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Surge arresters –

Part 6:
Surge arresters containing both series and parallel gapped structures – Rated 52 kV and less

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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International Standard IEC 60099-6 has been prepared by IEC technical committee 37: Surge arresters.

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

FDIS	Report on voting
37/282/FDIS	37/283/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.

Annexes A, B, C and D form an integral part of this standard.

Annexes E and F are for information only.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

The committee has decided that the contents of this publication will remain unchanged until 2004. At this date, the publication will be

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- withdrawn;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

INTRODUCTION

This part of IEC 60099 presents the minimum criteria for the requirements and testing of metal-oxide surge arresters containing gapped structures that are applied to a.c. power systems.

Arresters covered by this standard can be applied to overhead installations in place of the non-linear type arresters covered in IEC 60099-1 and IEC 60099-4.

An accelerated ageing procedure is incorporated in the standard to simulate the long-term effects of voltage and temperature on the arrester. This is necessary since during the arrester's service life the gaps and resistor elements will have portions of the system power frequency voltage continuously applied across them.

SURGE ARRESTERS –

Part 6: Surge arresters containing both series and parallel gapped structures – Rated 52 kV and less

1 General

1.1 Scope

This part of IEC 60099 applies to non-linear metal-oxide resistor type surge arresters with spark gaps designed to limit voltage surges on a.c. power circuits.

This standard basically applies to all metal-oxide surge arresters with gaps and housed in either porcelain or polymeric housings.

This standard specifies requirements and tests for metal-oxide surge arresters with internal series gaps, with rated voltages 52 kV and below.

The following arrester types and ratings are presently under consideration, but are not addressed in this standard. They will not be addressed until more information can be ascertained on the individual subjects:

- series gapped arresters above 54 kV;
- externally gapped arresters, all ratings;
- shunt gapped arresters, all ratings;
- line discharge class 2, 3, 4 and 5.

1.2 Normative references

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

IEC 60060-1:1989, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60060-2:1994, *High-voltage test techniques – Part 2: Measuring systems*

IEC 60099-1:1991, *Surge arresters – Part 1: Non-linear resistor type gapped surge arresters for a.c. systems*

IEC 60099-3:1990, *Surge arresters – Part 3: Artificial pollution testing of surge arresters*

IEC 60099-4:1991, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*
Amendment 1 (1998)
Amendment 2 (2001)[1]

IEC 60270: 2000, *High-voltage test techniques – Partial discharge measurements*

[1] A consolidated edition 1.2 exists (2001) that includes edition 1.0 (1991), its amendment 1 (1998) and amendment 2 (2001).

2 Definitions

For the purposes of this part of IEC 60099, the following definitions apply.

2.1
metal-oxide surge arrester without gaps
arrester having non-linear metal-oxide resistors connected in series and/or in parallel without any integrated series or parallel spark gaps

NOTE See 2.55 for metal-oxide surge arrester with series gapped structures.

2.2
non-linear metal-oxide resistor
part of the surge arrester which by its non-linear voltage versus current characteristics acts as a low resistance to overvoltages, thus limiting the voltage across the arrester terminals, and as a high resistance at normal power frequency voltage

2.3
internal grading system of an arrester
grading impedance, in particular linear/non-linear resistors and/or grading capacitors connected in parallel to one or to a group of non-linear metal-oxide resistors and/or series gap, to control the voltage distribution along the arrester and/or between the metal oxide resistors and gaps

2.4
grading ring of an arrester
metal part usually circular in shape, mounted to modify electrostatically the voltage distribution along the arrester

2.5
section of an arrester
complete, suitably assembled part of an arrester necessary to represent the behaviour of a complete arrester with respect to a particular test

NOTE A section of an arrester is not necessarily a unit of an arrester.

2.6
unit of an arrester
completely housed part of an arrester which may be connected in series and/or in parallel with other units to construct an arrester of higher voltage and/or current rating

NOTE A unit of an arrester is not necessarily a section of an arrester.

2.7
pressure relief device of an arrester
means for relieving internal pressure in an arrester and preventing violent shattering of the housing following prolonged passage of fault current or internal flashover of the arrester

2.8
rated voltage of an arrester, U_r
maximum permissible r.m.s. value of power frequency voltage between its terminals at which it is designed to operate correctly under temporary overvoltage conditions as established in the operating duty tests, see 7.5

NOTE 1 The rated voltage is used as a reference parameter for the specification of operating characteristics.

NOTE 2 The rated voltage as defined in this standard is the 10 s power frequency voltage used in the operating duty test after high current. Tests used to establish the voltage rating in the IEC 60099 series, as well as some national standards, involve the application of repetitive impulses at nominal impulse current with power frequency voltage applied. Attention is drawn to the fact that these two methods used to establish rating do not necessarily produce equivalent values. (A resolution to this discrepancy is under consideration.)

2.9
continuous operating voltage of an arrester, U_c
continuous operating voltage is the designated permissible r.m.s. value of power frequency voltage that may be applied continuously between the arrester terminals in accordance with 7.5

2.10
rated frequency of an arrester
frequency of the power system on which the arrester is designed to be used

2.11
disruptive discharge
phenomena associated with the failure of insulation under electric stress, which include a collapse of voltage and the passage of current

NOTE 1 The term applies to electrical breakdowns in solid, liquid and gaseous dielectric, and combinations of these.

NOTE 2 A disruptive discharge in a solid dielectric produces permanent loss of electric strength. In a liquid or gaseous dielectric the loss may be only temporary.

2.12
puncture (breakdown)
disruptive discharge through a solid

2.13
flashover
disruptive discharge over a solid surface

2.14
impulse
unidirectional wave of voltage or current which without appreciable oscillations rises rapidly to a maximum value and falls – usually less rapidly – to zero with small, if any, excursions of opposite polarity

NOTE The parameters which define a voltage or current impulse are polarity, peak value, front time and time to half value on the tail.

2.15
designation of an impulse shape
combination of two numbers, the first representing the virtual front time (T_1) and the second the virtual time to half value on the tail (T_2), written as T_1/T_2, both in µs, the sign "/" having no mathematical meaning

2.16
steep current impulse
current impulse with a virtual front time of 1 µs with limits in the adjustment of equipment such that the measured values are from 0,9 µs to 1,1 µs and the virtual time to half value on the tail not longer than 20 µs

NOTE The time to half value on the tail is not critical and may have any tolerance during the residual voltage type tests, see 7.3.1.

2.17
lightning current impulse
an 8/20 current impulse with limits on the adjustment of equipment such that the measured values are from 7 µs to 9 µs for the virtual front time and from 18 µs to 22 µs for the time to half value on the tail

NOTE The time to half value on the tail is not critical and may have any tolerance during the residual voltage type tests, see 7.3.1.

2.18
long duration current impulse
rectangular impulse which rises rapidly to maximum value, remains substantially constant for a specified period and then falls rapidly to zero. The parameters which define a rectangular impulse are polarity, peak value, virtual duration of the peak and virtual total duration.

2.19
peak (crest) value of an impulse
maximum value of a voltage or current impulse

NOTE Superimposed oscillations may be disregarded, see 7.4.2 c) and 7.5.3.2 e).

2.20
front of an impulse
part of an impulse which occurs prior to the peak

2.21
tail of an impulse
part of an impulse which occurs after the peak

2.22
virtual origin of an impulse
point on a graph of voltage versus time or current versus time determined by the intersection between the time axis at zero voltage or zero current and the straight line drawn through two reference points on the front of the impulse

NOTE 1 For current impulses the reference points are 10 % and 90 % of the peak value.

NOTE 2 This definition applies only when scales of both ordinate and abscissa are linear.

NOTE 3 If oscillations are present on the front, the reference points at 10 % and 90 % should be taken on the mean curve drawn through the oscillations.

2.23
virtual front time of a current impulse, T_1
time in µs equal to 1,25 multiplied by the time in µs for the current to increase from 10 % to 90 % of its peak value

NOTE If oscillations are present on the front, the reference points at 10 % and 90 % should be taken on the mean curve drawn through the oscillations.

2.24
virtual steepness of the front of an impulse
quotient of the peak value and the virtual front time of an impulse

2.25
virtual time to half value on the tail of an impulse, T_2
time interval between the virtual origin and the instant when the voltage or current has decreased to half its peak value, expressed in µs

2.26
virtual duration of the peak of a rectangular impulse
time during which the amplitude of the impulse is greater than 90 % of its peak value

2.27
virtual total duration of a rectangular impulse
time during which the amplitude of the impulse is greater than 10 % of its peak value

NOTE If small oscillations are present on the front, a mean curve should be drawn in order to determine the time at which the 10 % value is reached.

2.28
peak (crest) value of opposite polarity of an impulse
maximum amplitude of opposite polarity reached by a voltage or current impulse when it oscillates about zero before attaining a permanent zero value

2.29
discharge current of an arrester
impulse current which flows through the arrester

2.30
nominal discharge current of an arrester, I_n
peak value of lightning current impulse (see 2.17 and table 1) which is used to classify an arrester

2.31
high current impulse of an arrester
peak value of discharge current having a 4/10 impulse shape which is used to test the stability of the arrester on direct lightning strokes

2.32
switching current impulse of an arrester
peak value of discharge current having a virtual front time greater than 30 µs but less than 100 µs and a virtual time to half value on the tail of roughly twice the virtual front time

2.33
continuous current of an arrester
continuous current is the current flowing through the arrester when energized at the continuous operating voltage, expressed either by its r.m.s. or peak value

NOTE The continuous current, which consists of a resistive and a capacitive component, may vary with temperature, stray capacitance and external pollution effects. The continuous current of a test sample may, therefore, not be the same as the continuous current of a complete arrester.

2.34
reference current of an arrester
peak value (the higher peak value of the two polarities if the current is asymmetrical) of the resistive component of a power frequency current used to determine the reference voltage of the arrester

NOTE 1 The reference current should be high enough to make the effects of stray capacitance at the measured reference voltage of the arrester units (with designed grading system) negligible and should be specified by the manufacturer.

NOTE 2 Depending on the nominal discharge current and/or line discharge class of the arrester, the reference current will be typically in the range of 0,05 mA to 1,0 mA per square centimetre of disc area for single column arresters.

2.35
reference voltage of the main series metal-oxide resistors
peak value of power frequency voltage divided by $\sqrt{2}$ applied to the main series metal-oxide resistors of arrester to obtain the reference current

NOTE The reference voltage of a multi-unit arrester is the sum of the reference voltages of the main series metal-oxide resistors of the individual units.

2.36
residual voltage of an arrester, U_{res}
peak value of voltage that appears between the terminals of an arrester during the passage of discharge current

NOTE The term “discharge voltage” is used in some countries.

2.37
power frequency withstand voltage versus time characteristic of an arrester (temporary overvoltage, TOV)
power frequency withstand voltage versus time characteristic showing maximum time durations for which corresponding power frequency voltages may be applied to arresters without causing damage or thermal instability under specified conditions in accordance with 5.9.

2.38
prospective current of a circuit
current which would flow at a given location in a circuit if it were short-circuited at that location by a link of negligible impedance

2.39
protective characteristics of an arrester
Regarded as a combination of the following:

a) residual voltage for steep current impulse and front-of-wave sparkover according to 7.3.2 and 7.3.6.2
b) residual voltage versus discharge current characteristic for lightning impulses and the 1,2/50 impulse sparkover according to 7.3.3 and 7.3.7.2
c) residual voltage for switching impulse and the switching impulse sparkover according to 7.3.4 and 7.3.8.2

2.40
thermal runaway of an arrester
situation when the sustained power loss of an arrester exceeds the thermal dissipation capability of the housing and connections, leading to a cumulative increase in the temperature of the resistor elements culminating in failure

2.41
thermal stability of an arrester
arrester is thermally stable if, after an operating duty causing temperature rise, the temperature of the resistor elements decreases with time when the arrester is energized at specified continuous operating voltage and at specified ambient conditions

2.42
arrester disconnector
device for disconnecting an arrester from the system in the event of arrester failure, to prevent a persistent fault on the system and to give visible indication of the failed arrester

NOTE The device is not required to clear arrester fault current.

2.43
type tests
(design tests)
tests, which are made upon the completion of the development of a new arrester design, to establish representative performance and to demonstrate compliance with the relevant standard

NOTE Once made, these tests need not be repeated unless the design is changed so as to modify its performance. In such a case only the relevant tests need be repeated.

2.44
routine tests
tests made on each arrester, or on parts and materials, as required, to ensure that the product meets the design specifications

2.45
acceptance tests
tests which are made when it has been agreed between the manufacturer and the purchaser that the arresters or representative samples of an order are to be tested

2.46
sparkover of an arrester
disruptive discharge between the electrodes of the gaps of an arrester

2.47
follow current of an arrester
current from the connected power source which flows through an arrester following the passage of discharge current

2.48
average sparkover voltage
This can be sub-divided into two types:

2.48.1
power frequency sparkover voltage
average of at least five successive power frequency sparkovers

2.48.2
lightning impulse sparkover voltage
average of at least five successive lightning impulse sparkovers

2.49
impulse sparkover voltage of an arrester
highest value of voltage attained before sparkover during an impulse of given waveshape and polarity applied between the terminals of an arrester

2.50
front-of-wave sparkover voltage of an arrester
impulse sparkover voltage obtained on the wavefront of the voltage which increases linearly with time

2.51
standard lightning impulse sparkover voltage of an arrester
lowest prospective peak value of a standard lightning voltage impulse which, when applied to an arrester, causes sparkover on every application

2.52
time to sparkover of an arrester
time interval between virtual origin and the instant of sparkover of the arrester, expressed in µs

2.53
impulse sparkover voltage-time curve
curve which relates the impulse sparkover of the voltage to the time to sparkover

2.54
grading current
peak value of current flowing through the arrester while power frequency voltage is applied

2.55
metal-oxide surge arrester with gapped structures
arrester having non-linear metal-oxide resistors connected in series and/or in parallel with any internal or external series or shunt spark gaps

2.56
power frequency sparkover voltage
value of the power frequency voltage, measured as the peak value divided by $\sqrt{2}$ applied between the terminals of an arrester, which causes sparkover

2.57
line arrester
type of arrester that is commonly applied to power systems to reduce the risk of insulator flashover during a lightning transient

NOTE It is not generally used to protect the insulator from other types of transients such as switching surges. Neither is it generally used to protect any equipment other than line insulators.

2.58
impulse protective levels

These can be sub-divided into three types:

2.58.1
fast front protective level
highest of either the steep current residual voltage at (I_n) or the front-of-wave impulse sparkover voltage

2.58.2
standard lightning impulse protective level
highest of either the residual voltage at nominal current (I_n) or 1,2/50 lighting impulse sparkover voltage

2.58.3
switching impulse protective level
highest of either the maximum residual voltage for the specified switching current or the specified switching impulse sparkover voltage

2.59
main series metal oxide resistors
resistors that carry energy during an impulse, not to be confused with resistors that separate gaps for voltage grading

NOTE Measurement of reference voltage is necessary for the selection of a correct test sample in the operating duty test, see 6.2

2.60
series gap
intentional gap(s), between spaced electrodes in series with one or more metal-oxide resistors, across which all or part of the imparted terminal voltage appears

2.61
shunt gap
intentional gap(s) between spaced electrodes electrically in parallel with one or more main metal-oxide resistors

2.62
switching voltage impulse
impulse voltage having a virtual front time greater than 30 µs

3 Identification and classification

3.1 Arrester identification

Metal-oxide surge arresters containing gapped structures shall be identified by the following minimum information which shall appear on a nameplate permanently attached to the arrester:

– continuous operating voltage;
– rated voltage;
– rated frequency, only if other than one of the standard frequencies, see 4.2;
– nominal discharge current;
– short-circuit withstand current rating in kA r.m.s. (for arresters with short-circuit withstand ratings);
– manufacturer's name or trade mark, type and identification of the complete arrester;
– identification of the assembling position of the unit (for multi-unit arresters only);
– year of manufacture.

3.2 Arrester classification

Surge arresters are classified by their standard nominal discharge currents and they shall meet at least the test requirements and performance characteristics specified in table 1.

Table 1 – Arrester classification and tests

	Standard nominal discharge current			
	10 000 A	**5 000 A**	**2 500 A**	**1 500 A**
1 Rated voltage U_r (kV_{RMS})	$3 \leq U_r \leq 52$	$3 \leq U_r \leq 52$	$3 \leq U_r \leq 52$	$3 \leq U_r \leq 52$
2 Insulation withstand tests on arrester housings	7.2	7.2	7.2	7.2
3 Residual voltage tests:	Table F.1	Table F.1	Table F.1	Table F.1
a) steep current impulse residual voltage test	7.3.2	7.3.2	7.3.2	7.3.2
b) lighting impulse residual voltage test	7.3.3	7.3.3	7.3.3	7.3.3
c) switching impulse residual voltage test	7.3.4	Not required	Not required	Not required
4 Sparkover voltage tests:				
a) front-of-wave impulse sparkover voltage test	7.3.6	7.3.6	7.3.6	7.3.6
b) lightning impulse sparkover voltage test	7.3.7	7.3.7	7.3.7	7.3.7
c) switching impulse sparkover voltage test	7.3.8	Not required	Not required	Not required
5 Long duration current impulse withstand test	7.4.3	7.4.3	7.4.3	Not required
6 High current impulse operating duty test	7.5.3 and table 8	7.5.3 and table 8	7.5.3 and table 8	7.5.3 and table 8
7 Power frequency voltage versus time curve	5.9	5.9	5.9	5.9
8 Short-circuit withstand (when it applies)	5.10	5.10	Not required	Not required
9 Arrester disconnector (when fitted)	7.6	7.6	7.6	7.6
10 Power frequency sparkover voltage test	7.7	7.7	7.7	7.7
11 Moisture ingress tests	7.8	7.8	7.8	7.8
12 Weather ageing tests (polymeric housing only)	7.9 and table 9	7.9 and table 9	7.9 and table 9	7.9 and table 9
13 Artificial pollution test	Annex D	Annex D	Annex D	Annex D

4 Standard ratings

4.1 Standard rated voltages

Standard values of rated voltages for arresters (in kV r.m.s.) are specified in table 2 in equal voltage steps within specified voltage ranges:

Table 2 – Steps of rated voltages

Range of rated voltage kV	**Steps of rated voltage** kV r.m.s.
3-30	1 kV
30-52	3 kV

NOTE All other ratings are considered non-standard but are still subject to conformance to this standard.

4.2 Standard rated frequencies

The standard rated frequencies are 50 Hz and 60 Hz.

4.3 Standard nominal discharge currents

The standard nominal 8/20 discharge currents are: 10 000 A, 5 000 A, 2 500 A and 1 500 A, see 2.30.

4.4 Service conditions

4.4.1 Normal service conditions

Surge arresters that conform to this standard shall be suitable for normal operation under the following normal service conditions:

a) ambient air temperature within the range of –40 °C to +40°C;

b) solar radiation;

NOTE The effects of maximum solar radiation (1,1 kW/m^2) have been taken into account by preheating the test specimen in the type tests. If there are other heat sources near the arrester, the application of the arrester shall be subject to an agreement between the manufacturer and the purchaser.

c) altitude not exceeding 1 000 m;

d) frequency of the a.c. power supply shall not be less than 48 Hz and not exceeding 62 Hz;

e) power frequency voltage applied continuously between the terminals of the arrester not exceeding its continuous operating voltage;

f) mechanical conditions (under consideration);

g) pollution conditions (no requirement at this time).

4.4.2 Abnormal service conditions

Surge arresters subject to other than normal application or service conditions may require special consideration in design, manufacture or application. The use of this standard in case of abnormal service conditions is subject to agreement between the manufacturer and the purchaser. A list of possible abnormal service conditions is given in annex A.

5 Requirements

5.1 Insulation withstand of the arrester housing

The arrester housing shall withstand the following voltages when tested according to 7.2:

– the standard lightning impulse protection level of the arresters (see 2.58.2) multiplied by 1,3;

  NOTE The 1,3 factor covers variations in atmospheric conditions and discharge currents higher than nominal.

– power frequency voltage in wet conditions for arrester housings for outdoor use and in dry conditions for arrester housings for indoor use.

Housings of 1 500 A, 2 500 A and 5 000 A arresters shall withstand a power frequency voltage with a peak value equal to the standard lightning impulse protection level (see 2.58.2) multiplied by 0,88 for a duration of 1 min.

Housings of 10 000 A arresters shall withstand a power frequency voltage with a peak value equal to the switching impulse protection level multiplied by 1,06 for a duration of 1 min (see 2.58.3)

5.2 Reference voltage

The reference voltage of each of the main series metal-oxide resistors shall be measured by the manufacturer at the reference current selected by the manufacturer, see 6.2. The minimum reference voltage of the main series of metal-oxide prorated section shall be stated in the type test report.

5.3 Impulse protective levels

The arrester shall be tested to determine whether the protective level for a specified wave-shape (7.3.6, 7.3.7, 7.3.8) is a function of the maximum impulse sparkover value or residual voltage (7.3.2, 7.3.3, 7.3.4), whichever is greatest.

5.4 Partial discharges

When required, the partial discharge level in the arrester energized at 1,05 times its continuous operating voltage shall not exceed 10 pC, see 8.1 b) and 8.2.1 c).

5.5 Seal leakage

Arrester units with sealed housings containing gaseous material shall meet the gas leakage requirements of 8.1 c). Arresters with polymeric housings shall be tested per the moisture ingress test see 7.8.

5.6 Thermal stability

When agreed between manufacturer and purchaser, a special thermal stability test may be performed according to 8.2.2.

5.7 Long duration current impulse withstand

Arresters shall withstand long duration currents as verified during type tests, see 7.4.

For 10 000 A arresters, the long duration withstand is demonstrated by a line discharge test (see 7.4.2) with the line discharge class specified by the user.

For 5 000 A and 2 500 A arresters, the long duration withstand is demonstrated by a long duration impulse test, see 7.4.3.

The samples shall be considered to have passed if all the following requirements are met:

a) The residual voltage at nominal discharge current has not changed by more than 5 %.

b) The average power frequency sparkover voltage or average standard lightning impulse sparkover voltage has not changed by more than 5 %.

c) If the manufacturer declares that the resistors may be removed, then visual examination of the test samples after the test shall reveal no evidence of puncture, flashover, cracking or other significant damage of the metal-oxide resistors, or the gap structure. In other cases, visual inspection only applies to external parts. To check the integrity of the internal parts, an additional long duration impulse shall be performed after the sample has cooled down to ambient temperature to verify that no damage occurred. If the sample withstood the nineteenth long duration current impulse with no damage (checked by oscillographic records) then the sample has passed the test.

5.8 Operating duty

Arresters shall be able to withstand the combination of stresses arising in service as demonstrated by the operating duty tests, see 7.5. These stresses shall not cause damage or thermal runaway.

For 1 500 A, 2 500 A, 5 000 A and 10 000 A line discharge class 1 arresters, this is demonstrated by the high current impulse operating duty test, see 7.5.3 and table 8.

The arrester has passed the test if:

a) residual voltage has not changed by more than 5 %;

b) the average power frequency sparkover voltage or average standard lightning impulse sparkover voltage has not changed by more than 5 %;

c) if the manufacturer declares that the internal components may be removed, then visual examination of the test samples after the test shall reveal no evidence of puncture, flashover, cracking or other significant damage of the metal-oxide resistors or gap structures. In other cases, visual inspection only applies to external parts;

d) there is a decrease in watts loss, leakage current, or temperature during the application of U_c for 30 min after the application of U_r;

e) final interruption of the follow current occurs not later than at the end of the half cycle following that in which the impulse is applied. There shall be no further sparkover of the test sample in any subsequent half-cycle.

5.9 Power frequency voltage versus time characteristics of an arrester

The manufacturer shall supply data on the allowable time duration of power frequency voltage and the corresponding voltage value which may be applied to the arrester after the arrester has been preheated to 60 °C and subjected to the high current or line discharge class energy duty respectively, without damage or thermal runaway.

This information shall be presented, together with initial temperature, as power frequency voltage versus time curves with the impulse energy absorption prior to this power frequency voltage application stated on the curve.

NOTE 1 Such curves are necessary for the selection of the arrester rated voltage depending on local system conditions, such as lightning, switching and temporary overvoltages.

NOTE 2 The curves may be established by calculation.

NOTE 3 The temporary overvoltage curve should cover the time range from 0,1 s to 20 min. For arresters to be used in isolated neutral or resonant earthed systems without earth fault clearing, the time should be extended to 24 h.

If verification of the power frequency voltage versus time curve is agreed upon by the manufacturer and the purchaser, the procedure described in annex C shall be used.

5.10 Short-circuit withstand

When an arrester has short-circuit withstand capabilities, this device shall pass all short-circuit withstand tests as specified in IEC 60099-4. In these tests, the gap structure shall be short-circuited by fuse wires and the test carried out with the selected procedure for metal-oxide arresters without gaps.

5.11 Disconnectors

5.11.1 Disconnector withstand

When an arrester is fitted or associated with a disconnector, this device shall withstand, without operating, each of the following tests:

– long duration current impulse test, see 7.6.2.1;

– operating duty test, see 7.6.2.2.

5.11.2 Disconnector operation

The time delay for the operation of the disconnector is determined for three values of current according to 7.6.3. There shall be clear evidence of effective and permanent disconnection by the device.

5.12 Requirements for internal and external grading components

Under consideration.

5.13 Power frequency sparkover

A power frequency sparkover test shall be performed on gapped arresters in which the sparkover occurs for grading currents less than 1 A r.m.s. The minimum power frequency sparkover voltage of the arrester shall be stated by the manufacturer.

5.14 Grading current

The grading current shall be measured by the manufacturer at rated voltage.

5.15 Weather ageing tests

Arrester designs as specified in table 9 shall pass weather ageing tests as specified in IEC 60099-4. (See also 7.9.)

6 General procedures

6.1 Measuring equipment and accuracy

The measuring equipment shall meet the requirements of IEC 60060-2. The values obtained shall be accepted as accurate for the purpose of compliance with the relevant test clauses.

Unless elsewhere stated, all tests with power frequency voltages shall be made with an alternating voltage having a frequency between the limits of 48 Hz and 62 Hz and an approximately sinusoidal waveshape.

6.2 Reference voltage measurements

The reference voltage of the main metal-oxide elements of an arrester (see 2.35) is measured at the reference current (see 2.34) on sections and units when required. The measurement shall be performed at an ambient temperature of 20 °C ± 15 °C and this temperature shall be recorded.

NOTE As an acceptable approximation, the peak value of the resistive component of current may be taken to correspond to the momentary value of the current at the instant of voltage peak.

6.3 Test samples

Unless otherwise specified, all tests shall be made on the same arresters, arrester sections or arrester units. They shall be new, clean, completely assembled (e.g. with grading rings if applicable) and arranged as closely as possible to simulate the conditions in service. This means that during the arrester sparkover voltage tests, the arrester shall be positioned at approximately the same height above the ground planes as usually foreseen in service (unless demonstrated that a lower height above the ground plane gives the same sparkover values). Further, a grounded metal wall shall be positioned beside the arrester at the minimum distance which the manufacturer specifies for phase to ground clearances. The height of the grounded wall shall be at least as high as the arrester length plus the distance from arrester base to ground.

When tests are made on sections, it is necessary that the sections represent the behaviour of all possible arresters within the manufacturer's tolerances with respect to a specific test.

The samples to be chosen for the operating duty test (7.5) shall have a characteristic representative of the most critical design, taking into account the variation range declared by the manufacturer. In order to comply with this demand, the following shall be fulfilled:

a) The ratio between rated voltage of the complete arrester to the rated voltage of the section is defined as *n*. The volume of the resistor elements used as test samples shall not be greater than the minimum volume of all resistor elements used in the complete arrester divided by *n*. The section shall have equivalent thermal characteristics of the most thermally disadvantaged equivalent section within the main arrester. The voltage gradient shall be the maximum occurring in any section of the arrester.

   The factor *n* of the test samples shall be recorded in the test report.

b) The average dry power frequency sparkover voltage of the section shall not be higher than the minimum power frequency sparkover for the complete arrester divided by *n*. The minimum power frequency sparkover shall be the lowest sparkover decided by U_r for the arrester series under test. Grading current measured at U_r shall be the lowest for the range of arresters being tested. Neither of these characteristics need be applied to the same sample, unless the arrester series under test may at some point demonstrate the combination at the same time. The number of spark gaps in the section shall not be greater than the minimum number of spark gaps in the complete arrester divided by *n*, except that a minimum of one spark gap shall be used in the test sample. If it is not possible to fulfil this requirement, then the number of gaps shall be agreed upon between the manufacturer and the purchaser.

7 Type tests (design tests)

7.1 General

The following type tests shall be carried out, insofar as they are required in table 1:

a) Insulation withstand tests, see 5.1 and 7.2.

   These tests demonstrate the ability of the arrester housing to withstand voltage stresses under dry and wet conditions.

b) Impulse protective level tests, see 5.3 and 7.3.

These tests demonstrate the protective levels of the arrester.

c) Long duration current impulse withstand test, see 5.7 and 7.4.

These tests demonstrate the ability of the resistor elements and gaps to withstand possible dielectric and energy stresses.

d) Operating duty tests, see 5.8 and 7.5.

These tests demonstrate the thermal stability and dielectric strength of the arrester and the ability of the gaps to operate properly under defined conditions.

e) Short-circuit withstand tests, see 5.10.

For arresters with declared short-circuit withstand capabilities, these tests demonstrate the ability of the arrester to withstand short-circuit currents under specified test conditions.

f) Tests of arrester disconnectors, see 5.11 and 7.6.

For arresters fitted with disconnectors, these tests demonstrate the correct operation of the disconnector.

g) Artificial pollution test (see annex D)[2].

This test is made to show that the internal parts of the arrester, including its grading system, are able to withstand pollution without any damage and that the external insulation does not flashover.

h) Partial discharge test, see 5.4.

This test measures the internal partial discharges.

i) Seal leakage test (see 5.5 and 8.1 c) and moisture ingress tests, see 7.8.

Seal leakage tests apply to arresters with an internal gas volume of >10 % unit volume, and moisture ingress tests apply to arresters with internal gas volume ≥10 % of unit volume.

This test determines the integrity of the arrester seals.

j) Weather ageing tests for polymeric housed arresters.

Arrester designs as specified in table 9 of this standard, shall pass the weather ageing tests as specified in IEC 60099-4, figure 9.

7.2 Insulation withstand tests on the arrester housing

7.2.1 General

The voltage withstand tests demonstrate the voltage withstand capability of the external insulation of the arrester housing.

The tests shall be performed in the conditions and with the test voltages specified in 5.1 and repeated below. The outside surface of insulating parts shall be carefully cleaned and the internal parts removed or rendered inoperative to permit these tests.

7.2.2 Tests on individual unit housing

The applicable tests shall be run on the longest arrester housing. If this does not represent the highest specific voltage stress per unit length, additional tests shall be performed on the unit housing having the highest specific voltage stress. The internal parts may be replaced by an equivalent arrangement (e.g. grading elements) to provide approximately the same voltage distribution along the arrester axis as it would experience with internal components still installed.

2 Yet to be established.

7.2.3 Tests on complete arrester housing assemblies

Under consideration.

7.2.4 Ambient air conditions during tests

The voltage to be applied during a withstand test is determined by multiplying the specified withstand voltage by the correction factor, taking into account density and humidity. See IEC 60060-1.

Humidity correction shall not be applied for wet tests.

7.2.5 Wet test procedure

The external insulation of outdoor arresters shall be subjected to wet withstand tests under the test procedure given in IEC 60060-1.

7.2.6 Standard lightning impulse voltage test

The arrester shall be subjected to a standard lightning impulse voltage dry test according to IEC 60060-1.

Fifteen consecutive impulses at the test voltage value shall be applied for each polarity. The arrester shall be considered to have passed the test if no internal disruptive discharges occur and if the number of the external disruptive discharges does not exceed two in each series of 15 impulses. The test voltage shall be equal to the standard lightning impulse protection level of the arrester multiplied by 1,3.

If the dry arcing distance or the sum of the partial dry arcing distances is larger than the test voltage divided by 500 kV/m, this test is not required.

7.2.7 Power frequency voltage test

The housings of arresters for outdoor use shall be tested in wet conditions, and housings of arresters for indoor use shall be tested in dry conditions.

Housings of 1 500 A, 2 500 A and 5 000 A arresters shall withstand a power frequency voltage with a peak value equal to the standard lightning impulse protection level multiplied by 0,88 for a duration of 1 min.

Housings of 10 000 A arresters shall withstand a power frequency voltage with a peak value equal to the switching impulse protection level multiplied by 1,06 for a duration of 1 min.

7.3 Impulse protective level tests

The purpose of the impulse protective level measurement is to obtain the maximum protective level for a given design for all specified currents and voltage waveshapes.

The general test procedure shall be as follows:

a) Apply prospective impulse voltage waves, measure the resulting peak arrester voltages and compare these voltages with the appropriate residual voltage level.
b) Where the maximum arrester voltage resulting from application of these prospective voltage impulses is less than the arrester residual voltage level, then the protective level for that waveshape is the arrester residual voltage level.
c) Otherwise, sparkover tests shall be made and the protective level for that waveshape is the maximum sparkover value. Impulse protective levels shall be established by the front-of-wave sparkover, 1,2/50 impulse sparkover and switching impulse sparkover tests.

7.3.1 Residual voltage tests

The purpose of the residual voltage type test is to obtain the data necessary to derive the maximum residual voltage. It includes the calculation of the ratio between voltages at specified impulse currents and the voltage level checked in routine tests. The latter residual voltage can be either at the nominal discharge current or the residual voltage at a suitable lightning impulse current in the range 0,01 to 2 times the nominal discharge current, depending on the manufacturer's choice of routine test procedure.

The maximum residual voltage at a lightning impulse current used for routine tests shall be specified and published in the manufacturer's data. Maximum residual voltages of the design for all specified currents and waveshapes are obtained by multiplying the measured residual voltages of the test sections by the ratio of the declared maximum residual voltage at the routine test current to the measured residual voltage for the section at the same current.

All residual voltage tests shall be made on the same three samples of complete arresters or arrester sections. The time between discharges shall be sufficient to permit the samples to return to within 5 °C of ambient temperature.

7.3.2 Steep current impulse residual voltage test

One steep current impulse, in accordance with definition 2.16, with peak value equal to the nominal discharge current of the arrester ± 5 % shall be applied to each of the three samples. The three voltage peaks are recorded. The residual voltages are determined in accordance with 5.3. The highest value is defined as the steep current residual voltage of the arrester. The partial response time *T* of the voltage measuring circuit used shall not exceed 20 ns (see IEC 60060-2). The fast front protective level of the arrester is defined as the highest of either the steep current residual voltage or the front-of-wave impulse sparkover of the arrester.

7.3.3 Lightning impulse residual voltage test

One lightning current impulse, in accordance with definition 2.17, shall be applied to each of the three samples for each of the following three peak values of approximately 0,5, 1 and 2 times the nominal discharge current of the arrester. The virtual front time shall be 7 μs to 9 μs while the half value time (which is not critical) may have any tolerance. The residual voltages are determined in accordance with 5.3. The maximum values of the determined residual voltages shall be drawn in a residual voltage verses discharge current curve. The lightning impulse protective level of the arrester is defined as the highest of the residual voltages read on such a curve corresponding to the nominal discharge current or the lightning impulse sparkover voltage of the arrester.

NOTE If a complete arrester routine test cannot be carried out at one of the above currents, then additional type tests shall be carried out at a current in the range of 0,01 to 0,25 times the nominal discharge current for comparison with the complete arrester.

7.3.4 Switching impulse residual voltage test

One switching current impulse, in accordance with definition 2.32, of each value as specified in table 3 shall be applied to each of the three samples with peak values according to table 3 and with a tolerance of ±5 %. The residual voltages are determined in accordance with 5.3. The highest of these three voltages is defined as the switching impulse residual voltage of the arrester. The switching impulse protection level of the arrester is defined as the highest of the switching impulse residual voltages, as determined above, or the switching impulse sparkover of the arrester.

Table 3 – Peak currents for switching impulse residual voltage tests

Arrester classification	Peak currents A
10 000 A line discharge class 1	125 and 500

7.3.5 Sparkover tests

Sparkover tests shall be made on three samples of complete arresters of each voltage rating tested. The performance for other voltage ratings of the same design within ±20 % (or 3 kV, whichever is greater) of a test sample rating can be determined by adjusting the voltage level in proportion to the voltage ratings. In view of the dependency of gap sparkover on temperature, the tests should be carried out at 20 °C to 25 °C, and an additional test carried out at an elevated temperature (preferably between 40 °C and 50 °C). If there is a difference between the results, then the higher of the two results shall be used for subsequent tests and comparisons.

7.3.6 Fast front protective level

This test determines whether the arrester sparkover for a front-of-wave lightning impulse can exceed its steep current residual voltage.

7.3.6.1 Front-of-wave impulse sparkover determination test

This test is performed using both positive and negative polarity impulses. The prospective magnitude of the test wave shall be a minimum of 1,2 times the arrester's steep current residual voltage. At least five discharges shall be measured for each polarity. The nominal rate of rise of the test wave front shall be 8,33 kV/μs for each kilovolt of arrester voltage rating.

The maximum arrester voltage recorded during five positive and five negative polarity impulses shall be compared to the steep current residual voltage. If the steep current residual voltage exceeds the voltage values measured during the impulse test described above, the steep current residual voltage is the fast front protective level and no further testing is required on this waveshape. If the voltage measured during the impulse test exceeds the steep current residual voltage, proceed to 7.3.6.2 to determine the fast front protective level.

7.3.6.2 Front-of-wave impulse sparkover tests

This test shall be made using both positive and negative polarity impulses. The prospective crest value of the test wave shall be high enough that the sparkover of the arrester occurs before 90 % of the crest value of the test wave is reached. At least five sparkovers shall be recorded for each polarity and the highest crest value so recorded shall be reported as the maximum front-of-wave sparkover value of the test arrester and taken as the fast front protective level. The nominal rate of rise of the test wave front shall be the same as described in 7.3.6.1.

7.3.7 Standard lightning impulse protective level test

This test series determines whether the arrester sparkover voltage for a standard lightning impulse can exceed the residual voltage obtained from an 8/20 impulse at nominal current as shown in table 1.

7.3.7.1 Standard lightning impulse sparkover determination test

The test is performed using at least five positive and five negative waves. A minimum prospective magnitude of 1,2 times the arrester's residual voltage at the nominal discharge current as indicated in table 1 shall be used. The maximum arrester voltage recorded during the five positive and five negative polarity standard lightning impulses shall be compared to the residual voltage obtained with the nominal discharge currents in table 1. If the nominal discharge current residual voltage exceeds the voltage values measured during the standard lightning impulse sparkover voltage test described earlier, the nominal discharge current residual voltage is the standard lightning protective level and no further testing is required on this waveshape. If the voltage measured during the standard lightning impulse test exceeds the nominal discharge current residual voltage, proceed to 7.3.7.2, the standard lightning impulse sparkover voltage test, to determine the standard lightning impulse protective level.

7.3.7.2 The standard lightning impulse sparkover test

The purpose of this test is to determine the highest standard lightning impulse voltage greater than 3 µs duration that the arrester will withstand without sparkover.

For each polarity, the test procedure shall be as follows:

a) Determine the base generator charge voltage, V_G, according to the method described in the following note and record crest voltage and time to sparkover (where sparkover occurs) for each of the 20 impulses used for establishing V_G.

   NOTE The procedure for establishing V_G is as follows: Start by applying an impulse having a prospective crest voltage somewhat lower than the expected sparkover voltage of the arrester, raising the generator charge voltage in approximately 5 % steps for subsequent impulses until sparkover occurs. Then apply a series of 20 impulses, decreasing the prospective crest voltage by about 5 % after every sparkover and increasing the prospective crest voltage by about 5 % after every withstand. V_G is the average generator charge voltage used during the series of 20 impulses.

b) Apply five impulses using a generator charge voltage not more than 1,05 V_G and record crest voltage and time to sparkover. If sparkover does not occur within 3,0 µs after the virtual zero point on each of the five impulses, raise generator charge voltage in additional increments not greater than 0,05 V_G until a level is reached that results in sparkover within 3,0 µs after the virtual zero point on each of the five applications. The higher prospective crest voltage of either polarity required to obtain five sparkovers on five successive applications of test impulses with constant generator charge voltage shall be reported as the standard lightning impulse protective level of the arrester.

7.3.8 Switching impulse protective level test

This test series determines whether the arrester-specified switching impulse sparkover voltage can exceed the switching surge residual voltage at the classifying current in table 3.

7.3.8.1 Switching impulse sparkover determination test

The magnitude of the switching impulse sparkover voltage for each waveshape shall be a minimum of 1,2 times the arrester residual voltage corresponding to the switching surge current specified in table 3. The test consists of at least five positive and five negative wave applications for each of the following virtual front times of the prospective voltage impulse:

- 30 µs to 60 µs;
- 150 µs to 300 µs;
- 1 000 µs to 2 000 µs.

The times to half value on the tail should be appreciably longer than the virtual front time. The exact value is not of critical importance.

The maximum arrester voltage recorded during the five positive and five negative polarity impulses for each switching surge waveshape shall be compared to the switching impulse residual voltage. If the switching impulse residual voltage exceeds the voltage values measured during each of the specified switching impulse sparkover tests described earlier, the switching surge classifying current residual voltage is the switching impulse protective level and no further switching surge testing is required. If the voltage measured during any of the switching surge impulse tests exceeds the switching surge classifying current residual voltage, proceed to 7.3.8.2 and perform sparkover tests on only the waveshape or waveshapes that demonstrated high switching surge impulse test voltages.

7.3.8.2 Switching impulse sparkover voltage-time characteristics

Sparkover tests shall be made using the following test waves (but not necessarily in the order given), having virtual front times of

- 30 µs to 60 µs,
- 150 µs to 300 µs,
- 1 000 µs to 2 000 µs.

The times to half value on the tail should be appreciably longer than twice the virtual front time but the exact value is not of critical importance.

For each polarity, the waveshape shall be checked with the arrester in the test circuit at a test voltage that does not cause arrester sparkover in at least one of five trials.

For each waveshape and polarity, the test procedure shall be as follows:

a) Determine the base generator charge voltage, V_G, according to the method described in 7.3.7.2, recording crest voltage and time to sparkover (where sparkover occurs) for each of the 20 impulses used for establishing V_G.
b) Apply 10 impulses using a generator charge voltage of 1,2 times V_G and record crest voltage and time to sparkover.
c) Apply 10 impulses using a generator charge voltage of 1,4 times V_G and record crest voltage and time to sparkover.

The highest crest value of voltage with a time duration greater than 30 µs recorded during these tests shall be considered the maximum switching impulse sparkover voltage of the test arrester and taken as the switching impulse protective level.

7.4 Long duration current impulse withstand test

7.4.1 General

Before the tests, the lightning impulse residual voltage at nominal discharge current and average dry power frequency sparkover voltage, or average standard lightning impulse sparkover voltage, of each test sample shall be measured for evaluation purposes.

Each long duration current impulse withstand test shall be made in accordance with 6.3 and 7.1 on three new samples of complete arresters, arrester sections, resistor elements or resistor elements with gaps which have not been subjected previously to any test except that specified above for evaluation purposes. The non-linear metal-oxide resistors and gaps may be exposed to the open air at a still air temperature of 20 °C ± 15 °C during these tests. The rated voltage of the test samples shall be at least 3 kV if the rated voltage of the arrester is not less than this and need not exceed 6 kV. If an arrester disconnector is built into the design of the arrester under consideration, these tests shall be made with the disconnector in operable condition, see 7.6.

Each long duration current impulse test shall consist of 18 discharge operations divided into six groups of three operations. Intervals between operations shall be 50 s to 60 s and between groups such that the sample cools to within 5 °C of ambient temperature.

Following the long duration current test and after the sample has cooled to near ambient temperature, the sample shall be considered as having passed if

e) the residual voltage shall not have changed by more than ±5 %,
e) the average power frequency sparkover values or the average standard lightning impulse sparkover values shall not have changed by more than ±5 %,

e) providing the manufacturer declares that the internal components may be removed, visual examination of the test samples after the test reveal no evidence of puncture, flashover, cracking or other significant damage of the metal-oxide resistors or gap components. In other cases, visual inspection only applies to external parts. Pre- and post-residual voltage oscillograms shall be compared for evidence of internal damage.

7.4.2 Line discharge test requirements for 10 000 A arresters

This test involves the application of current impulses to the test sample, simulating discharges through it of a precharged line as defined by the parameters given in table 4.

Table 4 – Parameters for the line discharge test (10 000 A arresters)

Arrester classification A	Line discharge class	Surge impedance of the line Z Ω	Virtual duration of peak T µs	Charging voltage U_L kV d.c.
10 000	1	4,9 U_r [a]	2 000	3,2 U_r
[a] U_r is the rated voltage of the test sample in kV r.m.s.				

The energy, W, injected into the test sample is determined from the parameters of table 4 by the formula:

$$W = U_{res} \times (U_L - U_{res}) \times 1/Z \times T$$

where U_{res} is the lowest value of the switching impulse residual voltage measured on the three test samples for the lower current value of table 3.

The test may be carried out with any generator fulfilling the following requirements:

a) the virtual duration of the peak of the current impulse shall be between 100 % and 120 % of the value specified in table 4;

b) the virtual total duration of the current impulse shall not exceed 150 % of the virtual duration of the peak;

c) oscillations or initial overshoot shall not exceed 10 % of the peak of the current value. If oscillations occur, a mean curve shall be drawn for the determination of the peak value;

d) the energy for each impulse on each tested sample shall lie between 90 % and 110 % of the above calculated value for the first impulse and between 100 % and 110 % of this value for the following impulses.

The current generator shall be disconnected from the test sample after once and earlier than twice the virtual total duration of the current impulses, after passing through zero.

An example of a suitable test circuit is described in annex J of IEC 60099-4.

7.4.3 Long duration current requirements for 5 000 A and 2 500 A arresters

The generator used in this test shall deliver a current impulse fulfilling the following requirements:

a) the virtual duration of the peak shall lie between 100 % and 120 % of the value specified in table 5;

b) the virtual total duration shall not exceed 150 % of the virtual duration of the peak;

c) oscillations or initial overshoot shall not exceed 10 % of the peak current value. If oscillations occur, a mean curve shall be drawn for the determination of the peak value;

d) the peak current shall lie between 90 % and 110 % of the value specified in table 5 for the first impulse and between 100 % and 110 % of this value for the following impulses.

Table 5 – Requirements for the long-duration current impulse test on 5 000 A and 2 500 A arresters

Arrester classification A	Peak current A	Virtual duration of peak *T* µs
5 000	75	1 000
2 500	50	500

7.5 Operating duty tests

7.5.1 General

As explained in 5.8, these are tests in which service conditions are simulated by the application to the arrester of a stipulated number of specified impulses in combination with energization by a power supply of specified voltage and frequency. The voltage shall be measured to within an accuracy of 1 % as specified in IEC 60099-4 and its peak value is not allowed to vary by more than 1 % according to IEC 60099-4 from no load to full load condition. The ratio of peak voltage to r.m.s. value shall not deviate from $\sqrt{2}$ by more than 2 %. During the operating duty tests the power frequency voltage shall not deviate from the specified values by more than 1 % as specified in IEC 60099-4.

NOTE 1 With the manufacturer's agreement, higher voltages may be used to ensure compliance with the minimum voltage requirement.

The impedance of the power source shall be selected so that during the flow of follow current the peak value of the power frequency voltage measured at the arrester terminals does not fall below the peak value of the specified test voltage.

The main requirement to pass these tests is that the arrester is able to cool during the power frequency voltage application, i.e. thermal runaway does not occur and that the gaps can reseal properly after carrying lightning current as well as current impulses caused by switching operations. It is required, therefore, that the arrester sections tested shall have both a transient and a steady state heat dissipation capability equal to or less than for the complete arrester, see 7.5.3.3.

The test sequence comprises:

- initial measurements;
- conditioning;
- application of impulses;
- measurements and examination.

This sequence is illustrated in table 10.

The test shall be made on three samples of the most thermally disadvantaged equivalent of the longest unit of the series in accordance with 6.2, 6.3 and 7.1 at an ambient temperature of 20 °C ± 15 °C. The rated voltage of the test samples shall be at least 3 kV and need not exceed 12 kV. If an arrester disconnector is built into the design of the arrester under consideration, these tests shall be made with the disconnector in operable condition, see 7.6.

For arresters rated above 12 kV, it is usually necessary to make this test on an arrester section because of limitations of existing test facilities. It is important that the voltage across the test sample and the power frequency current through the sample represent, as closely as possible, the conditions in the complete arrester.

The critical arrester parameter for successfully passing the operating duty test is the resistor power loss and the ability of the gaps to interrupt the follow current. The operating duty test shall therefore be carried out on new resistors and gap assemblies at elevated test voltages U_c* or U_r* that give the same power losses as aged resistors and gap assemblies at continuous operating and rated voltage, respectively. These elevated test voltages shall be determined from the accelerated ageing procedure in the way described in 7.5.2.2.

The power frequency test voltages to be applied to the test arrester section shall be the continuous operating voltage (definition 2.9) and the rated voltage (definition 2.8) of the complete arrester divided by the total number of similar arrester sections, *n*, see 6.3. These voltages, U_{sc} equal to U_c/n and U_{sr} equal to U_r/n are modified according to 7.5.2.2 to establish the elevated test voltages U_c* and U_r*.

NOTE 2 The established preheat temperature of 60 °C ± 3 °C specified in tables 10 and 11 is a weighted average that covers the influence of ambient temperature, solar radiation and some influence of pollution on the arrester housing.

7.5.2 Accelerated ageing procedure

This test procedure is designed to determine the voltage values U_c* and U_r* used in the operating duty tests (see table 10) which allows those tests to be carried out on new resistors and gap assemblies at a later time. Table 6 specifies which test each arrester design type must conform to.

Table 6 – Arrester design and ageing test requirements

Surge arrester design			Tests
Housing material	**Gap position**	**Presence of grading elements**	**Accelerated ageing tests of internal parts**
Porcelain	Internal	Yes	7.5.2
Porcelain	Internal	No	Not required
Porcelain	External	Under consideration	Under consideration
Polymeric	Internal	Yes	7.5.2
Polymeric	Internal	No	Not required
Polymeric	External	Under consideration	Under consideration

7.5.2.1 Test procedure

The distribution of U_{ct} across the resistors and gap assemblies shall be determined at 40 °C with a measuring device or the voltage distribution may be determined by passing the same peak current through the individual assemblies as measured at U_c of the full assembly and measuring the resulting voltage.

The voltage metering impedance shall be high enough so as not affect the voltage distribution measurement. The values of U_{ct} for the resistor and gap assemblies shall be adjusted to reflect the real voltage applied across that element as determined in the voltage distribution tests above.

Three resistors and gap assemblies samples shall be stressed at a voltage equal to the corrected maximum continuous operating voltage U_{ct} (see below) of the samples for 1 000 h, during which the temperature shall be controlled to keep the surface temperature of the resistors and gap assemblies at 115 °C ± 4 °C. All material (solid or liquid) in direct contact with the resistors shall, for the ageing test, present the same design as for a complete arrester.

During this accelerated ageing, the resistors and gap assemblies shall be in the surrounding medium used in the arrester. In this case, the procedure shall be carried out on single resistors and gap assemblies in a closed chamber where the volume of the chamber is at least twice the volume of the resistors and gap assemblies and where the density of the medium in the chamber is not less than the density of the medium in the arrester.

NOTE 1 If the manufacturer can prove that the test carried out in open air is equivalent to that carried out in the actual medium, the ageing procedure can be carried out in open air.

NOTE 2 The medium surrounding the resistor within the arrester may be subject to a modification during the normal life of the arrester including the effects of the internal gap sparkover. A suitable test procedure taking account of such modifications is under consideration.

The relevant voltage for this procedure is the corrected maximum continuous operating voltage, U_{ct}, which the resistors shall support in the arrester including voltage unbalance effects. This voltage should be determined from the formula:

$$U_{ct} = U_c\,(1 + 0{,}15\,L)$$

where L is the total length of the arrester in metres.

If lower values are claimed by the manufacturer, they shall be demonstrated by voltage distribution measurements or computations. Alternatively, if the voltage distribution on each unit in a multi-unit arrester is determined by measurement or by calculation, then the formula is applied on the maximum stressed unit.

NOTE 4 Where a procedure differing from the above formula is employed, the details of the adopted procedure for determination of voltage distribution have to be agreed upon by the manufacturer and the purchaser, taking into account possible arrester mounting configurations in service.

The ageing procedure described above shall be carried out on three typical samples of resistor and gap assemblies with a reference voltage fulfilling the requirements of 6.3. The power frequency voltage shall fulfil the requirements stated for the operating duty test, see 7.5.1.

7.5.2.2 Determination of elevated rated and continuous operating voltages

The three test samples shall be heated to 115 °C ± 4 °C and the complete sample power losses P_{1ct} shall be measured at a voltage U_{ct} 1 h to 2 h after the voltage application. The arresters power losses shall be measured once every 100 h time span after the first measurement giving P_{1ct}. Finally, the resistor power losses P_{2ct} shall be measured after 1 000 h (0 h + 100 h) of ageing under the same conditions. Accidental intermediate de-energizing of the test samples, not exceeding a total duration of 24 h during the test period, is permissible. The interruption shall not be counted in the test's duration. The final measurement shall be performed after not less than 100 h of continuous energizing. Within the temperature range allowed, all measurements shall be made at the same temperature ±1 °C. The minimum power losses value among those measured at least every 100 h time span shall be called P_{3ct}.

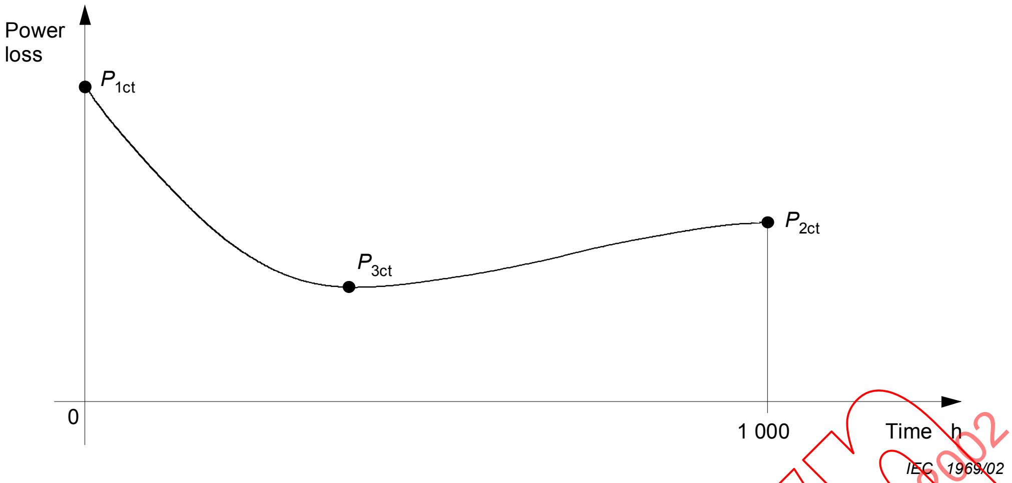

Figure 1 – Power losses of arrester at elevated temperatures vs. time

- if P_{2ct} is equal to or below 1,1 times P_{3ct}, then the test according to 7.5.3.2 shall be performed on new arresters;
- if P_{2ct} is equal to or less than P_{1ct}, U_{sc} and U_{sr} are used without any modification;
- if P_{2ct} is greater than P_{1ct}, the ratio P_{2ct} / P_{1ct} is determined for each sample.

  The highest of these three ratios is called K_{ct}. On three new arresters at ambient temperature, the power losses P_{1c}, and P_{1r} are measured at U_{sc} and U_{sr}, respectively. Thereafter, the voltages are increased so that the corresponding power losses P_{2c} and P_{2r} fill the relation:

  $$P_{2c} / P_{1c} = K_{ct}; \quad P_{2r} / P_{1r} = K_{ct}$$

  U_c* and U_r* are the highest of the three increased voltages obtained.

  As an alternative, aged arresters may also be used after agreement between the user and the purchaser.

- If P_{2ct} is greater than 1,1 times P_{3ct}, then aged arresters shall be used for the following tests of 7.5.3.2. New arresters with corrected values U_c* and U_r* could be used, but only after agreement between the purchaser and the manufacturer, and provided P_{2ct} is greater than or equal to P_{1ct}. Aged arresters are, by definition, resistors tested according to 7.5.2.1 test procedures.

Table 7 – Determination of elevated rated and continuous operating voltages

Power losses measured	Test samples and test voltage for the operating duty test
P_{2ct} less than or equal to 1,1 × P_{3ct} and P_{2ct} less than or equal to P_{1ct}	New samples at U_{sc} and U_{sr}
P_{2ct} less than or equal to 1,1 × P_{3ct} and P_{2ct} greater than P_{1ct}	New samples at U_{sc}* and U_{sr}*
P_{2ct} greater than 1,1 × P_{3ct} and P_{2ct} less than P_{1ct}	Aged samples at U_{sc} and U_{sr}
P_{2ct} greater than 1,1 × P_{3ct} and P_{2ct} greater than or equal to P_{1ct}	Aged samples at U_{sc} and U_{sr} (or new samples at U_{sc}* and U_{sr}* after agreement between the purchaser and the manufacturer)

In cases where aged arresters are used in the operating duty test, it is recommended that the time delay between the ageing test and the operating duty test be reduced to 24 h.

NOTE Possible change of the medium surrounding the resistors and gap structure in the field can, in this last case, increase significantly the power losses.

The measuring time shall be short enough to avoid increased power loss due to heating.

7.5.2.3 Arrester section requirements

This subclause specifies a thermal model of the arrester section and shall be followed when thermal equivalence is required:

a) the model shall electrically and thermally represent the most disadvantaged section within the longest unit of the arrester series;

b) the housing shall meet the following requirements

   i) material shall be the same as that of the arrester housing,

   ii) inside diameter shall be the same as that of the arrester ± 5 %,

   iii) the total mass of the housing shall not be more than 10 % greater than the mass of the average housing section of the arrester being modelled,

   iv) the housing shall be long enough to enclose the arrester section and the amount of insulation at the two ends shall be adjusted so as to meet the thermal requirements described in annex B;

c) the maximum conductor size used for electrical connections within the sample is 3 mm diameter copper wire.

7.5.3 High current impulse operating duty test

This test applies to 1 500 A, 2 500 A, 5 000 A and 10 000 A line discharge class 1 arresters.

The complete test sequence is illustrated in table 10.

Before the conditioning test, as the first part of the operating duty test, the lightning impulse residual voltage at nominal discharge current and the average dry power frequency sparkover voltage or average standard lightning impulse sparkover voltage of each of the three test samples (resistor elements and gap assemblies) is determined at ambient temperature, see 7.3.

7.5.3.1 Conditioning

The samples are exposed to a conditioning test consisting of twenty 8/20 lightning current impulses according to definition 2.17 and having a peak value equal to the nominal discharge current of the arrester. The impulses are applied while the test sample is energized at U_r*. The 20 impulses are applied in four groups of five impulses. The interval between the impulses shall be 50 s to 60 s and the interval between groups shall be 25 min to 30 min. It is not required that the test sample be energized between groups of impulses. The polarity of the current impulse shall be the same as that of the half cycle of power frequency voltage during which it occurs and it shall be applied at the most onerous time on the voltage wave with respect to follow current. The first impulse shall be applied at 60 ± 15 electrical degrees before the peak of the power frequency voltage. The timing is then retarded in approximately 10° steps toward voltage peak. For the remaining groups of impulses, the most onerous timing with respect to follow current found for the first group of impulses is used.

NOTE The intent of this tuning is to find the most onerous time. If the above method does not yield it, then reduce the retardation steps to 5°.

Final interruption of the follow current shall occur not later than at the end of the half cycle following that in which the impulse is applied. There shall be no further sparkover of the test sample in any subsequent half cycle.

If the internal components are not in direct contact with a solid material, the conditioning test may be carried out on the resistor and gap elements in open air at a still air temperature of 20 °C ± 15 °C. In other cases, the conditioning test shall be carried out in the section at a still air temperature of 20 °C ± 15 °C. The measured peak value of the current impulse shall be within 90 % and 110 % of the specified peak value.

After this conditioning test, the resistors and gaps are stored for future use in the operating duty tests, see table 10.

7.5.3.2 Application of impulses

At the beginning of the operating duty test, the temperature of the complete section shall be 20 °C ± 15 °C.

The section is subjected to two high current impulses with peak value and impulse shape as specified in table 8.

Table 8 – Requirements for high current impulses

Arrester classification A	**Peak current (4/10)** kA
10 000	100
5 000	65
2 500	25
1 500	10

Between the two impulses the section shall be preheated in an oven so that the temperature at the application of the second impulse is 60 °C ± 3 °C. The tests shall be carried out at an ambient temperature of 20 °C ± 15 °C.

If a higher temperature is deemed necessary because of high pollution or abnormal service conditions, then the higher value is used for the test if agreed to between manufacturer and purchaser.

The tolerances on the adjustment of the equipment shall be such that the measured values of the current impulses are within the following limits:

a) from 90 % to 110 % of the specified peak value;

b) from 3,5 µs to 4,5 µs for virtual front time;

c) from 9 µs to 11 µs for virtual time to half value on the tail;

d) the peak value of any opposite polarity current wave shall be less than 20 % of the peak value of the current;

e) small oscillations on the impulse are permissible provided their amplitude near the peak of the impulse is less than 5 % of the peak value. Under these conditions, for the purpose of measurement, a mean curve shall be accepted for determination of the peak value.

The conditioning test and the following high current impulses shall be applied at the same polarity.

Annex H of IEC 60099-4 describes a typical test circuit which may be used.

As soon as possible, but not later than 100 ms after the last high current impulse, a power frequency voltage equal to the elevated rated voltage, U_r*, and the elevated continuous operating voltage, U_c* (see 7.5.2.2) shall be applied for a time period of 10 s and 30 min, respectively to prove thermal stability or thermal runaway.

NOTE 1 It is under consideration whether the sample should be energized during the second impulse to show that the gaps can successfully interrupt current under these conditions.

Final interruption of the follow current shall occur not later than at the end of the half cycle following that in which the impulse is applied. There shall be no further sparkover of the test sample in any subsequent half cycle.

The current and voltage shall be recorded in each impulse and the current records from the same resistors shall show no difference that indicates puncture or flashover.

The current at the elevated continuous operating voltage, U_c*, shall be registered continuously during the power frequency voltage application.

Non-linear metal-oxide resistor temperature or resistive component of current or power dissipation shall be monitored during the power frequency voltage application to prove thermal stability or thermal runaway, see 7.5.3.3.

NOTE 2 As an alternative test procedure when the resources are not sufficient to superimpose high current impulses as per table 8 on power frequency voltage, it is acceptable to first determine the energy subjected to the test sample by the high current impulse in a separate test. This test must be performed on the resistors and series gaps housed in a true model of the arrester in order to verify the insulation withstand for the design. A current impulse with an amplitude of at least twice the nominal current to the full value of table 8 and a duration sufficiently long to subject the test sample to the same energy as the high current impulse is selected. This current is then used in the high current operating duty test instead of the current given in table 8.

Following the complete test sequence and after the test sample has cooled to near ambient temperature, evaluate as specified in 5.8.

7.5.3.3 Evaluation of thermal stability in the operating duty tests

The arrester sections subjected to the operating duty tests are considered to be thermally stable and to have passed the test if the peak of the resistive component of the leakage current, or power dissipation, or resistor temperature steadily decreases at least during the last 15 min of U^*_c voltage application.

The peak of the resistive component of leakage current is strongly influenced by the stability of the applied voltage and also by the change in ambient temperature. Because of this, judgement as to whether the arrester is thermally stable or not may, in some cases, not be clear at the end of the U^*_c voltage application. If that is the case, the time of the U^*_c voltage application shall be extended until the steady decrease in the current or power dissipation or temperature is clearly confirmed. If an increasing trend of current or power dissipation or temperature is not observed within 3 h of voltage application, the section is considered stable.

7.6 Tests of arrester disconnectors

7.6.1 General

As noted in 5.11, these tests shall be made on arresters which are fitted with arrester disconnectors or on the disconnector assembly alone if its design is such as to be unaffected by the heating of adjacent parts of the arrester in its normally installed position.

The test sample shall be mounted in accordance with the manufacturer's published recommendations, using the maximum recommended size and stiffness and the shortest recommended length of connecting lead. In the absence of published recommendations, the conductor shall consist of hard drawn bare copper, approximately 5 mm in diameter and 30 cm long, arranged so as to allow freedom of movement of the disconnector when it operates.

7.6.2 Current impulse and operating duty withstand tests

As noted in 7.4 and 7.5, these tests shall be made at the same time as the tests on the arrester, for arresters with built-in disconnectors. In the case of disconnectors designed for attachment to an arrester, or for insertion into the line or ground lead as an accessory, these tests may be made separately or in conjunction with tests on arrester samples. The disconnector shall withstand, without operating, each of the following tests. Three new samples shall be used for each different test.

7.6.2.1 Long duration current impulse test

This test shall be made in accordance with 7.4 with the peak current and duration corresponding to the highest classification of arrester with which the disconnector is designed to be used, see tables 4 and 5.

7.6.2.2 Operating duty test

This test shall be made in accordance with 7.5 with the sample disconnector in series with a test sample section of the arrester design having the highest reference current of all the arresters with which it is designed to be used.

7.6.3 Disconnector operation

7.6.3.1 Time versus current curve test

Data for a time versus current curve shall be obtained at three different symmetrically initiated current levels – 20 A, 200 A and 800 A r.m.s. ± 10 % – flowing through test sample disconnectors with or without arresters as required by 7.6.1.

For tests on disconnectors affected by internal heating of the associated arresters, the non-linear resistors and gap structure shall be bypassed with a bare copper wire 0,08 mm to 0,13 mm in diameter in order to start the internal arcing.

For tests on disconnectors unaffected by the operation of the associated arrester, the arrester, if it is used for mounting the disconnector, shall have its non-linear resistors and gap structure shunted or replaced by a conductor of size sufficient to ensure that it will not be melted during the test.

The test voltage may be any convenient value so long as it is sufficient to maintain full current flow in the arc over the arrester elements and sufficient to cause and maintain arcing of any gaps upon which operation of the disconnector may depend. The test voltage shall not exceed the rated voltage of the lowest rated arrester with which the disconnector is designed to be used.

The parameters of the test circuit should first be adjusted, with the test sample shunted by a link of negligible impedance to produce the required value of current. The closing switch should be timed to close the circuit within a few electrical degrees of voltage crest so as to produce a nearly symmetrical current. An opening switch may be provided with provision for adjusting the time of current flow through the test sample. This switch may be omitted when accurate control over the current duration is not necessary. After the test circuit parameters have been adjusted, the link shunting the test sample shall be removed.

The current flow shall be maintained at the required level until operation of the disconnector occurs. At least five new samples shall be tested at each of the three current levels.

The r.m.s. value of current through the specimen and the duration to the first movement of the disconnector shall be plotted for all the samples tested. The time versus current characteristic curve of the disconnector shall be drawn as a smooth curve through the points representing maximum duration.

For disconnectors which operate with an appreciable time delay, the time versus current curve test shall be made by subjecting the test samples to controlled duration of current flow to determine the minimum duration for each of the three current levels which will consistently result in successful operation of the disconnector. For the points to be used for the time versus current curve, successful operation of the disconnector shall occur in five tests out of five trials or, if one unsuccessful test occurs, five additional tests at the same current level and duration shall result in successful operations.

7.6.3.2 Evaluation of disconnector performance

There shall be clear evidence of effective and permanent disconnection by the device. If there is no such clear evidence, a power frequency voltage equal to 1,2 times the rated voltage of the highest rated arrester with which the disconnector is designed to be used shall be applied for 1 min without current flow in excess of 1 mA r.m.s.

7.7 Power frequency voltage sparkover tests

Dry and wet tests shall be made on three samples of complete arresters of each voltage rating tested. The performance for other voltage ratings of the same design within ±20 % (or 3 kV, whichever is greater) of a test sample rating can be determined by adjusting the voltage level in proportion to the voltage ratings. The voltage applied to the arrester shall be switched on at a value low enough to avoid sparkover of the arrester by the resulting switching surge and raised rapidly at a uniform rate until sparkover of the series gap occurs. The time during which the voltage may exceed the rated voltage of the arrester shall be in the range of 2 s to 5 s when testing arresters using grading resistors which may be damaged by overheating if the applied voltage exceeds the rated voltage for too long. After sparkover, the test voltage shall be switched off as rapidly as possible, preferably by automatic tripping and in any case within 0,5 s.

The load imposed on the testing circuit by a surge arrester having non-linear grading resistors of high conductivity gives rise to harmonics and the test circuit shall have a sufficiently low impedance to maintain the waveform of the voltage across the specimen within the limits specified in IEC 60060-1 and IEC 60060-2.

The voltage shall be applied not less than five times with an interval of about 10 s between successive applications.

The average sparkover value of the five tests is adopted as the power frequency sparkover voltage for purposes of comparison of tests made before and after other type tests.

7.8 Moisture ingress tests

Evaluation shall be as prescribed in IEC 60099-4 with the added requirement for passing:

– The average power frequency sparkover voltage or average standard lightning impulse sparkover voltage shall not change by more than ±5 %.

7.9 Weather ageing tests

Arrester designs as specified in table 9 shall pass weather ageing tests as specified in IEC 60099-4.

Table 9 – Weather ageing test selection

Surge arrester design			Tests
Housing material	**Gap position**	**Presence of grading elements**	**Weather ageing tests**
Porcelain	Internal	Yes	Not required
Porcelain	Internal	No	Not required
Porcelain	External	Under consideration	Under consideration
Polymeric	Internal	Yes	7.9
Polymeric	Internal	No	7.9
Polymeric	External	Under consideration	Under consideration

Evaluation shall be as prescribed in IEC 60099-4 with the added constraint for passing:

– The average power frequency sparkover voltage or average standard lightning impulse sparkover voltage shall not change by more than ±5 %.

8 Routine tests and acceptance tests

8.1 Routine tests

The minimum requirements for routine tests to be made by the manufacturer shall be as follows:

a) Application of a residual voltage test. This test is compulsory for arresters with rated voltage above 1 kV. The test may be performed either on complete arresters, assembled arrester units or on a sample comprising one or several resistor elements. The manufacturer shall specify a suitable lightning impulse current in a range between 0,01 and 2 times the nominal current at which the residual voltage is measured. If not directly measured, the residual voltage of the complete arrester is taken as the sum of the residual voltages of the resistor elements or the individual arrester units. The residual voltage for the complete arrester shall not be higher than the value specified by the manufacturer.

   NOTE When 5 000 A and 2 500 A arresters below 54 kV rating are supplied in volume, the residual voltage test may be omitted in the routine tests, if agreed between manufacturer and purchaser.

b) Satisfactory absence from partial discharges and contact noise shall be checked on each unit by any sensitive method adopted by the manufacturer, see IEC 60270 and 8.2.1 c). It shall not exceed 10 pC.

c) For arresters with an internal gas volume of >10 % unit volume, a leakage check shall be made on each unit by any sensitive method adopted by the manufacturer. The arrester shall meet the manufacturer's maximum acceptable test level.

d) The dry power frequency sparkover voltage or standard lightning impulse sparkover voltage shall be measured and shall be within the range specified by the manufacturer.

e) Grading current at rated voltage.

8.2 Acceptance tests

8.2.1 Standard acceptance tests

When the purchaser specifies acceptance tests in the purchase agreement, the following tests shall be made on the nearest lower whole number to the cube root of the number of arresters to be supplied:

a) Lightning impulse residual voltage on the complete arrester or arrester unit (see 7.3), at nominal discharge current if possible, or at a current value chosen according to 7.3, in this case the virtual time to half value on the tail is less important and need not be complied with.

   NOTE The residual voltage of a complete arrester is taken as the sum of the residual voltages of the individual arrester units. The residual voltage for the complete arrester should not be higher than a value specified by the manufacturer.

b) The average power frequency sparkover voltage or average standard lightning impulse sparkover voltage test shall be measured**.**

c) For the partial discharge test, the power frequency voltage applied to the complete arrester, or arrester unit, shall be increased up to its rated voltage and after less than 10 s decreased to 1,05 times its continuous operating voltage. At that voltage, the partial discharge level according to IEC 60270 shall be measured. The measured values for the internal partial discharges shall not exceed 10 pC.

Any alteration in number of test samples or type of test shall be negotiated between the manufacturer and the purchaser.

8.2.2 Special thermal stability test

The following test requires additional agreement between manufacturer and purchaser prior to the commencement of arrester assembly, see 5.6.

This test shall be performed on three totally different test sections consisting of metal-oxide resistors and gap structures taken from current routine production and having the same dimensions and characteristics as those of the arresters under test. The test consists of a part of the operating duty test relevant to the type of arrester as indicated in table 11.

Metal-oxide resistor temperature or resistive component of current or power dissipation shall be monitored during the power frequency voltage application to prove thermal stability. The test is passed if thermal stability occurs in all three samples, see 7.5.3.3. If one sample fails, agreement shall be reached between the manufacturer and the purchaser regarding any further tests.

Table 10 – Summary of high current operating duty test (see 7.5.3)

10 000 A line discharge class 1, 5 000 A, 2 500 A and 1 500 A arresters	
Initial tests	Residual voltage at I_n, 8/20 and sparkover voltage (power frequency or lightning impulse voltage) See 7.5.3
	Time interval not specified
Conditioning	Conditioning test; 4 groups of 5 impulses superimposed on a continuous power frequency voltage of U_r* See 7.5.3.1
	Time interval not specified, 20 °C ± 15 °C
High current test section	High current impulse, 4/10 Preheat to 60 °C ± 3 °C High current impulse, 4/10 See 7.5.3.2
	Time interval: As short as possible, not longer than 100 ms
	Elevated rated voltage, U_r*, for 10 s
	Elevated continuous operating voltage, U_c*, for 30 min
	Cool to ambient 20 °C ± 15 °C
Measurement and examination	Residual voltage at I_n, 8/20 and sparkover voltage (power frequency or lightning impulse voltage) See 7.5.3
	Visual examination

Table 11 – Thermal stability test

For 10 000 A line discharge class 1, 5 000 A, 2 500 A and 1 500 A arresters, see 8.2.2
Preheat to 60 °C ± 3 °C High current impulse, 4/10 See 7.5.3.2
Time interval: As short as possible, not longer than 100 ms See 7.5.3.2
Elevated rated voltage U_r*, r 10 s
Elevated continuous operating voltage U_c*, for 30 min