temperature ($\theta_{max}$)

The upper limit of the case temperature $\theta_{max}$ at which the capacitor may be operated, shall normally be chosen from the values 45 °C, 55 °C, 70 °C and 85 °C. A different maximum operating temperature shall be subject to agreement between manufacturer and user.

### 4.1.4 Operating temperature with forced cooling

If capacitors are intended for use with forced cooling using a fluid medium, the operating temperature conditions specified in 4.1.3 shall be observed. The lowest inlet temperature for the cooling fluid should be defined, taking into account the viscosity of the fluid.

There are two methods for specifying the upper temperature limit of the cooling medium, using either the inlet or the outlet cooling fluid 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 such 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 1 000 m above sea level.
- superimposed electromagnetic fields.
- excessive overvoltages, as far as they exceed the limits given in Clause 6.

# 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 range of +5 °C to +35 C. If corrections are necessary, the reference temperature shall be +20 C, unless otherwise agreed between the manufacturer and the user.

NOTE It is 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 substantially sinusoidal voltage at a frequency specified by the manufacturer.

## 5.2 Classification of tests

### 5.2.1 General

The tests are classified as routine tests and type tests.

### 5.2.2 Routine tests

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 $\delta$ 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 above.

#### 5.2.3 Type tests

a) Mechanical tests (5.14).
b) Voltage test between terminals (5.5.3).
c) Voltage test between terminals and case (5.6.2).
d) Surge discharge test (5.9).
e) Self-healing test (5.11).
f) Environmental testing (5.13).
g) Measurement of the tangent of the loss angle (tan $\delta$) (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.

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.

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.

### 5.3 Capacitance and tan $\delta$ measurements (routine test)

#### 5.3.1 Measuring procedure

The capacitance and tan $\delta$ shall be measured at a voltage and 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 $\delta$.

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 $\delta$)

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

## 5.4 Measurement of the tangent of the loss angle (tan $\delta$) of a capacitor (type test)

### 5.4.1 Measurements

#### 5.4.1.1 General

The following measurements shall be made.

#### 5.4.1.2 AC capacitors

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

#### 5.4.1.3 DC capacitors

The measurement shall be carried out at the end of thermal stability test at an AC voltage appropriate to capacitor rating, subject to this voltage being a maximum of $U_r$ divided by $2\sqrt{2}$.

### 5.4.2 Loss requirements

The value of tan $\delta$ 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 Table 1.

**Table 1 – 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 1 can be reduced if capacitors are intended for intermittent duty (see 3.27) or for short service duration; the new values shall be agreed upon between the manufacturer and the user.

NOTE The AC test voltage has to be at a frequency of 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 %.

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 The routine test is intended to be applied once. If repeated it has to be carried out at 90 % of the original value unless agreed otherwise with the manufacturer.

### 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 voltage test between terminals the capacitance and tan $\delta$ shall be measured.

## 5.6 AC voltage test between terminals and case

### 5.6.1 Routine test

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

The test voltage values are the following:

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

where $U_i$ is the insulation voltage.

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

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 container in service.

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

Units having insulated containers shall not be subjected to this test.

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

NOTE 2 The voltage test between the overpressure detector and the container has to be be agreed between user and manufacturer.

NOTE 3 This test can be carried out a maximum of two times on the same capacitor.

### 5.6.2 Type test

Units having all terminals insulated from the container shall be subjected to a test according to 5.6.1 with the same voltage value, but with a duration of 1 min. Capacitors with insulating container shall have a metal foil tightly wrapped all around them during the test. The foil shall be connected to one terminal of the test supply.

## 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

The unit (in a non-painted state) shall be exposed to a test that will effectively detect any leak of the container and terminals. The test procedure is left to the manufacturer who shall describe the method concerned.

If no procedure is stated by the manufacturer the following test procedure shall apply.

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 by agreement between the manufacturer and the user, taking into account the use position of the device.

NOTE If the capacitor contains no liquid material, the choice to carry out this test or not is left to the manufacturer and it has to be 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 short-circuiting device situated as close as possible to the capacitor. They shall be subjected to five such discharges.

After this test, the units shall be subjected to a voltage test between terminals (see 5.5).

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

The two measurements shall not differ 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 $\delta$ is the value after the test, tan $\delta_o$ before the test.

For capacitors without specified surge current limitation (short-circuit-proof capacitors), the test voltage for the surge discharge test shall be equal to 1,1 $U_N$ or 1,1 $U_{NDC}$.

Test voltages higher than 1,1 $U_N$ or 1,1 $U_{NDC}$ have to be agreed between manufacturer and user.

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

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

NOTE Be aware of the energy stored in the capacitor during surge-discharge testing.

## 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, 5 degrees above the highest temperature of the ambient ($\theta_{amb}$) at which the capacitor can operate under steady state condition at $P_{max}$;

b) for forced cooling, 5 degrees above the specified outlet cooling temperature at which the capacitor can operate under steady state condition at $P_{max}$ + 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 supply conditions are those indicated in Figure B.1 with the equal power to 1,21 $P_{max}$.

For pure AC capacitors of single frequency the maximum reactive power is the base for the determination of the test conditions and the calculations. The thermal stability test should be performed with a reactive power of $Q_{test}$ = 1,21 $Q$ [$Q_{test}$ = 1,21 $(U_N)^2$ / 2 x $\omega$ C] which is equivalent to 1,21 $P_{max}$.

During the last 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 K.

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 for non-self-healing capacitors shall be less than an amount corresponding to either breakdown of an element or operation of an internal fuse.

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

At the end of this test, the tan$\delta$ measurement is performed (see 5.4.1).

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

Tan $\delta$ is the value after the test, tan $\delta_o$ before the test.

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 has to be 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 can be performed, on agreement between the manufacturer and the user, with a non-sinusoidal voltage, provided the value of power loss remains at 1,21 $P_{max}$.

NOTE 3 The test is not intended to be representative of the final application

### 5.11 Self-healing test

The purpose of the test is to confirm the presence of self-healing technology. This test is applicable only to self-healing capacitors and 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.

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 a.c. 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 or more 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 $\delta$ 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 $\delta$ is the value after the test, tan $\delta_o$ is the value 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 Figures C.1, C.2 and C.3.

This measurement is not necessary for all applications.

NOTE 1 The self inductance is calculated from the resonance frequency and the value of self inductance has not to exceed the value agreed upon between the manufacturer and the user.

NOTE 2 Modern equipments can require the capacitor to have very low self inductance for correct operation.

### 5.13 Environmental testing

#### 5.13.1 Change of temperature

The test of temperature change 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 K/min).

### 5.13.2 Damp heat, steady state

The damp heat steady-state test (test Cab) 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 test condition as described at 5.1.2. After completion of the steady-state test, the capacitor shall be subjected to a voltage test between terminals in accordance with 5.5.2, and a voltage test between terminals and container in accordance with 5.6.1.

Finally a capacitance measurement shall be carried out in accordance with 5.3.1 at stable at test condition as described at 5.1.2.

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

## 5.14 Mechanical testing

### 5.14.1 Mechanical tests of terminals

The robustness of terminations shall be tested in accordance with Table 2.

**Table 2 – Testing the robustness of terminals**

| 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<br>Size A |

### 5.14.2 External inspection

Capacitors are visually examined and checked for finish, marking and overall dimensions.

### 5.14.3 Vibration and shocks

This test shall be performed only at the request of the user and agreed with the manufacturer.

a) Vibration, in accordance with IEC 60068-2-6.

   1) For capacitors of weight not exceeding 3 kg:

      $f$ = 10 Hz to 55 Hz

      $a$ = ±0,35 mm

      Test duration per axis = 10 frequency cycles (3 axes offset from each other by 90°), 1 octave/min.

   2) For capacitors whose weight exceeds 3 kg: the choice of the test condition shall be agreed between the manufacturer and user.

b) Impacts: the choice of the test condition shall be agreed between the manufacturer and user.

Before and after the mechanical tests, the capacitance shall be measured. No change of the capacitance equal to/higher than 0,5 % shall be permitted.

### 5.15 Endurance test

#### 5.15.1 General

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 capacitor.

#### 5.15.2 Conditioning of the units before the test

The unit 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. The unit shall be allowed to cool down and reach thermal equilibrium at room temperature after conditioning.

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

#### 5.15.3 Initial capacitance and loss factor measurements

The unit shall be tested for capacitance and tan δ per 5.3 at test condition as described at 5.1.2. The ambient temperature during this measurement shall be recorded.

#### 5.15.4 Endurance test

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

The test unit shall be placed in the heated chamber and energized at the appropriate conditions as described in Table 3. AC and D.C. 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 ($\theta_{max}$) during maximum continuous operating condition, i.e. excluding short time and exceptional conditions.

The test voltage $U_t$ (pure d.c. voltage equal to $U_{NDC}$ or a.c. sinusoidal voltage with a peak voltage equal to $U_N$ multiplied by the acceleration factor) shall be applied."

A different acceleration factor/test duration can be selected according to Table 3. 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 3.21).

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

Following the 1 000 surge-discharges, the capacitor shall be energized again in order to complete the test.

**Table 3 – 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 (see 5.1.2) | 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 (see 5.1.2) | 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 (see 5.1.2) | 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 (see 5.1.2) | 1 000 times |
| | | 1,25 $U_N$ | Test temperature | 500 h |

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

Additional cooling has to be used if the temperature of the case exceeds $\theta_{max}$.

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 a.c. capacitors.

Due to the length of this test, voltage interruptions are allowed. During these interruptions, the unit has to remain in the controlled ambient. If power is lost to the chamber, the ambient test temperature shall be established for 12h prior to re-energization of the units.

NOTE The purpose of the tests is not to predict the capacitor lifetime but to show the capability of the capacitor to work under stringent conditions.

#### 5.15.5 Final capacitance and tan $\delta$ measurement

The measurement shall be performed as indicated in 5.3 within two days after completing the endurance test. The ambient temperature during the final measurements shall not differ more than ±2 °K from the temperature recorded during the initial measurements.

#### 5.15.6 Acceptance criteria

The capacitance measurement performed in Clauses 5.15.3 and 5.15.5 shall differ by not more than 3 % of the initial values. The losses shall be reported.

If the unit/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 and to prove the proper work of the safety system within the specification limits. Completely safe failure during this test cannot be guaranteed.

This test shall be applied to protected capacitors (see 8.1.1). However, the following notes should be taken into account.

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

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

NOTE 1 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) has to be considered in the application. Compliance with 5.16 does not guarantee safe end of life of a capacitor.

NOTE 2 successful completion of the test is not sufficient to guarantee the total safe failure of the components in service. For this reason, there is a residual risk of fire and/or explosions that has to be carefully taken in consideration.

The destruction test shall be carried out related to the type of safety system and to the main application of capacitors, according to Table 4. Performing of the test by applying DC-AC cycles or DC-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.

**Table 4 – Destruction test as a function of type of safety system**

| Type of unit | Safety system | Main application | Test subclause |
|---|---|---|---|
| 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 or 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 a.c. 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 5.17.4. 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 operating temperature 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 F or the status of the overpressure detector shall be checked. If the fuse F 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 F 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 fused segmented design, another sample may be used, and/or test voltage and test time may be increased, or the unit shall 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 $I_{max}$.

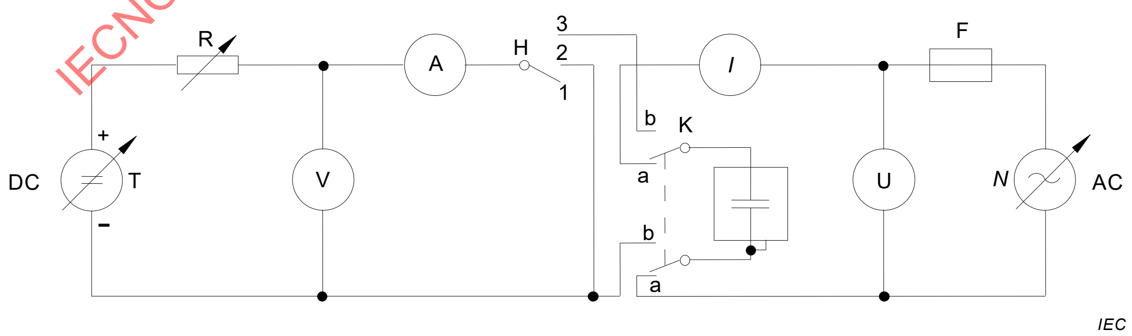



**Figure 1 – Destruction test arrangement**

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 has to 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 has to 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 $I^2t$, this information can reasonably help the designer to estimate the risk of explosion.

### 5.16.3 Test sequence for d.c. 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, as an alternative, when AC or DC low voltage with low internal impedance is applied.

The failure of non-self-healing capacitors with internal fuses may be promoted according to the procedures of 5.17.4. 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 operating temperature 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 F shall be not less than 2 $I_{max}$. A 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 $U_{NDC}$ 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 F 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 F 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 $U_{NDC}$.

   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 fused segmented design, another sample may be used, and/or test voltage and test time may be increased, or the unit shall be subjected to an externally operated overpressure until the disconnector or the overpressure detector has operated. The value of this pressure shall be given by the manufacturer.

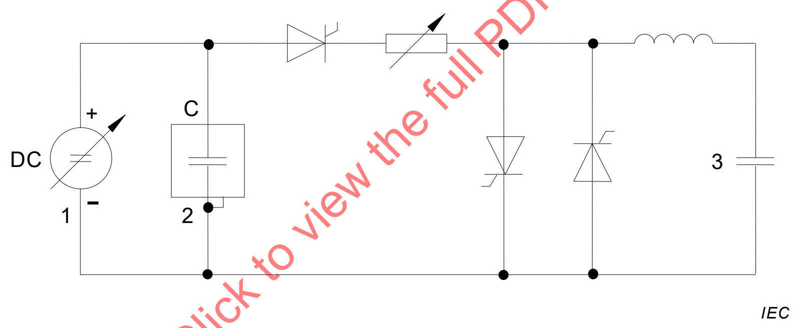
When the procedure is interrupted, the capacitor is cooled to the ambient temperature, and the voltage test between terminals and terminals and case shall be carried out according to 5.5 and 5.6.

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 d.c. current is generated by a diode bridge. The d.c. and a.c. generators shall be adjustable.

Item a) of 5.16.3 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 $I_{max}$.



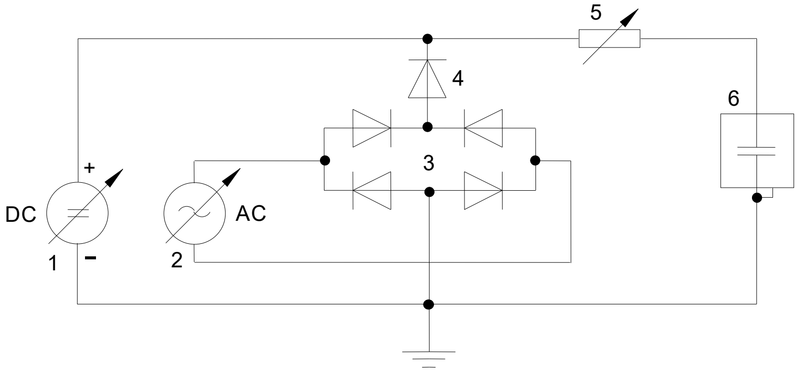

**Key**

1 high-voltage, high-current DC generator

2 specimen under test

3 inverter device, thyristors, inductor

**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 has to 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 has to be performed on agreement between the manufacturer and user.

The AC voltage shall be selected in such way as to allow a circulation of the short-circuit current.

In case of protected self-healing capacitors other methods to demonstrate the ability of a capacitor to lose 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 determinated 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 1.

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 has to 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 at the upper and at the lower voltage limits. The upper d.c. 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 measured throughout the test. If the voltage immediately before and 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 container.

   NOTE 1 Puncture of only one element cannot be guaranteed.

NOTE 2 In order to limit the possibility of a flashover to the container along the nail, or through the hole caused by the nail, it is recommended to use a "nail" made of insulating material and/or to perform the punctures in the element connected permanently, or during the test, to the container.

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 1 Precautions has to be taken when performing this test against the possible explosion of a capacitor unit.

NOTE 2 In case of internal element series connections it is recommended that all the series element groups be discharged after each test.

#### 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 container shall be apparent.

#### 5.17.7 Voltage test

The unit shall withstand for 10 s, without further operation of fuses, a voltage test. This withstand test voltage should normally be equal to the test voltage specified in Table 1, unless otherwise agreed by the manufacturer and the user in accordance with the provisions of item d) of 5.17.4.

# 6 Overloads

## 6.1 Maximum permissible voltages

Capacitor units shall be suitable for operation at voltage levels and duration according to Table 5 without any failure. It should be recognised that any significant period of operation at voltages above the rated one will reduce overall life

**Table 5 – Maximum permissible voltages**

| 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 |
| An overvoltage equal to 1,5 $U_N$ for 30 ms is permitted 1 000 times during the life of the capacitor.<br><br>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.<br><br>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.<br><br>The average applied voltage shall not be higher than the specified voltage. | | |

# 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 10 min to 75 V or less, from an initial voltage $U_N$ or $U_{NDC}$.

Capacitors without discharge resistors and with energy above 100 J shall 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 container 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.

Products of combustion shall be environmentally acceptable. Self extinguishing materials are necessary for the terminals (test temperature 750 °C: see IEC 60695-2-11 or IEC 60695-2-12.

### 7.4 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.

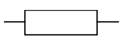
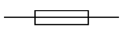
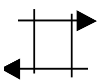
## 8 Markings

### 8.1 Marking of the units – 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.
- Capacitance (µF)
- Tolerance *(%)*
- $U_{NDC}$ or $U_N$ (volts)
- $U_i$ (volts, a.c.) (if specified, see 3.20)
- $I_{max}$ (optional) (A)
- $\hat{I}_s$ (if any) (A)
- $\theta_{min}$ ( °C)
- $\theta_{max}$ ( °C)
- Maximum tightening torque (Nm) (see note 2)
- Type of cooling medium and temperature (only for forced cooling – see Clause 4)
- Reference to this standard.

The following signs shall be added if applicable:

- for internal discharge device 
- for internal fuse or disconnector 
- for self-healing capacitors SH or 
- type of protection: protected / unprotected

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

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

NOTE 2 Additional data can be added to the rating plate, or additional warning plate, on agreement between the manufacturer and the user.

# 9 Guidance on 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 capacitor 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 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 shaped 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, not so much because of the intrinsic stress, but because the high values of $dV/dt$ in power electronics may induce partial discharge and losses which affect the capacitor life.

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 5).

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

## 9.3 Operating temperature

### 9.3.1 General

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

Temperature in excess of $\theta_{max}$ accelerates electrochemical degradation of the dielectric.

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

### 9.3.2 Installation

Capacitors shall be so placed that there is adequate dissipation by convection, conduction and radiation of the heat produced by the capacitor losses. The losses generated by associated equipment shall be taken into account.

The cooling of the operating enclosure and the arrangement of the capacitor units shall provide adequate cooling of 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 be lower than $\theta_{max}$ with the maximum service conditions (voltage, current and cooling temperature).

Depending on 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 and 9.2;
- capacitors installed at altitudes above 1 000 m will be subjected to decrease heat dissipation; this should be considered when determining the power of the units.

### 9.3.3 Unusual cooling conditions

In exceptional cases, the inlet temperature 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. 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.

The most important conditions are the following:

a) Frequent occurrence of periods of high relative humidity

   It may be necessary to use insulators of special design. Attention is drawn to the possibility of external fuses being shunted by a deposit of moisture on their surfaces.

b) Rapid mould growth

   Metals, ceramic materials and some paints and lacquers do not support mould growth. When fungicidal materials are used, they do not retain their poisoning property for more than several months; in any case, mould may develop in an installation on places where dust etc. can settle.

c) Corrosive atmospheres are found in industrial and coastal areas

   It should be noted that in climates of higher temperature the effects of such atmospheres may be more severe than in temperate climates. Highly corrosive atmospheres may be present even in indoor application.

d) Pollution

When capacitors are mounted in a location with a high degree of pollution, special precautions shall be taken.

e) Altitude exceeding 1 000 m

Capacitors used at altitudes exceeding 1 000 m are subject to special conditions. The choice of the type shall be made by agreement between the user and the manufacturer (see 4.2).

### 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 5 (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 Overcurrents

Capacitors should never be operated with currents exceeding the maximum values of the parameters defined in 3.21, 3.22 and 3.23.

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.

### 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 has to be chosen with an adequate thermal capacity.

### 9.8 Choice of creepage distance and clearance

#### 9.8.1 Creepage distance

The recommendations given in IEC 60664-1 shall apply. The user shall specify which one of the pollution levels, or specific creepage distance, is applicable. Table 15 of IEC 60947-1:2007 gives specific creepage distances for different pollution levels.

#### 9.8.2 Air clearances

Guidelines for selection of air clearance distance are found in IEC 60947-1. Table 13 of IEC 60947-1:2007 gives specific clearance distances for different impulse voltages.

## 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

In d.c. capacitors, because of variations in the insulation resistance of units, the correct voltage sharing between units should be ensured by resistive voltage dividers for safety reasons. The lifetime of the resistor must not be shorter than the lifetime of the equipment.

NOTE Interruption in a resistor leads to overcharging of the affected capacitor.

AC voltages and intermittent d.c. 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 Guidance 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 electronics capacitor shall be protected by an overpressure disconnector or overpressure detector.

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

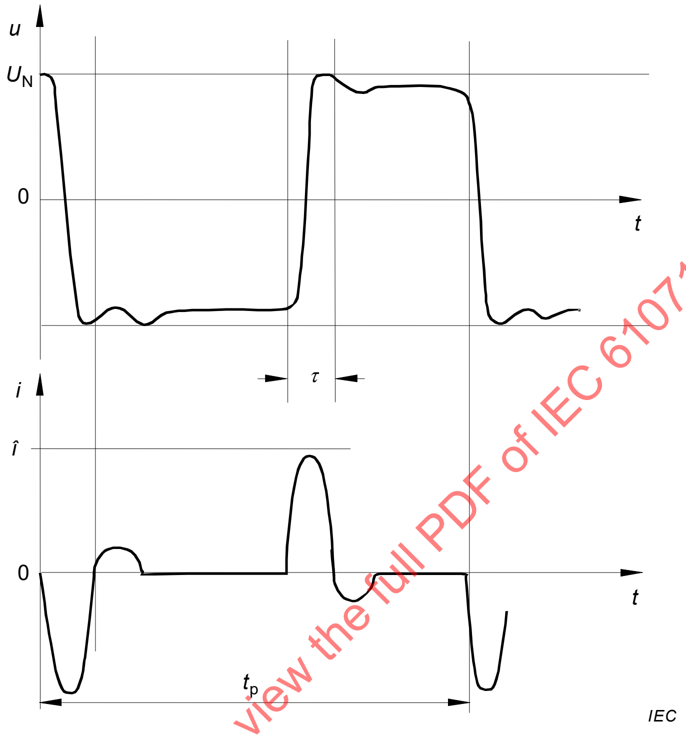
### 9.14 Guidance for unprotected capacitors

For power electronics capacitors, the user has to assure by qualified installation, that no danger appears due to a failing capacitor. This 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, as shown in Figure A.1.




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

**Key**

- $\tau$ capacitor current pulse width
- $t_p$ system pulse duration
- $f_p$ system pulse frequency
- $U_N$ peak recurrent voltage
- $\hat{i}$ peak current
- $L$ inductance of the inductor connected in series with the capacitor
- $C$ capacitor capacitance

**Figure A.1a – Commutating waveform**

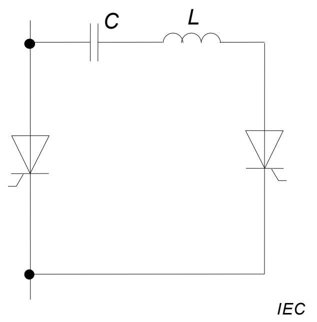



**Figure A.1b – Commutating circuit example**

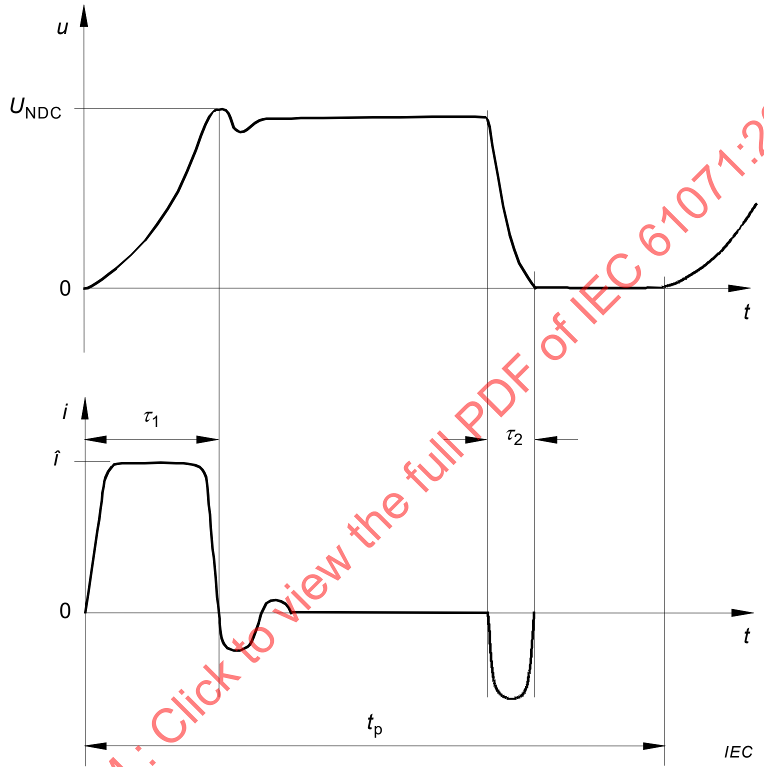



**Figure A.1c – Damping capacitor for gate turn-off thyristors waveform**

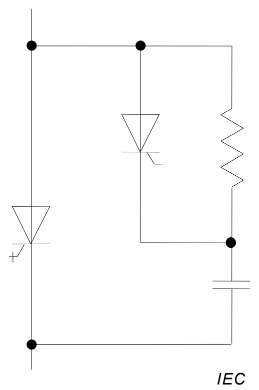



**Figure A.1d – Damping circuit example**

**Figure A.1 – Example of waveforms and their circuits**

# Annex B
(normative)

## Operational limits of capacitors with sinusoidal voltages as a function of frequency and at maximum temperature (θmax)

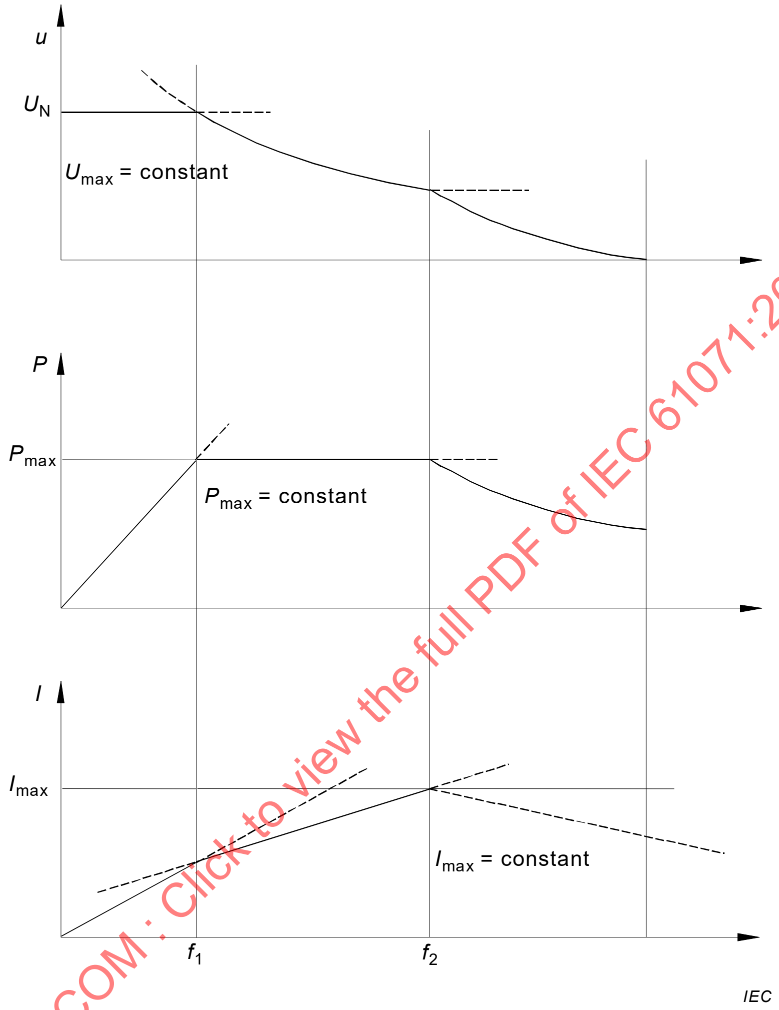





**Figure B.1 – Supply conditions**

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

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

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 |

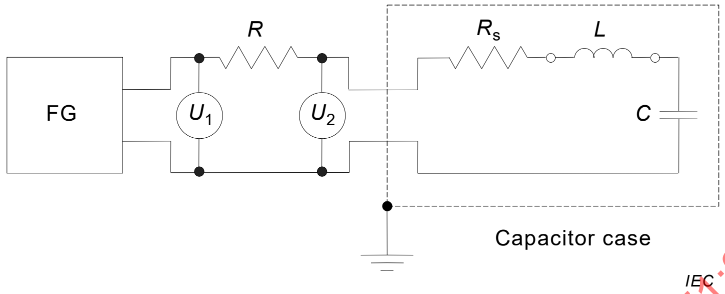
NOTE The suggested thermal stability test conditions are the following:

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

# Annex C
(normative)

## Resonance frequency measuring methods – Examples

### C.1 Method 1




where

| | |
|---|---|
| FG | is the variable frequency generator; |
| $R$ | is the non-inductive load resistance directly connected to the tested capacitor terminals; |
| $R_s$ | is the capacitor equivalent series resistance; |
| $L$ | is the capacitor equivalent series inductance; |
| $C$ | is the capacitor capacitance; |
| $U_1$ $U_2$ | are the 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.

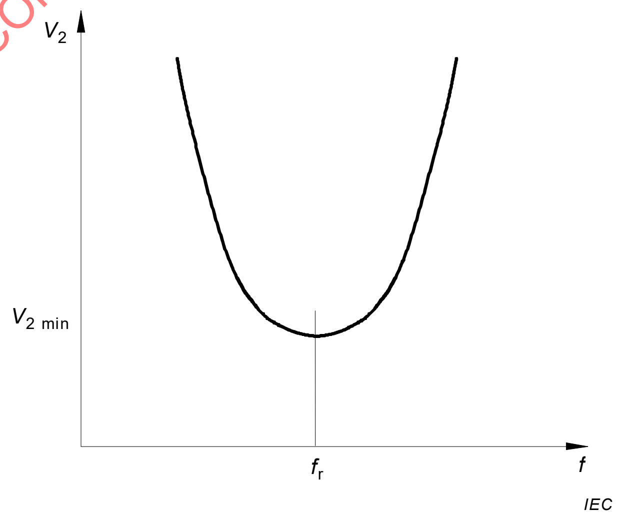



**Figure C.2 – Relation between the voltage across the capacitor and the supply frequency**

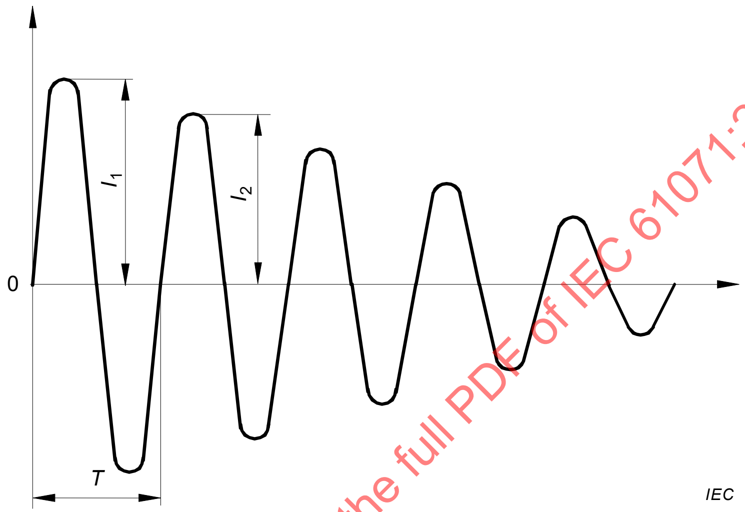
## C.2 Method 2

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.




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.

**Figure C.3 – Discharge current wave shape**

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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# CONDENSATEURS POUR ÉLECTRONIQUE DE PUISSANCE

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La Norme internationale IEC 61071 a été établie par le comité d'études 33 de l'IEC: Condensateurs de puissance et leurs applications.

Cette deuxième édition annule et remplace la première édition publiée en 2007. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

- introduction de nouveaux termes et définitions
- clarifications des essais de décharge
- indications sur la procédure de mesure pendant l'essai de stabilité thermique
- clarifications des essais d'autorégénération
- clarifications des essais d'endurance
- clarifications des essais de destruction

- mise à jour des références normatives
- révision éditoriale générale

Le texte de cette Norme internationale est issu des documents suivants:

| FDIS | Rapport de vote |
|---|---|
| 33/610/FDIS | 33/612/RVD |

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette norme.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

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# CONDENSATEURS POUR ÉLECTRONIQUE DE PUISSANCE

## 1 Domaine d'application

La présente Norme internationale s'applique aux condensateurs pour les applications de l'électronique de puissance.

La fréquence de fonctionnement des systèmes utilisant ces condensateurs atteint généralement 15 kHz, mais les fréquences d'impulsions peuvent atteindre 5 à 10 fois la fréquence de fonctionnement.

Une distinction est faite dans le présent document entre les condensateurs à courant alternatif et les condensateurs à courant continu qui sont considérés comme des composants lorsqu'ils sont montés dans un boîtier fermé.

Le présent document couvre une très grande variété de technologies de condensateurs pour répondre à de nombreuses applications, par exemple la protection contre les surtensions, le filtrage à courant continu et à courant alternatif, les circuits de commutation, le stockage d'énergie à courant continu, les inverseurs auxiliaires, etc.

Les condensateurs suivants sont exclus du présent document:

- les condensateurs destinés à des installations de production de chaleur par induction fonctionnant sur des plages de fréquences pouvant atteindre 50 kHz (voir IEC 60110-1 et IEC 60110-2);
- les condensateurs utilisés pour des moteurs et similaires (voir IEC 60252-1 et IEC 60252-2);
- les condensateurs destinés à être utilisés dans des circuits pour le blocage d'une ou de plusieurs harmoniques dans les réseaux d'alimentation;
- les petits condensateurs à courant alternatif utilisés pour les lampes fluorescentes et à décharge (voir IEC 61048 et IEC 61049);
- les condensateurs d'antiparasitage (voir IEC 60384-14);
- les condensateurs shunt destinés à être installés sur des réseaux à courant alternatif de tension assignée supérieure à 1 000 V (voir les normes de la série IEC 60871);
- les condensateurs shunt de puissance autorégénérateurs destinés à être installés sur des réseaux à courant alternatif de tension assignée inférieure ou égale à 1 000 V (voir IEC 60831-1 et IEC 60831-2);
- les condensateurs shunt de puissance non autorégénérateurs destinés à être installés sur des réseaux à courant alternatif de tension assignée inférieure ou égale à 1 000 V (voir les normes de la série IEC 60931);
- les condensateurs pour l'électronique, qui ne sont pas utilisés dans les circuits de puissance;
- les condensateurs en série destinés à être utilisés sur des réseaux (voir IEC 60143);
- les condensateurs de couplage et les diviseurs capacitifs (voir IEC 60358);
- les condensateurs pour les fours à micro-ondes (voir IEC les condensateurs pour les applications pour chemins de fer (voir IEC 61881);
- les condensateurs pour les applications pour chemins de fer (voir IEC 61881);

Des exemples d'applications sont donnés en 9.1.

## 2 Références normatives

Les documents suivants cités dans le texte constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60068-2-6, *Essais d'environnement – Partie 2-6: Essais – Essai Fc: Vibrations (sinusoïdales)*

IEC 60068-2-14, *Essais d'environnement – Partie 2-14: Essais – Essai N: Variation de température*

IEC 60068-2-20, *Essais d'environnement – Partie 2-20: Essais – Essai T: Méthodes d'essai de la brasabilité et de la résistance à la chaleur de brasage des dispositifs à broches*

IEC 60068-2-21, *Essais d'environnement – Partie 2-21: Essais – Essai U: Robustesse des sorties et des dispositifs de montage incorporés*

IEC 60068-2-78, *Essais d'environnement – Partie 2-78: Essais – Essai Cab: Chaleur humide, essai continu*

IEC 60269-1, *Fusibles basse tension – Partie 1: Exigences générales*

IEC 60664-1, *Coordination de l'isolement des matériels dans les systèmes (réseaux) à basse tension – Partie 1: Principes, exigences et essais*

IEC 60695-2-11, *Essais relatifs aux risques du feu – Partie 2-11: Essais au fil incandescent/chauffant – Méthode d'essai d'inflammabilité pour produits finis (GWEPT)*

IEC 60695-2-12, *Essais relatifs aux risques du feu – Partie 2-12: Essais au fil incandescent/chauffant – Méthode d'essai d'indice d'inflammabilité au fil incandescent (GWFI) pour matériaux*

IEC 60947-1:2007, *Appareillage à basse tension – Partie 1: Règles générales*



## 3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

**3.1**
**élément de condensateur (ou élément)**
dispositif constitué essentiellement par deux électrodes séparées par un diélectrique

[SOURCE: IEC 60050-436:1990, 436-01-03]

**3.2**
**condensateur unitaire (ou unité)**
ensemble d'un ou plusieurs éléments de condensateurs placés dans une même enveloppe et reliés à des bornes de sortie

[SOURCE: IEC 60050-436:1990, 436-01-04]

**3.3**
**batterie de condensateurs**
ensemble de condensateurs unitaires raccordés de façon à agir conjointement

[SOURCE: IEC 60050-436:1990, 436-01-06]

**3.4**
**condensateur**
terme générique utilisé quand il n'est pas nécessaire d'indiquer s'il est fait référence à un élément, à une unité ou à une batterie de condensateurs

**3.5**
**ensemble de condensateurs**
ensemble de condensateurs unitaires avec leurs accessoires pour être connecté à un équipement d'électronique de puissance

**3.6**
**condensateur pour électronique de puissance**
condensateur de puissance destiné à être utilisé dans des équipements d'électronique de puissance et capable de fonctionner de façon continue avec des courants et tensions sinusoïdaux et non sinusoïdaux

**3.7**
**condensateur à feuille métallique (non autorégénérateur)**
condensateur dont les électrodes sont généralement constituées de feuilles métalliques séparées par un diélectrique

Note 1 à l'article: En cas de claquage du diélectrique, le condensateur ne se rétablit pas.

**3.8**
**condensateur à diélectrique métallisé autorégénérateur**
condensateur dont au moins une des électrodes est constituée d'un dépôt métallique sur le diélectrique

Note 1 à l'article: Dans le cas d'un claquage local du diélectrique, les propriétés électriques du condensateur sont rapidement et quasiment rétablies.

**3.9**
**condensateur à courant alternatif**
condensateur principalement conçu pour travailler avec une tension alternative

Note 1 à l'article: Les condensateurs à courant alternatif peuvent être utilisés avec une tension continue jusqu'à la tension assignée, mais seulement avec l'autorisation du fabricant de condensateurs.

**3.10**
**condensateur à courant continu**
condensateur principalement conçu pour travailler avec une tension continue

Note 1 à l'article: Les condensateurs à courant continu peuvent être utilisés avec une tension alternative spécifiée, mais seulement avec l'autorisation du fabricant de condensateurs.

**3.11**
**condensateur modèle**
unité simulant une unité ou un élément complet lors d'un essai électrique, sans diminuer la sévérité des conditions électriques, thermiques ou mécaniques

Note 1 à l'article: L'unité modèle peut être d'une taille différente de l'unité complète.

Note 2 à l'article: Il convient de toujours considérer la somme combinée des contraintes; par exemple la somme des conditions thermiques et mécaniques et des contraintes électriques.

**3.12**
**coupe-circuit interne (élément)**
coupe-circuit monté à l'intérieur d'une unité de condensateur et relié en série avec un élément ou un groupe d'éléments

[SOURCE: IEC 60050-436:1990, 436-03-16]

**3.13**
**dispositifs de sécurité**

**3.13.1**
**sectionneur à surpression**
dispositif de déconnexion placé à l'intérieur d'un condensateur, destiné à interrompre le passage du courant en cas d'augmentation anormale de la surpression interne

**3.13.2**
**détecteur de surpression**
dispositif conçu pour détecter une augmentation anormale de la pression interne, généralement utilisé pour effectuer une commutation électrique et qui interrompt indirectement le passage du courant

**3.13.3**
**structure de métallisation segmentée**
structure de la couche métallique située au-dessus du diélectrique formée de façon à permettre d'en isoler une petite partie en cas de court-circuit ou de claquage local, pour rétablir toute la fonctionnalité de l'unité avec une perte de capacité négligeable

**3.13.4**
**structure de métallisation spéciale non segmentée**
structure de la couche métallique située au-dessus du diélectrique formée de façon que les caractéristiques d'autorégénération de sûreté agissant à une tension allant jusqu'à Us garantissent toute la fonctionnalité de l'unité avec une perte de capacité négligeable

**3.14**
**protection de sécurité**
**condensateur protégé**
condensateur pouvant être soumis à l'essai de destruction décrit en 5.16

Note 1 à l'article: Des condensateurs protégés seuls ne suffisent pas à empêcher tous les dangers possibles en cas de dysfonctionnement.

**3.15**
**condensateur non protégé**
condensateur non conforme à l'essai de destruction décrit en 5.16

**3.16**
**dispositif de décharge d'un condensateur**
dispositif pouvant être incorporé au sein d'un condensateur, capable de réduire pratiquement jusqu'à zéro la tension entre bornes, en une durée donnée, après avoir déconnecté le condensateur d'un réseau

[SOURCE: IEC 60050-436:1990, 436-03-15, modifiée ("à une valeur donnée" remplacé par "pratiquement jusqu'à zéro")]

**3.17**
**tension alternative assignée**
***$U_N$***
tension de crête récurrente maximale de service de l'une ou de l'autre des polarités d'une forme d'onde réversible pour laquelle le condensateur a été conçu

Note 1 à l'article: La forme d'onde peut avoir différentes formes. Des exemples sont donnés à l'Annexe A.

Note 2 à l'article: La valeur moyenne de la forme d'onde peut être positive ou négative.

Note 3 à l'article: Il est important de noter que la tension alternative assignée n'est pas une valeur efficace.

**3.18**
**tension continue assignée**
***$U_{NDC}$***
tension de crête maximale de service de l'une ou l'autre des polarités, mais d'une forme d'onde non réversible pour laquelle, en fonctionnement de façon continue, le condensateur a été conçu

Note 1 à l'article: Les condensateurs d'amortissement pour thyristor blocable (GTO: Gate Turn-Off) peuvent être considérés comme des condensateurs à courant continu avec une tension d'ondulation égale à la tension continue assignée $U_{NDC} = U_r$.

Dans le cas d'une tension d'inversion ($U_{rev}$), il convient que l'utilisation fasse l'objet d'un accord entre l'utilisateur et le fabricant.

Note 2 à l'article: Si la tension d'inversion est faible (moins de 10 %), la forme d'onde de la tension peut être considérée comme non réversible. Pour les essais, il convient d'augmenter $U_{NDC}$ et $U_r$ de la tension d'inversion $U_{rev}$.

**3.19**
**tension d'ondulation**
***$U_r$***
composante alternative crête à crête de la tension unidirectionnelle

**3.20**
**surtension non récurrente**
***$U_s$***
tension de crête produite par une commutation ou par tout autre type de perturbation du système, tolérée un nombre limité de fois et pendant une durée plus courte que la période de récurrence

**3.21**
**tension d'isolement**
***$U_i$***
valeur efficace de la tension sinusoïdale conçue pour l'isolement des bornes des condensateurs par rapport au boîtier ou à la terre

**3.22**
**courant de crête maximal**
***$\hat{I}$***
courant de crête maximal répétitif qui peut apparaître durant un fonctionnement de façon continue

**3.23**
**courant maximal**
***$I_{max}$***
valeur efficace maximale du courant pour un fonctionnement de façon continue

**3.24**
**surintensité maximale**
$\hat{I}_s$
courant de crête non répétitif produit par une commutation ou par tout autre type de perturbation du système, toléré un nombre limité de fois et pendant une durée plus courte que la période de récurrence

**3.25**
**fréquence des impulsions**
$f_p$
fréquence de répétition des impulsions périodiques de courant

**3.26**
**largeur des impulsions de courant**
$\tau$
durée du passage du courant durant la charge ou la décharge, d'une valeur de tension à une autre au niveau du condensateur

Note 1 à l'article: Des exemples de formes d'impulsions de courant sont donnés à l'Annexe A.

**3.27**
**fréquence de résonance**
$f_r$
fréquence la plus basse pour laquelle l'impédance du condensateur est minimale

**3.28**
**cycle de fonctionnement**

**3.28.1**
**service continu**
temps de fonctionnement pendant lequel le condensateur est la plupart du temps à son équilibre thermique

**3.28.2**
**service intermittent**
fonctionnement discontinu avec des charges variables qu'il convient de décrire en termes de périodes MARCHE/ARRET ou ELEVE/FAIBLE accompagnées de leur durée

**3.29**
**équilibre thermique**
état d'un condensateur lorsque la température mesurée n'importe où sur le boîtier ou à l'intérieur du condensateur ne varie pas de plus de 3 °K par rapport à la température qui serait atteinte après une longue période de temps dans des conditions fixées de température ambiante, de refroidissement et de perte de puissance interne

**3.30**
**constante de temps thermique**
mesure du temps exigé pour qu'un condensateur atteigne l'équilibre thermique après une variation de température ambiante, un refroidissement ou une perte de puissance interne

**3.31**
**température de fonctionnement minimale**
$\theta_{min}$
température la plus basse du diélectrique à laquelle le condensateur peut être mis sous tension

**3.32**
**élévation de température du boîtier**
$\Delta\theta_{\mathbf{case}}$
différence de température entre le point le plus chaud du boîtier et la température de l'air de refroidissement

**3.33**
**température de l'air de refroidissement**
$\theta_{\mathbf{amb}}$
température de l'air de refroidissement mesurée au niveau du point le plus chaud du condensateur, dans des conditions de régime établi et à mi-chemin entre deux unités

Note 1 à l'article: S'il n'y a qu'une seule unité à prendre en considération, il s'agit de la température mesurée au niveau d'un point situé approximativement à 0,1 m du boîtier du condensateur et aux deux tiers de la hauteur depuis sa base.

**3.33.1**
**température de sortie du fluide pour condensateurs à refroidissement forcé**
température du fluide de refroidissement lorsqu'il quitte le condensateur, mesurée au point le plus chaud

**3.33.2**
**température d'entrée du fluide pour condensateurs à refroidissement forcé**
température du fluide de refroidissement mesurée au milieu du canal d'entrée du fluide en un point ne subissant pas l'influence de la dissipation de chaleur du condensateur

**3.34**
**température maximale de fonctionnement**
$\theta_{\mathbf{max}}$
température maximale du boîtier à laquelle le condensateur peut fonctionner dans des conditions de régime établi

**3.35**
**température de point chaud**
température maximale présente à l'intérieur du diélectrique d'un condensateur

**3.36**
**conditions de régime établi**
équilibre thermique atteint par le condensateur pour une puissance constante et des conditions de refroidissement constantes

**3.37**
**pertes d'un condensateur**
puissance active dissipée dans le condensateur

Note 1 à l'article: Sauf indication contraire, les pertes du condensateur comprennent également les pertes dans les fusibles et dans les résistances de décharge qui font partie intégrante du condensateur. A haute fréquence, les pertes du condensateur sont principalement dues aux pertes dans les connexions, contacts et électrodes.

[SOURCE: IEC 60050-436:1990, 436-04-10]

**3.38**
**tangente de l'angle de perte d'un condensateur**
**tan $\delta$**
rapport entre la résistance série équivalente et la réactance capacitive d'un condensateur dans des conditions spécifiées de tension alternative sinusoïdale, de fréquence et de température

Note 1 à l'article: $\tan \delta = R_{esr}\, \omega C = \tan \delta_d + R_s\, \omega C$

tan $\delta_d$ = facteur de perte du diélectrique

[SOURCE: IEC 60050-436:1990, 436-04-11]

**3.39**
**résistance série équivalente d'un condensateur**
$\boldsymbol{R_{esr}}$
résistance effective qui, connectée en série avec un condensateur idéal de capacité égale à celle du condensateur considéré, occasionnerait une perte de puissance égale à la puissance active absorbée par le condensateur, dans des conditions de fonctionnement spécifiées

**3.40**
**résistance série**
$\boldsymbol{R_s}$
résistance ohmique effective des conducteurs d'un condensateur dans les conditions de fonctionnement spécifiées

**3.41**
**perte de puissance maximale**
$\boldsymbol{P_{max}}$
perte de puissance maximale avec laquelle le condensateur peut fonctionner à la température maximale de boîtier

**3.42**
**fréquence maximale pour perte de puissance maximale et courant maximal**
$\boldsymbol{f_2}$
fréquence à laquelle le courant maximal ($I_{max}$) produit la perte de puissance maximale ($P_{max}$) dans le condensateur

Note 1 à l'article: Pour les explications de $f_2$, voir la Figure B.1.

# 4 Conditions de service

## 4.1 Conditions de service normales

### 4.1.1 Généralités

La présente norme donne des exigences applicables aux condensateurs destinés à être utilisés dans les conditions qui suivent.

### 4.1.2 Altitude

L'altitude ne doit pas dépasser 1 000 m, à moins que les effets de refroidissement et d'isolement externe ne soient pris en compte.

NOTE L'effet de l'altitude sur le refroidissement par convection et sur les isolations externes doit être pris en considération lorsque l'altitude dépasse 1 000 m.

### 4.1.3 Température de fonctionnement ($\theta_{max}$)

La limite haute de la température du boîtier $\theta_{max}$ à laquelle le condensateur peut être amené à fonctionner, doit être choisie normalement parmi les valeurs 45 °C, 55 °C, 70 °C et 85 °C. Une température de fonctionnement maximale différente doit faire l'objet d'un accord entre le fabricant et l'utilisateur.

### 4.1.4 Température de fonctionnement avec refroidissement forcé

Si les condensateurs sont destinés à être utilisés avec un refroidissement forcé par un fluide, les conditions de température de fonctionnement spécifiées en 4.1.3 doivent être observées.

Il convient de définir la plus basse température du fluide de refroidissement à l'entrée en prenant en compte la viscosité du fluide.

Il y a deux méthodes pour spécifier la limite supérieure de température du fluide de refroidissement, en utilisant la température du fluide de refroidissement à l'entrée ou à la sortie.

Sauf accord contraire, le choix de la méthode doit être laissé au fabricant de condensateurs.

Pour la méthode à l'entrée, le débit du fluide de refroidissement doit être spécifié.

### 4.2 Conditions de service inhabituelles

Sauf accord contraire passé entre le fabricant et l'utilisateur, la présente norme ne s'applique pas aux condensateurs dont les conditions de service ne sont généralement pas compatibles avec ses exigences.

Les conditions de service inhabituelles exigent des mesures additionnelles qui assurent que les conditions décrites dans la présente norme sont compatibles avec ces éventuelles conditions de service inhabituelles.

Si de telles conditions de service inhabituelles existent, elles doivent être notifiées au fabricant de condensateurs.

De telles conditions de service inhabituelles peuvent être:

- des chocs et des vibrations mécaniques inhabituels;
- de l'eau de refroidissement avec des particules corrosives ou obstruantes (eau de mer, eau très dure);
- des particules corrosives et abrasives dans l'air de refroidissement;
- des poussières dans l'air de refroidissement, particulièrement si elles sont conductrices;
- des poussières ou des gaz explosifs;
- de la vapeur d'huile ou d'eau, ou des substances corrosives;
- un rayonnement nucléaire;
- une température inhabituelle de stockage ou de transport;
- une humidité inhabituelle (région tropicale ou subtropicale);
- des variations excessives et rapides de température (plus de 5 °C/h) ou d'humidité (plus de 5 %/h);
- des zones de fonctionnement à plus de 1 000 m au-dessus du niveau de la mer;
- des champs électromagnétiques superposés;
- des surtensions excessives, si elles dépassent les limites données à l'Article 6.

## 5 Exigences et essais relatifs à la qualité

### 5.1 Exigences relatives aux essais

#### 5.1.1 Généralités

Ce paragraphe donne les exigences relatives aux essais des condensateurs unitaires.

### 5.1.2 Conditions d'essai

Sauf spécification contraire pour un essai ou une mesure particulière, la température du diélectrique du condensateur doit être comprise entre +5 °C et +35 °C. Si des corrections sont nécessaires, la température de référence doit être +20 °C, sauf accord contraire entre le fabricant et l'utilisateur.

NOTE Par hypothèse, la température du diélectrique est la même que la température ambiante, à condition que le condensateur ait été laissé hors tension à une température ambiante constante pendant une durée suffisante pour atteindre l'équilibre thermique.

Les essais et mesures en courant alternatif doivent être réalisés avec une tension de forme pratiquement sinusoïdale à une fréquence spécifiée par le fabricant.

## 5.2 Classification des essais

### 5.2.1 Généralités

Les essais sont classés en essais individuels et essais de type.

### 5.2.2 Essais individuels

a) Essai d'étanchéité (5.8).

b) Contrôle externe (5.14.2).

c) Essai de tension entre bornes (5.5.2).

d) Essai de tension entre les bornes et le boîtier (5.6.1).

e) Mesure de la capacité et de tan $\delta$ (5.3).

f) Essai du dispositif interne de décharge (5.7).

Les essais individuels doivent être exécutés par le fabricant sur chaque condensateur avant livraison.

Sur demande de l'utilisateur, un rapport d'essai avec les résultats détaillés doit lui être fourni.

L'ordre dans lequel les essais sont effectués est indiqué ci-dessus.

### 5.2.3 Essais de type

a) Essais mécaniques (5.14).

b) Essai de tension entre bornes (5.5.3).

c) Essai de tension entre les bornes et le boîtier (5.6.2).

d) Essai de décharge (5.9).

e) Essai d'autorégénération (5.11).

f) Essai d'environnement (5.13).

g) Mesure de la tangente de l'angle de perte (tan $\delta$) (5.4).

h) Essai de stabilité thermique (5.10).

i) Essai du dispositif interne de décharge (5.7).

j) Mesure de la fréquence de résonance (5.12).

k) Essai d'endurance entre bornes (5.15).

l) Essai de déconnexion des coupe-circuits (5.17).

m) Essai de destruction (5.16).

Les essais de type sont effectués afin de prouver le bon dimensionnement du condensateur et son aptitude à fonctionner suivant les considérations détaillées dans la présente norme.

Les essais de type doivent être effectués par le fabricant, qui doit, à la demande de l'utilisateur, lui fournir un certificat détaillant les résultats de tels essais.

Sauf spécification contraire, chaque échantillon de condensateur destiné à être soumis aux essais de type doit avoir passé tous les essais individuels avec succès.

Ces essais doivent être effectués sur un condensateur dont la conception est identique au condensateur du contrat ou sur un condensateur dont la conception donnerait aux essais des conditions de même sévérité ou de sévérité supérieure.

Il n'est pas essentiel que tous les essais de type soient effectués sur le même échantillon de condensateur.

## 5.3 Mesure de la capacité et de tan $\delta$ (essai individuel)

### 5.3.1 Procédure de mesure

La capacité et tan $\delta$ doivent être mesurées à une tension et à une fréquence choisies par le fabricant.

La méthode utilisée doit permettre d'éviter les erreurs dues à des harmoniques et aux accessoires extérieurs au condensateur à mesurer, tels que des réactances et des circuits de blocage dans les circuits de mesure.

La précision de la méthode de mesure doit être donnée et doit être meilleure que 0,2 % pour la capacité et 10 % pour tan $\delta$.

NOTE Pour les condensateurs situés dans la plage des millifarads, une précision inférieure peut convenir.

La capacité doit être mesurée après l'essai de tension entre bornes (voir 5.5).

Pour les condensateurs avec coupe-circuits internes, la capacité doit également être mesurée avant les essais de tension.

### 5.3.2 Tolérances sur la capacité

Sauf spécification contraire, la capacité mesurée ne doit pas s'écarter de la capacité assignée de plus de –10 % à +10 %.

### 5.3.3 Exigences relatives aux pertes (tan $\delta$)

Les exigences relatives aux pertes du condensateur peuvent faire l'objet d'un accord entre le fabricant et l'utilisateur.

## 5.4 Mesure de la tangente de l'angle de perte (tan $\delta$) d'un condensateur (essai de type)

### 5.4.1 Mesures

#### 5.4.1.1 Généralités

Les mesures suivantes doivent être faites.

#### 5.4.1.2 Condensateurs à courant alternatif

Les pertes du condensateur (tan $\delta$) doivent être mesurées à la fin de l'essai de stabilité thermique (voir 5.10). La tension et la fréquence de mesure peuvent faire l'objet d'un accord entre le fabricant et l'utilisateur.

#### 5.4.1.3 Condensateurs à courant continu

La mesure doit être réalisée à la fin de l'essai de stabilité thermique à une tension alternative appropriée aux caractéristiques assignées du condensateur, avec un maximum de $U_r$ divisée par $2\sqrt{2}$.

### 5.4.2 Exigences relatives aux pertes

La valeur de tan $\delta$ mesurée conformément à 5.4.1 ne doit pas dépasser la valeur déclarée par le fabricant ni la valeur définie par accord entre le fabricant et l'utilisateur.

## 5.5 Essai de tension entre bornes

### 5.5.1 Généralités

Les essais doivent être réalisés selon le Tableau 1.

**Tableau 1 – Tension d'essai entre bornes**

| | Condensateurs à courant alternatif | Condensateurs à courant continu | |
|---|---|---|---|
| | Tous les types | Non autorégénérateur | Autorégénérateur |
| Valeur efficace de la tension d'essai alternative | 1,5 $U_N$ | – | – |
| Tension d'essai continue | 2,15 $U_N$ | 2 $U_{NDC}$ | 1,5 $U_{NDC}$ |



Les tensions d'essai indiquées dans le Tableau 1 peuvent être réduites si les condensateurs sont destinés à un usage intermittent (voir 3.27) ou à un service de courte durée; les nouvelles valeurs doivent faire l'objet d'un accord entre le fabricant et l'utilisateur.

NOTE La fréquence de la tension d'essai alternative doit être 50 Hz ou 60 Hz.

### 5.5.2 Essai individuel

Chaque condensateur doit être soumis durant 10 s à l'un des essais de 5.5.1 à la température ambiante. Le choix est laissé au fabricant. Pendant l'essai, aucune perforation et aucun contournement ne doivent apparaître.

Les claquages autorégénérateurs sont admis.

La durée peut être réduite à 2 s, à condition que la tension soit augmentée de 10 %.

Dans le cas d'unités dont tous les éléments sont en parallèle, l'utilisation de coupe-circuits internes est admise, à condition que la capacité reste dans ses tolérances.

NOTE L'essai individuel est destiné à être appliqué une fois. S'il est répété, il doit être réalisé à 90 % de la valeur d'origine, sauf accord contraire du fabricant.

### 5.5.3 Essai de type

Le condensateur doit être soumis pendant 1 min à l'un des essais de 5.5.1.

Le choix est laissé au fabricant.

Après l'essai de tension entre bornes, la capacité et tan $\delta$ doivent être mesurées.

## 5.6 Essai de tension alternative entre les bornes et le boîtier

### 5.6.1 Essai individuel

Les unités, dont toutes les bornes sont isolées du boîtier, doivent être soumises pendant 10 s à une tension appliquée entre les bornes (raccordées entre elles) et le boîtier.

Les tensions d'essai sont les suivantes:

$U_{\text{t-boîtier}} = 2\ U_{\text{i}} + 1\,000$ V ou 2 000 V, la valeur la plus élevée étant applicable,

où $U_{\text{i}}$ est la tension d’isolement.

La durée peut être réduite à 2 s, à condition que la tension soit augmentée de 10 %.

La tension d'isolement du condensateur doit être spécifiée par l'utilisateur. La tension d'isolement est égale à la tension assignée du condensateur divisée par $\sqrt{2}$ , sauf spécification contraire.

Pendant l'essai, aucune perforation et aucun contournement ne doivent apparaître. L'essai doit être effectué même si, au cours de l'utilisation, une des bornes est destinée à être reliée au boîtier.

Les unités n'ayant qu'une seule borne connectée en permanence au boîtier ne doivent pas être soumises à cet essai.

Les unités ayant des boîtiers isolés ne doivent pas être soumises à cet essai.

NOTE 1 Si le condensateur (avec un boîtier métallique) est équipé d’un détecteur de surpression externe, les bornes du détecteur doivent être raccordées entre elles et connectées au boîtier.

NOTE 2 L’essai de tension entre le détecteur de surpression et le boîtier doit faire l’objet d’un accord entre l’acheteur et le fabricant.

NOTE 3 Cet essai peut être réalisé au maximum deux fois sur le même condensateur.

### 5.6.2 Essai de type

Les unités, dont toutes les bornes sont isolées du boîtier, doivent être soumises à un essai conforme à 5.6.1, avec la même valeur de tension, mais avec une durée de 1 min. Les condensateurs avec un boîtier d’isolation doivent être enroulés dans une feuille métallique bien serrée durant l’essai. La feuille doit être connectée à l’une des bornes de l’alimentation de l’essai.

## 5.7 Essai du dispositif interne de décharge

La résistance du dispositif interne de décharge, le cas échéant, doit être contrôlée par une mesure de résistance ou bien par la mesure du taux d'autodécharge.

L'essai doit être fait après les essais de tension de 5.5.

## 5.8 Essai d'étanchéité

L’unité (dans un état non peint) doit être exposée à un essai qui détectera effectivement toute fuite du boîtier et des bornes. La procédure d’essai est déterminée par le fabricant qui doit décrire la méthode applicable.

Si aucune procédure n’est précisée par le fabricant, la procédure d’essai suivante doit être appliquée.

Des condensateurs unitaires hors tension doivent être chauffés à une température uniforme au moins égale à leur température maximale de fonctionnement, augmentée de 5 °C, et doivent être maintenus à cette température pendant au moins trois fois la constante thermique, et pas moins de 2 h.

Aucune fuite ne doit apparaître. Il est recommandé d'utiliser un indicateur approprié.

L'origine de la fuite du condensateur doit être détectable par contrôle visuel.

La position d'essai du condensateur unitaire doit être définie par accord entre le fabricant et l'utilisateur, en prenant en compte la position d'utilisation du dispositif.

NOTE Si le condensateur ne contient aucun matériau liquide, le choix de réaliser ou non cet essai est laissé au fabricant. L'essai doit être réalisé par échantillonnage.

### 5.9 Essai de décharge

Les unités doivent être chargées au moyen d'une source de courant continu, puis être déchargées à travers un dispositif de court-circuit situé aussi près que possible du condensateur. Les unités doivent être soumises à cinq décharges.

Après cet essai, les unités doivent être soumises à un essai de tension entre bornes (voir 5.5).

La capacité doit être mesurée avant l'essai de décharge et après l'essai de tension.

Les résultats de ces deux mesures ne doivent pas faire apparaître de variation pouvant indiquer le claquage d'un élément ou la fusion d'un coupe-circuit interne.

Pour les condensateurs autorégénérateurs, la variation de capacité doit être inférieure à ±1 %.

La formule suivante doit être contrôlée: $\tan \delta \leq 1{,}2 \times \tan \delta_o + 1 \times 10^{-4}$.

Tan $\delta$ est la valeur après l'essai, tan $\delta_o$ est la valeur avant l'essai.

Les condensateurs pour lesquels aucune limite de surintensité n'est spécifiée (condensateurs résistant aux courts-circuits), la tension d'essai pour l'essai de décharge doit être égale à 1,1 $U_N$ ou 1,1 $U_{NDC}$.

Des tensions d'essai supérieures à 1,1 $U_N$ ou 1,1 $U_{NDC}$ doivent faire l'objet d'un accord entre le fabricant et l'utilisateur.

Toutefois, si une surintensité maximale est spécifiée, le courant de décharge doit être ajusté en réduisant la tension de charge et/ou en augmentant l'impédance du circuit de décharge à une valeur de:

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

NOTE Garder à l'esprit l'énergie stockée dans le condensateur pendant l'essai de décharge.

### 5.10 Essai de stabilité thermique

#### 5.10.1 Généralités

Cet essai est réalisé sur des condensateurs à courant alternatif et sur des condensateurs à courant continu; il donne les informations suivantes sur le condensateur soumis à l'essai:

a) il détermine la stabilité thermique du condensateur en conditions de surcharge;

b) il assure un conditionnement du condensateur qui permet de mesurer les pertes de façon reproductible.

### 5.10.2 Procédure de mesure

Un condensateur unitaire doit être placé dans une enceinte où la température de refroidissement doit être:

a) pour un refroidissement naturel, supérieure de 5 degrés par rapport à la température ambiante la plus élevée ($\theta_{amb}$) à laquelle le condensateur peut fonctionner dans des conditions de régime établi à $P_{max}$;
b) pour un refroidissement forcé, supérieure de 5 degrés par rapport à la température de refroidissement à la sortie spécifiée à laquelle le condensateur peut fonctionner dans des conditions de régime établi à $P_{max}$.

Dès que toutes les parties du condensateur ont atteint la température du fluide de refroidissement, le condensateur doit être soumis pendant une durée d'au moins 48 h à une tension alternative de forme pratiquement sinusoïdale.

La valeur de la tension et celle de la fréquence doivent être maintenues constantes pendant tout l'essai.

Les conditions d'alimentation sont celles qui sont indiquées à la Figure B.1 avec une puissance égale à 1,21 $P_{max}$.

Pour les condensateurs à courant alternatif purs à une seule fréquence, les conditions d'essai et les calculs sont déterminés en se basant sur la puissance réactive maximale. Il convient d'effectuer l'essai de stabilité thermique avec une puissance réactive $Q_{test}$ = 1,21 $Q$ [$Q_{test}$ = 1,21 $(U_N)^2$ / 2 x $\omega$ C], équivalente à 1,21 $P_{max}$.

Durant les 6 dernières heures, la température en partie haute du boîtier doit être mesurée au moins quatre fois. Pendant cette période de 6 h, la température ne doit pas augmenter de plus de 1 K.

Si une variation plus grande est observée, l'essai peut être poursuivi jusqu'à ce que les exigences ci-dessus soient satisfaites pendant quatre mesures successives, sur une période de 6 h.

Avant et après l'essai, la capacité doit être mesurée dans la plage des températures données en 5.1.2 et les deux mesures doivent être corrigées pour la même température du diélectrique.

La différence entre ces deux mesures pour des condensateurs non autorégénérateurs doit être inférieure à une quantité correspondant soit au claquage d'un élément, soit à la fusion d'un coupe-circuit interne.

Pour les condensateurs autorégénérateurs, la variation de capacité doit être inférieure à ±1 %.

A la fin de cet essai, la mesure de tan $\delta$ est effectuée (voir 5.4.1).

La formule suivante doit être contrôlée: tan $\delta \leq 1,2 \times$ tan $\delta_o + 1 \times 10^{-4}$.

Tan $\delta$ est la valeur après l'essai, tan $\delta_o$ est la valeur avant l'essai.

NOTE 1 Les fluctuations de la tension, de la fréquence et de la température du fluide de refroidissement au cours de l'essai doivent être prises en compte pour contrôler que les conditions sur la température ou les pertes du condensateur sont respectées. Pour cette raison, il est conseillé de tracer ces paramètres et la température du boîtier en fonction du temps.