

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Shunt capacitors for a.c. power systems having a rated voltage above 1 000 V –
Part 1: General**

**Condensateurs shunt pour réseaux à courant alternatif de tension assignée
supérieure à 1 000 V –
Partie 1: Généralités**



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Part 1: General**

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Partie 1: Généralités**

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HAVING A RATED VOLTAGE ABOVE 1 000 V –****Part 1: General****FOREWORD**

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International Standard IEC 60871-1 has been prepared by IEC technical committee 33: Power capacitors and their applications.

This fourth edition cancels and replaces the third edition published in 2005. This edition constitutes a technical revision.

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

- a) the overvoltage cycling test has been moved to this standard from the IEC 60871-2;
- b) the ranges of the standardized values of the highest voltage for equipment have been modified;
- c) for installations installed on altitudes above 1 000 m a correction factor to all insulation requirements has been introduced;
- d) new standard insulation tables have been defined;

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

FDIS	Report on voting
33/559/FDIS	33/564/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60871 series, published under the general title *Shunt capacitors for a.c. power systems having a rated voltage above 1 000 V*, can be found on the IEC website.

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

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SHUNT CAPACITORS FOR AC POWER SYSTEMS HAVING A RATED VOLTAGE ABOVE 1 000 V –

Part 1: General

1 Scope

This part of IEC 60871 is applicable to both capacitor units and capacitor banks intended to be used, particularly, for power-factor correction of a.c. power systems having a rated voltage above 1 000 V and frequencies of 15 Hz to 60 Hz.

This part of IEC 60871 also applies to capacitors intended for use in power filter circuits. Additional definitions, requirements and tests for filter capacitors are given in Annex B.

Additional requirements for capacitors protected by internal fuses as well as requirements for the internal fuses are given in IEC 60871-4.

Requirements for capacitors to be protected by external fuses, as well as requirements for the same, are given in Annex C.

This standard does not apply to capacitors of the self-healing metallized dielectric type.

The following capacitors are excluded from this part of IEC 60871:

- capacitors for inductive heat-generating plants operating at frequencies between 40 Hz and 24 000 Hz (IEC 60110-1);
- series capacitors for power systems (see the IEC 60143 series);
- capacitors for motor applications and the like (see the IEC 60252 series);
- coupling capacitors and capacitor dividers (IEC 60358);
- shunt capacitors for a.c. power systems having rated voltage up to and including 1 000 V (see the IEC 60831 and IEC 60931 series);
- small a.c. capacitors to be used for fluorescent and discharge lamps (IEC 61048 and IEC 61049);
- capacitors to be used in power electronic circuits (IEC 61071);
- capacitors for microwave ovens (IEC 61270-1);
- capacitors for suppression of radio interference;
- capacitors intended for use with a.c. voltage superimposed on d.c. voltage.

Accessories such as insulators, switches, instrument transformers, external fuses, etc. are in accordance with the relevant IEC standards.

The object of this part of IEC 60871 is as follows:

- a) to formulate uniform rules regarding the performance and rating of units and banks, and the testing of units;
- b) to formulate specific safety rules;
- c) to provide a guide for installation and operation.

2 Normative references

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

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60071-1:2006, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60549, *High-voltage fuses for the external protection of shunt capacitors*

IEC 60815 (all parts), *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions*

IEC 60871-4:1996, *Shunt capacitors for AC power systems having a rated voltage above 1 000 V – Part 4: Internal fuses*

3 Terms and definitions

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

3.1

capacitor element

element

device consisting essentially of two electrodes separated by a dielectric

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

3.2

capacitor 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

bank

number of capacitor units connected so as to act together

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

3.4

capacitor

two-terminal device characterized essentially by its capacitance

Note 1 to entry: The term "capacitor" is used when it is not necessary to specify whether a capacitor unit or capacitor bank is meant.

[SOURCE: IEC 60050-151:2001, 151-13-28]

3.5

capacitor installation

one or more capacitor banks and their accessories

[SOURCE: IEC 60050-436:1990, 436-01-07]

3.6

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 by replacement of “intended to” by “capable of” and of “to a given value” by “practically to zero”]

3.7

internal fuse of a capacitor

fuse connected inside a capacitor unit, in series with an element or a group of elements

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

3.8

line terminal

terminal intended for connection to a line conductor of a network

Note 1 to entry: In polyphase capacitors, a terminal intended to be connected to the neutral conductor is not considered to be a line terminal.

[SOURCE: IEC 60050-436:1990, 436-03-01, modified by addition of Note 1]

3.9

rated capacitance of a capacitor

C_N

capacitance value derived from the values of rated output, voltage and frequency of the capacitor

[SOURCE: IEC 60050-436:1990, 436-01-12, modified by addition of “ C_N ”]

3.10

rated output of a capacitor

Q_N

reactive power for which the capacitor has been designed

[SOURCE: IEC 60050-436:1990, 436-01-16, modified by addition of “ Q_N ”]

3.11

rated voltage of a capacitor

U_N

r.m.s. value of the alternating voltage for which the capacitor has been designed

Note 1 to entry: In the case of capacitors consisting of one or more separate circuits (for example single-phase units intended for use in polyphase connection, or polyphase units with separate circuits), U_N refers to the rated voltage of each circuit.

For polyphase capacitors with internal electrical connections between the phases, and for polyphase capacitor banks, U_N refers to the phase-to-phase voltage.

[SOURCE: IEC 60050-436:1990, 436-01-15, modified by addition of “ U_N ” and Note 1]

3.12

rated frequency of a capacitor

f_N

frequency for which the capacitor has been designed

[SOURCE: IEC 60050-436:1990, 436-01-14, modified by addition of " f_N "]

3.13

rated current of a capacitor

I_N

r.m.s. value of the alternating current for which the capacitor has been designed

[SOURCE: IEC 60050-436:1990, 436-01-13, modified by addition of " I_N "]

3.14

capacitor losses

active power dissipated in the capacitor

Note 1 to entry: All loss-producing components should be included, for example:

- for a unit, losses from dielectric, internal fuses, internal discharge resistor, connections, etc;
- for a bank, losses from units, external fuses, busbars, discharge and damping reactors, etc.

Note 2 to entry: The capacitor losses may be recalculated as an equivalent series resistor to the unit and/or bank.

[SOURCE: IEC 60050-436:1990, 436-04-10, modified by addition of Note 1]

3.15

tangent of the loss angle (of a capacitor)

$\tan \delta$

ratio between the equivalent series resistance and the capacitive reactance of the capacitor at specified sinusoidal alternating voltage and frequency

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

3.16

maximum permissible a.c. voltage of a capacitor

maximum r.m.s. alternating voltage which the capacitor can sustain for a given time in specified conditions

[SOURCE: IEC 60050-436:1990, 436-04-07]

3.17

maximum permissible a.c. current of a capacitor

maximum r.m.s. alternating current which the capacitor can sustain for a given time in specified conditions

[SOURCE: IEC 60050-436:1990, 436-04-09]

3.18

ambient air temperature

temperature of the air at the proposed location of the capacitor

3.19

cooling air temperature

temperature of the cooling air measured at the hottest position in the bank, 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.

3.20**steady-state condition**

thermal equilibrium attained by the capacitor at constant output and at constant ambient air temperature

3.21**residual voltage**

voltage remaining on the terminals of a capacitor at a certain time following disconnection

4 Service conditions**4.1 Normal service conditions**

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

a) Residual voltage at energization

This shall not exceed 10 % of the rated voltage (see Clause 21, Subclause 19.2 and Annex D).

b) Altitude

If the altitude exceeds 1 000 m above sea level a correction factor shall be applied to all external insulation requirements as stipulated in Clause 18.

c) Ambient air temperature categories

Capacitors are classified in temperature categories, each category being specified by a number followed by a letter. The number represents the lowest ambient air temperature at which the capacitor may operate. The letters represent upper limits of temperature variation ranges, having maximum values specified in Table 1. The temperature categories cover the temperature range of -50 °C to $+55\text{ °C}$.

The lowest ambient air temperature at which the capacitor may be operated should be chosen from the five preferred values $+5\text{ °C}$, -5 °C , -25 °C , -40 °C , -50 °C .

NOTE With the agreement of the manufacturer, the capacitor can be used at a lower temperature than the limits above, provided that energization takes place at a temperature at or above these limits (see 27.3.1).

Table 1 is based on service conditions in which the capacitor does not influence the ambient air temperature (for example outdoor installations).

Table 1 – Letter symbols for upper limit of temperature range

Ambient temperature °C			
Symbol	Maximum	Highest mean over any period of	
		24 h	1 year
A	40	30	20
B	45	35	25
C	50	40	30
D	55	45	35

NOTE These temperature values can be found in the meteorological temperature tables covering the installation site.

If the capacitor influences the air temperature, the ventilation and/or choice of capacitor shall be such that the Table 1 limits are maintained. The cooling air temperature in such an installation shall not exceed the temperature limits of Table 1 by more than 5 °C .

Any combination of minimum and maximum values can be chosen for the standard temperature category of a capacitor, for example –40/A or –5/C. Preferred standard temperature categories are: –40/A, –25/A, –5/A and –5/C.

4.2 Unusual service conditions

Unless otherwise agreed between manufacturer and purchaser, this standard does not apply to capacitors, the service conditions of which, in general, are incompatible with the requirements of the present standard.

5 Quality requirements and tests

5.1 General

Clauses 5 to 17 give the test requirements for capacitor units.

Supporting insulators, switches, instrument transformers, external fuses, etc. shall be in accordance with relevant IEC standards.

NOTE The year of issue (version number) of referred standards is given in test reports.

5.2 Test conditions

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

When a correction has to be applied, the reference temperature to be used is +20 °C, unless otherwise agreed between the manufacturer and the purchaser.

It may be assumed that the dielectric temperature of the capacitor unit is the same as the ambient temperature, provided that the capacitor has been left in an unenergized state at a constant ambient temperature for an adequate period.

The a.c. tests and measurements shall be carried out at a frequency of 50 Hz or 60 Hz independent of the rated frequency of the capacitor, if not otherwise specified.

6 Classification of tests

6.1 General

The tests are classified as routine tests, type tests and acceptance tests.

6.2 Routine tests

- a) Capacitance measurement (see Clause 7).
- b) Measurement of the tangent of the loss angle ($\tan \delta$) of the capacitor (see Clause 8).
- c) Voltage test between terminals (see Clause 9).
- d) AC voltage test between terminals and container (see Clause 10).
- e) Test of internal discharge device (see Clause 11).
- f) Sealing test (see Clause 12).
- g) Discharge test on internal fuses (see 5.1.1 of IEC 60871-4:1996).

Routine tests shall have been carried out by the manufacturer on every capacitor before delivery. If the purchaser so requests, he shall be supplied with a certificate detailing the results of such tests. The test sequence above is not mandatory.

6.3 Type tests

- a) Thermal stability test (see Clause 13).
- b) Measurement of the tangent of the loss angle ($\tan \delta$) of the capacitor at elevated temperature (see Clause 14).
- c) AC voltage test between terminals and container (see 15.1).
- d) Lightning impulse voltage test between terminals and container (see 15.2).
- e) Overvoltage test (see Clause 16).
- f) Short-circuit discharge test (see Clause 17).
- g) Disconnecting test on internal fuses (see 5.3 of IEC 60871-4:1996).
- h) Test of an external fuse in combination with a capacitor (see Annex C).

Type tests are carried out in order to ascertain that, as regards design, size, materials and manufacture, the capacitor complies with the characteristics and operational requirements specified in this standard. Type tests are mainly intended to verify the design and they are not a tool to reveal quality variations in serial production

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.

The type tests shall be made upon capacitors of a design identical with that of the capacitor to be supplied or on capacitors of design and processing that do not differ from it in any way that might influence the properties to be checked by the type test.

It is not essential that all type tests be carried out on the same capacitor unit; they may be carried out on different units having the same characteristics.

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

6.4 Acceptance tests

The routine and/or type tests, or some of them, may be repeated by the manufacturer in connection with any contract by agreement with the purchaser.

The number of samples that may be subjected to such tests, and the acceptance criteria, shall be subject to agreement between manufacturer and purchaser, and shall be stated in the contract.

6.5 Endurance test (special test)

The endurance test is an ageing test on the dielectric design and composition. It will ascertain that the progression of deterioration resulting from increased voltage stress at elevated temperature does not cause untimely failure of the dielectric. The test covers a range of capacitor designs (see IEC/TS 60871-2).

7 Capacitance measurement (routine test)

7.1 Measuring procedure

The capacitance shall be measured at 0,9 to 1,1 times the rated voltage, using a method that excludes errors due to harmonics.

Measurement at another voltage is permitted, provided that appropriate correction factors are agreed upon between the manufacturer and the purchaser.

The final capacitance measurement shall be carried out after the voltage test (see Clauses 9 and 10).

In order to reveal any change in capacitance, for example due to puncture of an element, or failure of an internal fuse, a preliminary capacitance measurement shall be made, before the other electrical routine tests. This preliminary measurement shall be performed with a reduced voltage not higher than 0,15 U_N .

The accuracy of the measuring method shall be such that the tolerances according to 7.2 can be met. If agreed upon, a higher accuracy may be required, and, in such a case, the accuracy of the measuring method shall be stated by the manufacturer.

The repeatability of the measuring method shall be such that a punctured element or an operated internal fuse can be detected.

NOTE For polyphase capacitors, the measuring voltage is adjusted to give 0,9 to 1,1 times rated voltage across each element.

7.2 Capacitance tolerances

The capacitance shall not differ from the rated capacitance by more than

–5 % to +10 % for capacitor units,

0 % to +10 % for banks.

The capacitance value is that measured under the conditions of 7.1.

In three-phase units and banks, the ratio of maximum to minimum values of capacitance measured between any two line terminals shall not exceed 1,05.

NOTE 1 For filters symmetric tolerances are normally used, see Annex B.

NOTE 2 A formula for the calculation of the output of a three-phase capacitor from single-phase capacitance measurements is given in Annex D.

NOTE 3 For banks above 3 Mvar total rating, closer tolerances for output and phase capacitance ratios can be agreed between manufacturer and purchaser.

8 Measurement of the tangent of the loss angle ($\tan \delta$) of the capacitor (routine test)

8.1 Measuring procedure

The capacitor losses ($\tan \delta$) shall be measured at 0,9 to 1,1 times rated voltage, using a method that excludes errors due to harmonics. The accuracy of the measuring system shall be reported.

NOTE 1 For polyphase capacitors, the measuring voltage is adjusted to give 0,9 to 1,1 times rated voltage across each element.

NOTE 2 The tangent of loss angle of impregnated low-loss dielectrics decreases during the first hours of initial energization. This decrease is not correlated to the $\tan \delta$ variation with temperature. The $\tan \delta$ measured in routine testing can vary significantly between identical units manufactured simultaneously. The final “stabilized” values are, however, usually within close limits, as indicated by differences recorded between routine test measurements and the value found in thermal stability testing or alternative methods for conditioning according to manufacturer's practice.

NOTE 3 The measuring equipment is calibrated according to IEC 60996 or to another method that will give the same or an improved accuracy.

8.2 Loss requirements

The requirements regarding capacitor losses shall be agreed upon between manufacturer and purchaser.

The value of capacitor losses is that measured under the conditions of 8.1.

8.3 Losses in external fuses

Losses in external fuses shall be calculated using the nominal a.c. resistance (specified by the fuse manufacturer at 20 °C) times the square of rated capacitor current.

9 Voltage test between terminals (routine test)

9.1 General

Every capacitor shall be subjected for 10 s to either the test of 9.2 or that of 9.3. In the absence of an agreement, the choice is left to the manufacturer. During the test, neither puncture nor flashover shall occur.

If the capacitors are to be re-tested a voltage of 75 % of U_t is recommended for the second test.

NOTE 1 For polyphase capacitors, the test voltage is adjusted to give the appropriate voltage across each element.

NOTE 2 Units having internal element fuses, and within the capacitance tolerances in spite of one or more operated element fuses, can only be delivered after agreement between purchaser and manufacturer.

9.2 AC test

The a.c. test shall be carried out with a substantially sinusoidal voltage:

$$U_t = 2,0 U_N$$

9.3 DC test

The test voltage shall be as follows:

$$U_t = 4,0 U_N$$

10 AC voltage test between terminals and container (routine test)

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

For units used in banks with isolated neutral, and with the containers connected to ground, test voltages according to 18.1 shall apply. For all other bank connections the test voltage is proportional to the rated voltage and calculated according to 18.3.

If it is not known whether a unit with terminals insulated from the container will be used with the container connected to ground or not, test voltages according to 18.1 shall apply. The purchaser shall specify if the test is required.

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

Units with separate phases shall be subjected to voltage tests between phases of the same value as for the terminals to container test.

During the test, neither puncture nor flashover shall occur.

11 Test of internal discharge device (routine test)

The resistance of the internal discharge device, if any, shall be checked by a resistance measurement (see Clause 21 and Annex D).

The choice of the method is left to the manufacturer.

The test shall be made after the voltage test of Clause 9.

12 Sealing test (routine test)

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

If no procedure is stated by the manufacturer, the following test procedure shall apply. Unenergized capacitor units shall be heated throughout for at least 2 h, so that all parts reach a temperature not lower than 20 °C above the maximum value in Table 1. No leakage shall occur. It is recommended that a suitable indicator is used.

13 Thermal stability test (type test)

13.1 General

This test is intended to

- a) determine the thermal stability of the capacitor under overload conditions,
- b) condition the capacitor to enable a reproducible loss measurement to be made.

13.2 Measuring procedure

The capacitor unit subjected to the test shall be placed between two other units of the same rating which shall be energized at the same voltage as the test capacitor. Alternatively, two dummy capacitors each containing resistors may be used. The dissipation in the resistors shall be adjusted to a value such that the case temperature of the dummy capacitors near the top opposing faces are equal to or greater than those of the test capacitor. The separation between the units shall be equal to or less than the normal spacing. The assembly shall be placed in a heated enclosure with no forced ventilation and in the most unfavourable thermal position according to the manufacturer's instructions for mounting on site. The ambient air temperature shall be maintained at or above the appropriate temperature shown in Table 2. It shall be checked by means of a thermometer having a thermal time constant of approximately 1 h. This thermometer shall be shielded so that it is exposed to the minimum possible thermal radiation from the three energized samples.

Table 2 – Ambient air temperature for the thermal stability test

Symbol	Ambient air temperature °C
A	40
B	45
C	50
D	55

The test capacitor shall be subjected for a period of at least 48 h, to an a.c. voltage of substantially sinusoidal form. The magnitude of the voltage throughout the test shall be adjusted to give a calculated output, using the measured capacitance (see 7.1), of at least 1,44 times its rated output.

During the last 6 h the temperature of the container 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 shall be continued until the above requirement is satisfied for four consecutive measurements during a subsequent 6 h period. In case the thermal stability condition is not reached in 72 h, the test shall be stopped and the capacitor shall be declared to have failed in this test.

Before and after the test the capacitance shall be measured (see 7.1) within the temperature range according to 5.2 and the two measurements shall be corrected to the same dielectric temperature. The difference between the two measurements shall be less than an amount corresponding to either breakdown of an element or operation of an internal fuse.

When interpreting the results of the measurements, two factors shall be taken into account:

- the repeatability of the measurements;
- the fact that internal change in dielectric may cause a small change of capacitance, without puncture of any element of the capacitor or operation of an internal fuse having occurred.

When checking if the temperature conditions are satisfied, fluctuations of voltage, frequency and ambient air temperature during the test should be taken into account. For this reason, it is advisable to plot these parameters, and the temperature rise of the container as a function of time.

Units intended for 60 Hz installation can be tested at 50 Hz and units intended for 50 Hz can be tested at 60 Hz provided that the specified output is applied. For units rated below 50 Hz the test conditions should be agreed between purchaser and manufacturer.

14 Measurement of the tangent of the loss angle ($\tan \delta$) of the capacitor at elevated temperature (type test)

14.1 Measuring procedure

The capacitor losses ($\tan \delta$) shall be measured at the end of the thermal stability test (see Clause 13). The measuring voltage shall be that of the thermal stability test.

14.2 Requirements

The value of $\tan \delta$ measured in accordance with 14.1 shall not exceed the value declared by the manufacturer, or the value agreed upon between manufacturer and purchaser.

15 Voltage tests between terminals and container (type tests)

15.1 AC voltage test between terminals and container

Capacitor units having all terminals insulated from the container shall be subjected for 1 min to a test voltage applied between the terminals (joined together) and the container.

For units used in banks with isolated neutral, and with the containers connected to ground, test voltages according to 18.1 shall apply. For all other bank connections, the test voltage is proportional to the rated voltage and calculated according to 18.3.

If it is not known whether a unit with terminals insulated from the container will be used with the container connected to ground or not, test voltages according to 18.1 shall apply. The purchaser shall specify if the test is required.

Units having one terminal permanently connected to the container shall also be subjected to a test voltage applied between terminals to check the adequacy of the insulation to the container. The test voltage is proportional to the rated voltage and is calculated according to 18.3. Whenever the voltage of this test exceeds the dielectric test requirement, the test unit's dielectric composition may be modified, for example by increasing the number of elements in series, to avoid dielectric failure. However, the insulation to container shall not be changed. Alternatively, this test may be completed using a similar unit with two isolated terminals having the same insulation to the container.

Units with separated phases shall be subjected to voltage tests between phases at the same test voltage as for the voltage test between terminals and container.

The tests are dry for units to be used indoors, and with artificial rain (see IEC 60060-1) for units to be used outdoors.

The positions of the bushings, when subjected to a test under artificial rain, shall correspond to their position in service.

During the test, neither puncture nor flashover shall occur.

Units intended for outdoor installation can be subjected to only a dry test if the manufacturer can supply a separate type test report showing that the bushings will withstand the wet test voltage for 1 min. The position of the bushings in this separate type test should correspond to their position in service.

15.2 Lightning impulse test between terminals and container

The lightning impulse test is applicable for capacitor units intended for use in banks with insulated neutral and for connection to overhead lines.

Units having all terminals insulated from the container and with the containers connected to ground shall be subjected to the following test.

Fifteen impulses of positive polarity followed by 15 impulses of negative polarity shall be applied between bushings joined together and the container.

After the change of polarity, it is permissible to apply some impulses of lower amplitude before the application of the test impulses.

The capacitor is considered to have passed the test if

- no puncture has occurred,

- not more than two external flashovers occurred at each polarity,
- the waveshape has revealed no irregularities or significant deviation from recordings at reduced test voltage.

The lightning impulse test shall be made in accordance with IEC 60060-1 but with a wave of 1,2/50 μ s to 5/50 μ s having a crest value corresponding to the insulation test requirement according to 18.1.

If it is not known whether a unit with terminals insulated from the container will be used with the container connected to ground, the lightning impulse test shall apply. The purchaser shall specify if the test is required.

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

16 Overvoltage test (type test)

16.1 General

The overvoltage test is a test on the capacitor unit dielectric design and composition, and on the manufacturing process of this dielectric when assembled into a capacitor unit.

The test sample shall be manufactured by using standard production material and processing procedures. The test sample shall pass the applicable routine tests in 6.2. The test sample ratings shall be no less than 100 kvar.

The test conditions specified below are requirements valid for power-factor correction applications according to Clause 1, with the general service voltage conditions outlined in this standard. For other applications where overvoltages related to rated voltage are better known and controlled, other test voltages can be agreed upon between purchasers and suppliers. This can be applicable when extra safety margins are taken into account in the design calculations or when means for dielectric overvoltage protection with arresters or equipments for synchronized switching are used. The repeated overvoltage as stipulated in sub clause 16.3 b) should not be lower than 1,9 U_N .

16.2 Conditioning of the sample before the test

The test sample shall be conditioned for no less than 12 h at no less than its rated voltage. After the test, the capacitance of the test sample shall be measured at its rated voltage. The ambient temperature for the conditioning test shall be +15 °C to +35 °C.

16.3 Test procedure

- Place test sample in cold chamber for no less than 12 h at a temperature equal to or lower than the lowest temperature category for which the capacitor is designed.

NOTE 1 The test temperature level has a significant impact on the severity of the test. The low temperature ambient is either specified by the purchaser or to be agreed upon between the purchaser and the supplier.

- Remove and place test sample in still air at an ambient of +15 °C to +35 °C. Within 5 min after test sample is removed from the cold chamber, the test unit shall be subjected to 1,1 U_N . Within 5 min after the voltage application, an overvoltage of 2,25 U_N shall be applied without any voltage interruption for a duration of 15 cycles after which 1,1 times U_N voltage is maintained again without any voltage interruption. After an interval of 1,5 min to 2 min at 1,1 U_N , the overvoltage 2,25 U_N will again be applied and the process repeated until a total of 60 applications are completed for 1 day. (For more details about test voltage characteristics, see 16.5.4) .
- Repeat steps a) and b) above for 4 more days. The combined application of overvoltage 2,25 U_N shall be 300 total.

- d) Within 1 h of completion of step c) above, proceed to apply $1,4 U_N$ for total 96 h. The test ambient temperature shall be at $+15\text{ }^{\circ}\text{C}$ to $+35\text{ }^{\circ}\text{C}$.
- e) Measurement of capacitance shall be repeated at rated voltage.

NOTE 2 For users who are concerned more on subjecting the test sample to continuous overvoltage switching for an extended period to verify its dielectric withstand capability, it might be agreed upon between purchaser and supplier to increase the number of applications of $2,25 U_N$ overvoltage per day. The number of days is then reduced accordingly to complete the total of 300 applications.

16.4 Acceptance criteria

The acceptance criteria are that no break down shall occur based on the capacitance measurement. If breakdown should occur, two more samples shall be tested and both samples shall have no breakdown.

16.5 Validity of test

16.5.1 General

Each overvoltage test will also cover other capacitor designs, which are allowed to differ from the tested design within the following stated limits.

16.5.2 Element design

An element design is considered to be comparable with the elements in the units to be manufactured if the following requirements are satisfied:

- a) the tested elements shall have the same or fewer number of layers of solid materials in the dielectric and be impregnated with the same fluid. The basic type of solid material shall be the same;
- b) both, the rated element voltage and the electrical stress level of the tested element shall be equal or higher;
- c) the aluminium foil (electrode) edge design shall be the same;
- d) element connections shall be of the same type, for example soldering, crimping, etc.

16.5.3 Test unit design

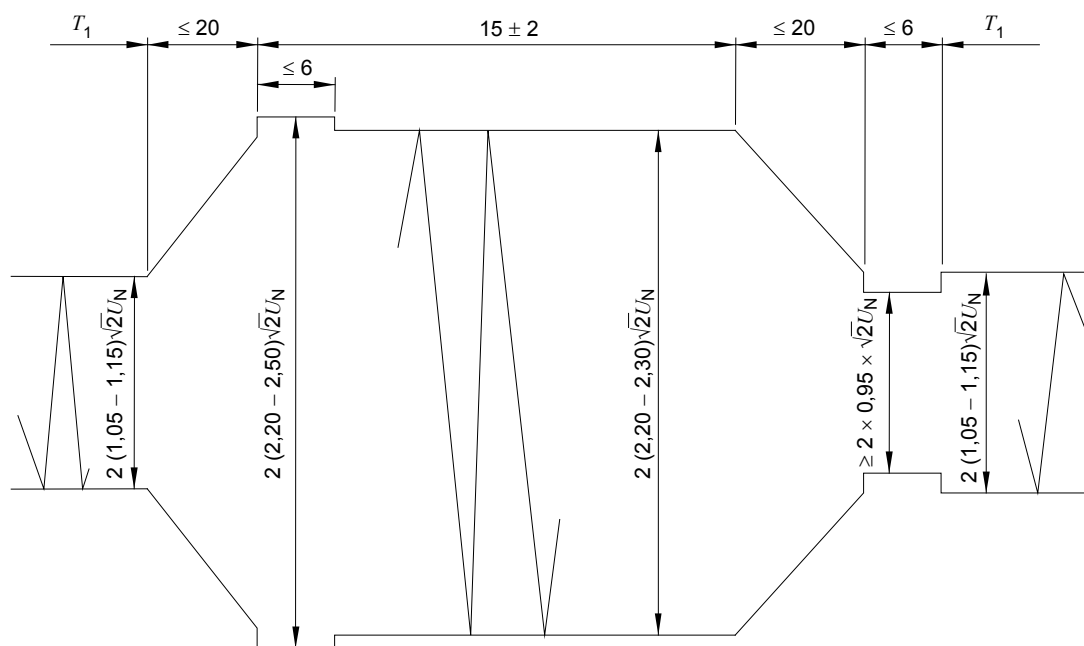
A test unit is considered to be comparable to the units to be manufactured if the following requirements are satisfied:

- a) test elements meeting the requirements of 16.5.2 shall be similarly assembled, have equal or thinner inter-element insulation, and be equally pressed within the manufacturing tolerance, as compared with the units to be manufactured;
- b) at least 4 of these test elements shall be connected to give not less than 100 kvar output at rated voltage. All connected elements shall be placed adjacent to each other and at least one inter-element insulation shall be assembled (at least two series groups of elements);
- c) a container to the manufacturer's standard design shall be used which height is not less than 20 % of the height of the unit to be manufactured. The depth and width of the container shall not be less than 50 % of the width and depth of the unit to be manufactured;
- d) the drying and impregnation process shall be identical with the normal production process.

16.5.4 Waveform of overvoltage

The test voltage shall have a frequency of 50 Hz or 60 Hz and the overvoltage shall be applied without any interruption of the steady voltage of $1,05 U_N$ to $1,15 U_N$.

The amplitude limits for the constant voltage and overvoltage are given in Figure 1.



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NOTE Time durations, other than T_1 , are expressed in numbers of cycles of the test frequency.

T_1 is the interval of 1,5 min to 2 min between two consecutive overvoltage periods.

Figure 1 – Time and amplitude limits for an overvoltage period

17 Short-circuit discharge test (type test)

The unit shall be charged by means of d.c. and then discharged through a gap situated as close as possible to the capacitor. It shall be subjected to five such discharges within 10 min.

The test voltage shall be $2,5 U_N$.

The capacitance shall be measured before and after the discharge tests. The differences between the two measurements shall be less than an amount corresponding to either breakdown of an element or operation of an internal fuse.

NOTE 1 The purpose of the discharge test is to reveal any weak design of the internal connections.

NOTE 2 For applications where overvoltages and/or transient currents are limited, test voltages lower than $2,5 U_N$ can be used, as agreed upon between manufacturer and purchaser.

18 Insulation levels

18.1 Standard insulation values

The insulation levels of the capacitor installation shall be chosen from the standard values prescribed by IEC 60071-1.

The standardized values of the highest voltage for equipment are divided in two ranges:

- **range I:** Above 1 kV to 245 kV included (Table 3). This range covers both transmission and distribution systems. The different operational aspects, therefore, shall be taken into account in the selection of the rated insulation level of the equipment.
- **range II:** Above 245 kV (Table 4). This range covers mainly transmission systems.

For most of the rated voltages, several rated insulation levels exist to allow for application of different performance criteria or overvoltage patterns. The choice should be made considering the degree of exposure to fast-front and slow-front overvoltages, the type of neutral earthing of the system and the type of overvoltage limiting devices (see IEC 60071-2).

18.2 General requirements

18.2.1 General

The general rules below shall apply for the capacitor, which could be either a single unit or a capacitor bank installation

Bushings, isolators and other insulating equipment shall be chosen with insulation ratings to comply with the requirements below. If an insulation consists of series-connected insulating parts each part shall have an appropriate proportion of the full insulation. Available standards for this type of equipment shall be used whenever applicable. Full insulation means an insulation level equal to or higher than that of the system.

For installations installed on altitudes above 1 000 m the following correction factor shall be multiplied to all insulation requirements defining external insulation performance such as a.c. wet and lightning impulse test voltage. It ensures that the insulation withstand at high altitude is achieved despite the equipment is tested at lower altitudes.

Correction factor:

$$k = e^{\frac{H-1000}{8150}}$$

18.2.2 Adjacent insulating components and equipment

All phase-to-phase and phase-to-ground insulating components or electrical equipment, in parallel to a capacitor phase or phases, shall withstand full insulation according to 18.1.

18.2.3 Capacitors insulated from ground

For capacitors insulated from ground (delta connection or star with isolated neutral) all insulation paths between any energized part of the capacitor (terminals, electrodes) and ground shall withstand full insulation according to 18.1.

Full insulation applies specifically to the bushings and terminal-to-container insulation for capacitor units with the container connected to ground (all terminals insulated from container).

Bushings and terminal-to-container insulation for capacitor units with containers not connected to ground shall withstand an a.c. voltage of 2,5 times the rated voltage.

Inter-rack insulation between line-terminal and neutral that are electrically in parallel and in close physical proximity to the capacitor dielectric shall withstand an a.c. voltage of 2,15 times the rated phase voltage.

18.2.4 Capacitors with neutral connected to ground

Bushings and terminal-to-container insulation shall withstand an a.c. voltage of 2,5 times the rated voltage.

Inter-rack insulation between line-terminal and ground that are electrically in parallel and in close physical proximity to the capacitor dielectric shall withstand an a.c. voltage of 2,15 times the rated phase voltage.

18.3 Test between terminals and container of capacitor units

Routine and type tests are required in Clauses 10, 15 and 16 to verify the requirements on bushings and terminal-to-container insulation according to 18.2.3 and 18.2.4.

For cases where the a.c. voltage test (see Clauses 10 and 15) is based on rated voltage, the test voltage shall be calculated according to the following equation:

$$U_t = 2,5 \times U_N \times n$$

where

U_t is the power-frequency test voltage;

U_N is the rated voltage of the capacitor;

n is the number of units in series relative to the electrical potential to which the containers are connected.

18.4 Capacitors in single-phase systems

For capacitors connected between line and ground, the same insulation requirements as for a three-phase system with neutral connected to ground shall apply.

For capacitors isolated from ground the same insulation requirements as for a three-phase system insulated from ground shall apply.

Table 3 – Standard insulation levels for range I ($1 \text{ kV} < U_m < 245 \text{ kV}$)

Highest voltage for equipment (U_m) kV (r.m.s. value)	Standard rated short-duration power-frequency withstand voltage kV (r.m.s. value)	Standard rated lightning impulse withstand voltage kV (peak value)
3,6	10	20 40
7,2	20	40 60
12	28	60 75 95
17,5 ^a	38	75 95
24	50	95 125 145
36	70	145 170
52 ^a	95	250
72,5	140	325
100 ^b	(150)	(380)
	185	450
123	(185)	(450)
	230	550
145	(185)	(450)
	230	550
	275	650
170 ^a	(230)	(550)
	275	650
	325	750
245	(275)	(650)
	(325)	(750)
	360	850
	395	950
	460	1 050
NOTE If values in brackets are considered insufficient to prove that the required phase-to-phase withstand voltages are met, additional phase-to-phase withstand voltage tests are needed.		
^a These U_m are non-preferred values in IEC 60038 and thus no most frequently combinations standardized in apparatus standards are given.		
^b This U_m value is not mentioned in IEC 60038 but it has been introduced in range I in some apparatus standards.		

Table 3 is extracted from IEC 60071-1:2006, Table 2.

Table 4 – Standard insulation levels for range II ($U_m > 245$ kV)

Highest voltage for equipment (U_m) kV (r.m.s. value)	Standard rated switching impulse withstand voltage			Standard rated lightning impulse withstand voltage ^b kV (peak value)
	Longitudinal insulation ^a kV (peak value)	Phase-to-earth kV (peak value)	Phase-to-phase (ratio to the phase-to-earth peak value)	
300 ^c	750	750	1,50	850
				950
	750	850	1,50	950
				1 050
362	850	850	1,50	950
				1 050
	850	950	1,50	1 050
				1 175
420	850	850	1,60	1 050
				1 175
	950	950	1,50	1 175
				1 300
	950	1 050	1,50	1 300
				1 425
550	950	950	1,70	1 175
				1 300
	950	1 050	1,60	1 300
				1 425
	950 1 050	1 175	1,50	1 425
				1 550
800	1 175	1 300	1,70	1 675
				1 800
	1 175	1 425	1,70	1 800
				1 950
	1 175 1 300	1 550	1,60	1 950
				2 100

NOTE The introduction of U_m above 800 kV is under consideration, and 1 050 kV, 1 100 kV and 1 200 kV are listed as U_m in IEC 60038:2009.

^a Value of the impulse component of the relevant combined test while the peak value of the power-frequency component of opposite polarity is $U_m \times \sqrt{2} / \sqrt{3}$.

^b These values apply as for phase-to-earth and phase-to-phase insulation as well; for longitudinal insulation they apply as the standard rated lightning impulse component of the combined standard rated withstand voltage, while the peak value of the power-frequency component of opposite polarity is $0,7 \times U_m \times \sqrt{2} / \sqrt{3}$.

^c This U_m is a non preferred value in IEC 60038.

Table 4 is extracted from IEC 60071-1:2006, Table 3.

19 Overloads – Maximum permissible voltage

19.1 Long duration voltages

Capacitor units shall be suitable for operation at voltage levels according to Table 5 (see 27.2 and 27.5.1).

Table 5 – Admissible voltage levels in service

Type	Voltage factor $\times U_N$ V r.m.s.	Maximum duration	Observation
Power frequency	1,00	Continuous	Highest average value during any period of capacitor energization. For energization periods less than 24 h, exceptions apply as indicated below (see 27.2)
Power frequency	1,10	12 h in every 24 h	System voltage regulation and fluctuations
Power frequency	1,15	30 min in every 24 h	System voltage regulation and fluctuations
Power frequency	1,20	5 min	Voltage rise at light load (see 27.2)
Power frequency	1,30	1 min	
Power frequency plus harmonics	Such that the current does not exceed the value given in Clause 20 (see also 27.6 and 27.7.1).		

The amplitudes of the overvoltages that may be tolerated without significant deterioration of the capacitor depend on their duration, their total number and the capacitor temperature (see 27.2). It is assumed that the overvoltages given in Table 5 and having a value higher than $1,15 U_N$ do not occur more than 200 times in the capacitor's life.

19.2 Switching overvoltages

The residual voltage on a capacitor prior to energization shall not exceed 10 % of the rated voltage (see 4.1 a)). The energization of a capacitor bank by a restrike-free circuit-breaker usually causes a transient overvoltage, the first peak of which does not exceed $2\sqrt{2}$ times the applied voltage (r.m.s. value) for a maximum duration of half a cycle.

It is assumed that the capacitors may be switched 1 000 times per year under these conditions. (The associated peak transient overcurrent may reach 100 times the value I_N ; see 27.6.2.)

In the case of capacitors which are switched more frequently, the values of the overvoltage amplitude and duration and the transient overcurrent shall be limited to lower levels. These limitations and/or reductions shall be agreed upon in the contract.

20 Overloads – Maximum permissible current

Capacitor units shall be suitable for continuous operation at an r.m.s. current of 1,30 times the current that occurs at rated sinusoidal voltage and rated frequency, excluding transients. Depending on the actual capacitance value, which may be a maximum of $1,10 C_N$, the maximum current can reach $1,43 I_N$ (see 27.6).

These overcurrent factors are intended to take care of the combined effects due to harmonics and overvoltages up to and including $1,10 U_N$ according to 19.1.

21 Safety requirements for discharge devices

Each capacitor unit shall be provided with means for discharging to 75 V or less from initial peak voltage of $\sqrt{2}$ times rated voltage U_N . The maximum discharge time is 10 min.

There shall be no switch, fuse, or any other isolating device between the capacitor unit and/or bank and the discharging device as defined above.

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

Capacitors connected directly to other electrical equipment providing a discharge path should be considered properly discharged, provided that the circuit characteristics are such as to meet the discharge requirements.

For banks whose capacitor units are connected in series, the voltage across the bank terminals can be higher than 75 V after 10 min due to the cumulative effect of the residual voltages for each unit. The discharge time to 75 V for the bank should be stated by the manufacturer in the instruction sheet or on a rating plate.

NOTE 1 In certain countries, smaller discharge times and voltages are required. In this event, the purchaser informs the manufacturer.

Discharge circuits should have adequate current-carrying capacity to discharge the capacitor from the peak of the 1,3 U_N overvoltage according to Clause 19.

NOTE 2 An electrical fault in a unit protected by a fuse, or a flashover across part of the bank, can produce local residual charges inside the bank which cannot be discharged within the specified time by means of a discharge device connected between the terminals of the bank.

NOTE 3 A formula for the calculation of the discharge resistance is given in Annex D.

22 Safety requirements for container 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 container, the container shall have provision for connection by means of a bolt of thread size at least M 10 or equivalent.

In case of a complete short circuit failure of a capacitor the short circuit current might exceed the fault current capability. Possible impact on personnel safety should always be carefully considered. The limitations of various protective means as fuses, current limiters, enclosures etc., shall be thoroughly taken into account. The risk of fire and subsequent smoke explosions should be specially considered for indoor or other enclosed assembly designs.

23 Safety requirements for protection of the environment

When capacitors are impregnated with materials that shall not be dispersed into the environment, precautions shall be taken. In some countries, there are legal requirements in this respect (see 25.3 and Annex A).

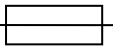
24 Other safety requirements

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

25 Markings of the capacitor unit

25.1 Rating plate

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

- a) name of manufacturer;
- b) identification number and manufacturing year. The year may be a part of identification number or be in code form;
- c) rated output Q_N in kilovars. For three-phase units the total output shall be given (see Annex D);
- d) rated voltage U_N in volts or kilovolts;
- e) rated frequency f_N in hertz;
- f) temperature category (see 4.1);
- g) discharge device, if internal, shall be indicated by wording or by the symbol  or by the rated ohmic value;
- h) insulation level U_i in kilovolts (only for units having all terminals insulated from the container).
The insulation level shall be marked by means of two numbers separated by a stroke, the first number giving the r.m.s. value of the power-frequency test voltage, in kilovolts, and the second number giving the peak value of the impulse test voltage, in kilovolts (for example 28/75) (see Clause 18). For units not tested according to 15.2 the insulation level marking shall be omitted;
- i) connection symbol. All capacitors, except single-phase having one capacitance only, shall have their connection indicated. For standardized connection symbols, see 25.2;
- j) internal fuses, if included, shall be indicated by wording or by the symbol  ;
- k) chemical or trade name of impregnant. (This indication shall be stated on the warning plate. See 25.3.);
- l) reference to IEC 60871 (plus year of issue).

NOTE On request of the purchaser, the measured capacitance is indicated either in absolute value, or in percentage, or by symbols.

25.2 Standardized connection symbols

The type of connection shall be indicated either by letters or by the following symbols:

D	or		= delta
Y	or		= star
YN	or		= star, neutral brought out
III	or		= three sections without internal interconnections

25.3 Warning plate

If the capacitor unit contains material which may pollute the environment (see Clause 23), or may be hazardous in any other way (for example flammability), the unit shall be equipped with a label according to the relevant laws of the country of the user. The purchaser shall inform the manufacturer about such law(s).

Regarding capacitors with polychlorobiphenyl impregnant, see Annex A.

26 Markings of the capacitor bank

26.1 Instruction sheet or rating plate

The following minimum information shall be given by the manufacturer in an instruction sheet or alternatively, on request of the purchaser, on a rating plate:

- a) name of manufacturer;
- b) rated output Q_N in megavars. Total output to be given;
- c) rated voltage U_N in kilovolts;
- d) insulation level U_i . The insulation level shall be marked by means of two numbers separated by a stroke, the first number giving the r.m.s. value of the rated power-frequency short-duration voltage (for $U_m < 300$ kV) or the peak value of the rated switching impulse voltage (for $U_m \geq 300$ kV) in kilovolts, and the second number giving the peak value of the rated lightning impulse withstand voltage in kilovolts (for example 185/450);
- e) connection symbol. For standardized connection symbols see 25.2. The connection symbol may be part of a simplified connection diagram showing for example unbalance protection, damping reactors, etc.;
- f) minimum time required between disconnection and reclosure of the bank (see 4.1 a), and Annex D);
- g) time to discharge to 75 V (in the case of banks rated above 25 kV).

26.2 Warning plate

Subclause 25.3 is also valid for the bank.

27 Guide for installation and operation

27.1 General

Unlike most electrical apparatus, shunt capacitors, whenever energized, operate continuously at full load, or at loads that deviate from this value only as a result of voltage and frequency variations.

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

It should be noted that the introduction of local capacitance in a system may produce unsatisfactory operating conditions (for example amplification of harmonics, self-excitation of machines, overvoltages due to switching, unsatisfactory working of audiofrequency remote-control apparatus, etc.).

Because of the different types of capacitor and the many factors involved, it is not possible to cover, by 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 recommendations of the manufacturer and the power supply authorities should be followed, especially those concerning the switching of capacitors when the network is under light load conditions.

27.2 Choice of the rated voltage

The rated voltage of the capacitor should be not less than the maximum operating voltage of the network to which the capacitor is to be connected, account being taken of the influence of the capacitor itself.

In certain networks, a considerable difference may exist between the operating and rated voltage of the network, details of which should be provided by the purchaser, so that due allowance can be made by the manufacturer. This is of importance for capacitors, since their performance and life may be adversely affected by an undue increase of the voltage across the capacitor dielectric.

Where inductive elements are inserted in series with the capacitor to reduce the effects of harmonics, etc., the resultant increase of the voltage at the capacitor terminals above the operating voltage of the network requires a corresponding increase in the rated voltage of the capacitor.

If no information to the contrary is available, the operating voltage should be assumed as equal to the rated or declared voltage of the network.

When determining the voltage to be expected on the capacitor terminals, the following considerations should be taken into account:

- shunt-connected capacitors may cause a voltage increase in the network where they are located (see Annex D). This voltage increase may be greater due to the presence of harmonics. Capacitors are therefore liable to operate at a higher voltage than that measured before connecting the capacitors;
- the voltage at the capacitor terminals may be particularly high at times of light load (see Annex D)

Only in case of emergency should capacitors simultaneously be operated at maximum permissible overvoltage and maximum ambient temperature and then only for short periods of time.

NOTE See Clause 19 concerning maximum permissible voltage.

Allowance should be made for the effect of unit capacitance tolerance on the operating voltage in series or star-connected assemblies. The operation of capacitor fuses will also increase the operating voltage on the remaining parallel connected units.

27.3 Operating temperature

27.3.1 General

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

When the capacitor dielectric reaches a temperature below the lower limit of its category, there may be the danger of initiating partial discharges in the dielectric. This is of particular importance at switching operations.

All loss-producing accessories, such as external fuses, reactors, etc., should be included in the calculation of total bank losses.

The manufacturer should, by agreement, provide curves or tables showing the capacitance, as well as losses ($\tan \delta$) under steady-state conditions at rated output, as a function of ambient temperature.

27.3.2 Installation

Capacitors should be so placed that there is adequate dissipation by convection and radiation of the heat produced by the capacitor losses. The ventilation of any enclosure and the arrangement of the capacitor units shall provide good air circulation around each unit. This is of importance for units mounted in rows above each other.

The temperature of capacitors subjected to radiation from the sun or from any high-temperature surface will be increased. Depending on the cooling air temperature, the intensity of the cooling and the intensity and duration of the radiation, it may be necessary to use one or more of the following remedies:

- protect the capacitors from radiation;
- choose a capacitor designed for a higher ambient air temperature (for example category –5/B instead of –5/A, or which is otherwise suitably designed);
- employ capacitors with rated voltage higher than that resulting from 27.2;
- employ forced air cooling.

Capacitors installed at high altitudes (more than 1 000 m) will be subject to decreased convective heat dissipation, which should be considered when determining the output of the units. The ambient temperature, however, is usually lower at such an altitude (see also 27.8.2).

27.3.3 High ambient air temperature

Capacitors for symbol C are generally suitable for the majority of applications under tropical conditions. In some locations, however, the ambient air temperature may be such that a symbol D capacitor is required. The latter may also be needed for those cases where the capacitors are frequently subjected to the radiation of the sun for several hours (for example in desert territories), even though the ambient temperature is not excessive.

In exceptional cases, the ambient air temperature may be higher than 55 °C maximum, or 45 °C daily mean. Where it is impossible to improve the cooling conditions, capacitors of special design or with a higher rated voltage should be used.

27.4 Special service conditions

In addition to the conditions covered in 27.3, the manufacturer should be advised by the purchaser of any special service conditions such as:

- **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;
- **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;
- **corrosive atmospheres:** such atmospheres are found in industrial and coastal areas. It should be noted that in climates of higher temperature the effects may be more severe than in temperate climates. Highly corrosive atmospheres may also be present in indoor applications;
- **pollution:** when capacitors are mounted in a location with a high degree of pollution, special precautions should be taken (see 27.9.1);
- **altitudes exceeding 1 000 m:** capacitors used at altitudes exceeding 1 000 m are subject to special conditions. Guidelines for correction of insulation requirements are given in 18.2.
- **earthquake areas:** in some areas there is a higher probability of earthquakes, which may affect the mechanical design of the capacitors and/or banks to be installed in such areas. The purchaser shall specify acceleration amplitude and damping values.

27.5 Overvoltages

27.5.1 General

Clause 19 specifies overvoltage factors.

With the manufacturer's agreement, some overvoltage factors may be increased if the estimated overvoltage incidence is lower, or if the temperature conditions are less severe. These power-frequency overvoltage limits are valid, provided that transient overvoltages are not superposed on them. The peak voltage should not exceed 1,41 times the given r.m.s. value.

27.5.2 Restriking of switches

High overvoltage transients may be encountered when capacitors are disconnected by switching devices which allow restriking. Care should be taken to select switching devices which operate without causing excessive overvoltage.

If, nevertheless, restriking cannot be prevented, it may be necessary to use capacitors having a higher insulation level and a higher rated voltage.

27.5.3 Lightning

Capacitors which are liable to be subjected to high overvoltages by lightning should be adequately protected. If surge arresters are used, they should be located as near as possible to the capacitors. Special arresters may be required to take care of the discharge current from the capacitor, especially from large banks (see the IEC 60099 series).

27.5.4 Motor self-excitation

When a capacitor is permanently connected to a motor, difficulties may arise after disconnecting the motor from the supply. The motor, while still rotating, may act as a generator by self-excitation and may give cause to voltages considerably in excess of the system voltage.

This, however, can usually be prevented by ensuring that the capacitor current is less than the no-load magnetizing current of the motor; a value of about 90 % is suggested. As a precaution, live parts of a motor to which a capacitor is permanently connected should not be handled before the motor stops.

27.5.5 Star-delta starting

When a capacitor is connected to a motor equipped with a star-delta starter, the arrangement should be such that no overvoltage can occur during the operation of the starter, unless otherwise agreed between purchaser and manufacturer.

27.5.6 Capacitor unit selection

When building up a capacitor bank from a random selection of units, care should be taken to avoid overvoltages due to the difference in capacitance between the units or groups of units connected in series.

In the case of star-connected banks with isolated neutral, capacitance differences between phases will lead to an increase of the voltage across the capacitors in the phase with the smallest capacitance.

27.6 Overload currents

27.6.1 Continuous overcurrents

Capacitors should never be operated with currents exceeding the permissible value specified in Clause 20, except for periods not longer than 5 min in conjunction with voltage rise at light loads according to Table 5.