

Surge arresters —

Part 4: Metal-oxide surge arresters without gaps for a.c. systems

The European Standard EN 60099-4:1993, with the incorporation of its amendments A1:1998 and A2:2002, has the status of a British Standard

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Cooperating organizations

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Ireland	United Kingdom

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National foreword

This British Standard has been prepared under the direction of the Power Electrical Engineering Standards Policy Committee and is the English language version of EN 60099-4:1993 *Surge arresters Part 4: Metal-oxide surge arresters without gaps for a.c. systems*, including amendments A1:1998 and A2:2002, published by the European Committee for Electrotechnical Standardization (CENELEC). It is identical with IEC 60099-4:1991, Edition 1.2:2001, which comprises Edition 1.0:1991 consolidated by the incorporation of amendments 1:1998 and 2:2001 published by the International Electrotechnical Commission (IEC).

Sidelining in this document indicates where amendments A1:1998 and A2:2002 have been implemented.

The CENELEC common modifications introduced by CENELEC amendment A2:2002 have been implemented at the appropriate places in the text. These common modifications delete Section 12, replace the existing Annex ZA and add a new Annex ZB.

The following print types are used:

- requirements proper: in roman type;
- *test specifications: in italic type;*
- notes: in smaller roman type.

Cross-references

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 135 and a back cover.

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English version

Surge arresters — Part 4: Metal-oxide surge arresters without gaps for a.c. systems

(includes amendments A1:1998 and A2:2002)
(IEC 99-4:1991 + A1:1998 + A2:2001)

Parafoudres —

Partie 4: Parafoudres à oxyde métallique sans
éclateur pour réseaux à courant alternatif
(inclut les amendements A1:1998 et A2:2002)
(CEI 60099-4:1991 + A1:1998
+ A2:2001, modifiée)

Überspannungsableiter —

Teil 4: Metalloxidableiter ohne Funkenstrecken für
Wechselspannungsnetze
(enthält Änderungen A1:1998 und A2:2002)
(IEC 60099-4:1991 + A1:1998
+ A2:2001, modifiziert)

This European Standard was approved by CENELEC on 1993-07-06; amendment A1 was approved by CENELEC on 1998-04-01, amendment A2 modifies the European Standard EN 60099-4:1993; it was approved by CENELEC on 2002-09-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B-1050 Brussels

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Ref. No. EN 60099-4:1993 + A1:1998 + A2:2002 E

Foreword

The CENELEC questionnaire procedure, performed for finding out whether or not the International Standard IEC 99-4:1991 could be accepted without textual changes, has shown that no common modifications were necessary for the acceptance as European Standard.

The reference document was submitted to the CENELEC members for formal vote and was approved by CENELEC as EN 60099-4 on 6 July 1993.

The following dates were fixed:

- latest date of publication of an identical national standard (dop) 1994-08-01
- latest date of withdrawal of conflicting national standards (dow) 1994-08-01

For products which have complied with the relevant national standard before 1994-08-01, as shown by the manufacturer or by a certification body, this previous standard may continue to apply for production until 1999-08-01.

Annexes designated “normative” are part of the body of the standard. Annexes designated “informative” are given only for information. In this standard, Annex A, Annex B, Annex C, Annex D and Annex ZA are normative and Annex E, Annex F, Annex G, Annex H, Annex J and Annex K are informative.

Foreword to amendment A1

The text of document 37/192/FDIS, future amendment 1 to IEC 60099-4:1991, prepared by IEC TC 37, Surge arresters, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as amendment A1 to EN 60099-4:1993 on 1998-04-01.

The following dates were fixed:

- latest date by which the amendment has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 1999-01-01
- latest date by which the national standards conflicting with the amendment have to be withdrawn (dow) 2001-01-01

Annexes designated “normative” are part of the body of the standard.

In this standard, Annex A, Annex B, Annex C, Annex D, Annex F and Annex ZA are normative.

Annex ZA has been added by CENELEC.

Foreword to amendment A2

The text of amendment 2:2001 to the International Standard IEC 60099-4:1991, prepared by IEC TC 37, Surge arresters, together with the common modifications prepared by CLC/SR 37, was submitted to the formal vote and was approved by CENELEC as amendment A2 to EN 60099-4:1993 on 2002-09-01.

The following dates were fixed:

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- latest date by which the national standards conflicting with the amendment have to be withdrawn (dow) 2005-09-01

Annexes designated “normative” are part of the body of the standard.

Annexes designated “informative” are given for information only.

In this standard, Annex A, Annex B, Annex C, Annex D, Annex F, Annex N, Annex O and Annex ZA are normative and, Annex E, Annex G, Annex H, Annex J, Annex K, Annex L, Annex M and Annex ZB are informative.

Annex ZA and Annex ZB have been added by CENELEC.

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INTRODUCTION

This International Standard presents the minimum criteria for the requirements and testing of gapless metal-oxide surge arresters that are applied to a.c. power systems.

Arresters covered by this standard are commonly applied to live/front overhead installations in place of the non-linear resistor type gapped arresters covered in IEC 60099-1. Protection of low-voltage circuits, below 3 kV, is under consideration.

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

SURGE ARRESTERS –

Part 4: Metal-oxide surge arresters without gaps for a.c. systems

SECTION 1: GENERAL

1.1 Scope

This International Standard applies to non-linear metal-oxide resistor type surge arresters without spark gaps designed to limit voltage surges on a.c. power circuits.

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 60068-2-11:1981, *Environmental testing – Part 2: Tests. Test Ka: Salt mist*

IEC 60068-2-14:1984, *Environmental testing – Part 2: Tests. Test N: Change of temperature*

IEC 60068-2-17:1994, *Basic environmental testing procedures – Part 2: Tests – Test Q: Sealing*

IEC 60068-2-42:1982, *Environmental testing – Part 2: Tests. Test Kc: Sulphur dioxide test for contacts and connections*

IEC 60071: *Insulation co-ordination*

IEC 60071-2:1976, *Insulation co-ordination – Part 2: Application guide*

IEC 60071-2:1996, *Insulation co-ordination – Part 2: Application guide*

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

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

IEC 60270:1981, *Partial discharge measurements*

IEC 60298:1990, *A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV to and up to and including 52 kV*

IEC 60507:1991, *Artificial pollution tests on high-voltage insulators to be used in a.c. systems*

IEC 60517:1990, *Gas-insulated metal-enclosed switchgear for rated voltages of 72,5 kV and above*

IEC 60694:1996, *Common specifications for high-voltage switchgear and controlgear standards*

IEC 60721-3-2:1997, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 2: Transportation*

IEC 60815:1986, *Guide for the selection of insulators in respect of polluted conditions*

IEC 61109:1992, *Composite insulators for a.c. overhead lines with a nominal voltage greater than 1 000 V – Definitions, test methods and acceptance criteria*

IEC 61166:1993, *High-voltage alternating current circuit-breakers – Guide for seismic qualification of high-voltage alternating current circuit-breakers*

IEC 61330:1995, *High-voltage/low voltage prefabricated substations*

IEEE C62.11:1999, *Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits*

SECTION 2: DEFINITIONS

For the purpose of this International Standard, the following definitions apply.

2.1

metal-oxide surge arrester without gaps

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

2.2

non-linear metal-oxide resistor

the 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 impedances, in particular grading capacitors connected in parallel to one single or to a group of non-linear metal-oxide resistors, to control the voltage distribution along the metal-oxide resistor stack

2.4

grading ring of an arrester

a metal part, usually circular in shape, mounted to modify electrostatically the voltage distribution along the arrester

2.5

section of an arrester

a complete, suitably assembled part of an arrester necessary to represent the behaviour of a complete arrester with respect to a particular test. A section of an arrester is not necessarily a unit of an arrester

2.6

unit of an arrester

a 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. 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)

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

NOTE The rated voltage as defined in this document is the 10 s power frequency voltage used in the operating duty test after high current or long duration impulses. Tests used to establish the voltage rating in IEC 60099-1, as well as some National Standards, involve the application of repetitive impulses at nominal 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)

the 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

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

2.11

disruptive discharge

the phenomena associated with the failure of insulation under electric stress, which include a collapse of voltage and the passage of current. The term applies to electrical breakdowns in solid, liquid and gaseous dielectric, and combinations of these

NOTE 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)

a disruptive discharge through a solid.

2.13

flashover

a disruptive discharge over a solid surface

2.14**impulse**

a 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

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**

a 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). It is written as T_1/T_2 , both in microseconds, the sign "/" having no mathematical meaning

2.16**steep current impulse**

a 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 . The virtual time to half value on the tail shall be 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.

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.

2.18**long duration current impulse**

a 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**

the maximum value of a voltage or current impulse. Superimposed oscillations may be disregarded, see 7.4.2c and 7.5.4.2e

2.20**front of an impulse**

the part of an impulse which occurs prior to the peak

2.21**tail of an impulse**

the part of an impulse which occurs after the peak

2.22

virtual origin of an impulse

the 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. For current impulses the reference points shall be 10 % and 90 % of the peak value

NOTE 1 This definition applies only when scales of both ordinate and abscissa are linear.

NOTE 2 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)

the time in microseconds equal to 1,25 multiplied by the time in microseconds 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

the 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)

the time interval between the virtual origin and the instant when the voltage or current has decreased to half its peak value. This time is expressed in microseconds

2.26

virtual duration of the peak of a rectangular impulse

the 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

the time during which the amplitude of the impulse is greater than 10 % of its peak value. 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

the 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

the impulse current which flows through the arrester

2.30

nominal discharge current of an arrester (I_n)

the peak value of lightning current impulse (see 2.17) which is used to classify an arrester

2.31

high current impulse of an arrester

the 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**

the 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**

the continuous current is the current flowing through the arrester when energized at the continuous operating voltage

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.

The continuous current is, for comparison purposes, expressed either by its r.m.s. or peak value.

2.34**reference current of an arrester**

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

NOTE 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 an arrester (U_{ref})**

the peak value of power frequency voltage divided by $\sqrt{2}$ which shall be applied to the arrester to obtain the reference current. The reference voltage of a multi-unit arrester is the sum of the reference voltages of the individual units

NOTE Measurement of reference voltage is necessary for the selection of a correct test sample in the operating duty test, see 7.5.

2.36**residual voltage of an arrester (U_{res})**

the 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**

the power frequency withstand voltage versus time characteristic shows the 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 5.10

2.38**prospective current of a circuit**

the 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

the combination of the following:

- a) Residual voltage for steep current impulse according to 7.3.1.
- b) Residual voltage versus discharge current characteristic for lightning impulses according to 7.3.2.

The lightning impulse protection level of the arrester is the maximum residual voltage for the nominal discharge current.

- c) Residual voltage for switching impulse according to 7.3.3.

The switching impulse protection level of the arrester is the maximum residual voltage at the specified switching impulse currents.

2.40

thermal runaway of an arrester

the term "thermal runaway" is used to describe a 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

an 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 disconnecter

a 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 Clearing of the fault current through the arrester during disconnection generally is not a function of the device.

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. 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 Housing and sheds

2.46.1

housing

external insulating part of an arrester, which provides the necessary creepage distance and protects the internal parts from the environment

NOTE A housing may consist of several parts providing mechanical strength and protection against the environment.

2.46.2

shed

insulating part projecting from the housing, intended to increase the creepage distance

2.47

polymer housed surge arrester

see subclause 2.60.

2.48

fault indicator

device intended to provide an indication that the arrester is faulty, and which does not disconnect the arrester from the system

2.49

electrical unit

portion of an arrester in which each end of the unit is terminated with an electrode which is exposed to the external environment

NOTE An electrical unit is identical to a "unit of an arrester" as defined in 2.6.

2.50

mechanical unit

portion of an arrester in which the resistors within the unit are mechanically restrained from moving in an axial direction

2.51

gas-insulated metal enclosed surge arrester (GIS-arrester)

gas-insulated metal-enclosed metal-oxide surge arrester without any integrated series or parallel spark gaps, filled with gas other than air

NOTE 1 The gas pressure is normally higher than 1 bar = 10^5 Pa.

NOTE 2 A surge-arrester used in gas-insulated switchgear.

2.52

arrester – separable type (separable arrester)

arrester assembled in an insulated or screened housing providing system insulation, intended to be installed in an enclosure for the protection of distribution equipment and systems. Electrical connection may be made by sliding contact or by bolted devices; however, all separable arresters are deadbreak arresters

NOTE Separable arrester use is common European practice.

2.53

arrester – deadfront type (deadfront arrester)

arrester assembled in a shielded housing providing system insulation and conductive ground shield, intended to be installed in an enclosure for the protection of underground and pad mounted distribution equipment and circuits

NOTE 1 Most deadfront arresters are loadbreak arresters.

NOTE 2 Deadfront arrester use is common U.S.A. practice.

2.54

deadbreak arrester

arrester which can be connected and disconnected from the circuit only when the circuit is de-energised

2.55

loadbreak arrester

arrester which can be connected and disconnected when the circuit is energised

2.56

arrester – liquid-immersed type (liquid-immersed arrester)

arrester designed to be immersed in an insulating liquid

2.57

fail-open current rating for liquid-immersed arrester

fault current level above which the arrester is claimed to evolve into an open circuit upon failure

2.58

fail-short current rating for liquid-immersed arrester

fault current level below which the arrester is claimed to evolve into a short-circuit upon failure

NOTE Definitions 2.57 and 2.58 are preliminary and may be superseded by more general definitions.

2.59

porcelain housed arrester

arrester using porcelain as housing material, with fittings and sealing systems

2.60

polymer housed arrester

arrester using polymeric and composite materials for housing, with fittings

NOTE Designs with an enclosed gas volume are possible. Sealing may be accomplished by use of the polymeric material itself or by a separate sealing system.

2.61

bending moment

horizontal force acting on the arrester housing multiplied by the vertical distance between the mounting base (lower level of the flange) of the arrester housing and the point of application of the force

2.62

terminal line force

force perpendicular to the longitudinal axis of the arrester measured at the centre line of the arrester

2.63

torsional loading

each horizontal force at the top of a vertical mounted arrester housing which is not applied to the longitudinal axis of the arrester

2.64

breaking load

force perpendicular to the longitudinal axis of a porcelain housed arrester leading to mechanical failure of the arrester housing

2.65

damage limit

lowest value of a force perpendicular to the longitudinal axis of a polymer housed arrester leading to mechanical failure of the arrester housing

2.66**maximum permissible service load (MPSL)**

greatest force perpendicular to the longitudinal axis of a polymer housed arrester, allowed to be applied during service without causing any mechanical damage to the arrester

2.67**maximum permissible dynamic service load (MPDSL)**

greatest force perpendicular to the longitudinal axis of a porcelain housed arrester, allowed to be applied during service for short periods (e.g. short-circuit current forces, seismic stress) without causing any mechanical damage to the arrester

2.68**permissible static service load (PSSL)**

force perpendicular to the longitudinal axis of a porcelain housed arrester, allowed to be continuously applied during service without causing any mechanical damage to the arrester

2.69**internal parts**

metal-oxide resistor elements with supporting structure

2.70**seal (gas/water-tightness)**

ability of an arrester to avoid ingress of matter affecting the electrical and/or mechanical behaviour into the arrester

SECTION 3: IDENTIFICATION AND CLASSIFICATION

3.1 Arrester identification

Metal-oxide surge arresters 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, if other than one of the standard frequencies, see 4.2;
- nominal discharge current;
- rated short-circuit withstand current in kiloamperes (kA). For arresters for which no short-circuit rating is claimed, the sign "-" shall be indicated;
- the 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);
- the year of the manufacture;
- serial number (at least for arresters with rated voltage above 60 kV).

NOTE If sufficient space is available the nameplate should also contain:

- line discharge class or high lightning duty type, see annex C;
- contamination withstand level of the enclosure, see IEC 60815.

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.

NOTE For the 10 000 A and 20 000 A arresters there are five types differentiated by the amplitude and the duration of the long duration current which they are capable of withstanding, see table 4 in 7.4.2.

Table 1 – Arrester classification and test requirements ¹⁾

	Standard nominal discharge current ²⁾				
	20 000 A	10 000 A	5 000 A	2 500 A	1 500 A
1. Rated voltage U_r (kV _{rms})	$360 < U_r \leq 756$	$3 \leq U_r \leq 360$	$U_r \leq 132$	$U_r \leq 36$	See note 3
2. Insulation withstand tests on the arrester housing	7.2.6, 7.2.7	7.2.6, 7.2.7, 7.2.8	7.2.6, 7.2.8	7.2.6, 7.2.8	7.2.6, 7.2.8
3. Residual voltage test	Table K.1	Table K.1	Table K.2	Table K.2	Table K.2
a) Steep current impulse residual voltage test	7.3.1	7.3.1	7.3.1	7.3.1	7.3.1
b) Lightning impulse residual voltage test	7.3.2	7.3.2	7.3.2	7.3.2	7.3.2
c) Switching impulse residual voltage test	7.3.3	7.3.3	Not required	Not required	Not required
4. Long duration current impulse withstand test	7.4.2	7.4.2	7.4.3	7.4.3	Not required
5. Operating duty test					
a) High current impulse operating duty test	Not required	7.5.4 Table 6	7.5.4 Table 6	7.5.4 Table 6	7.5.4 Table 6
b) Switching surge operating duty test	7.5.5 Table 4	7.5.5 Table 4	Not required	Not required	Not required
6. Power frequency voltage versus time curve	5.10	5.10	5.10	5.10	5.10
7. Pressure relief (when fitted with relief device)	5.11	5.11	5.11	Not required	Not required
8. Arrester disconnector (when fitted)	5.12	5.12	5.12	5.12	5.12
9. Polluted housing test	Annex F				
10. Internal partial discharge test	7.8	7.8	7.8	7.8	–
11. Mechanical tests	13	13	13	13	13
¹⁾ Numbers in rows 2 to 8, 10 and 11 refer to clauses and subclauses in this standard. ²⁾ In some countries it is customary to classify arresters as: – station for 10 000 A and 20 000 A arresters; – intermediate or distribution for 5 000 A arresters; – secondary for 1 500 A arresters. ³⁾ This low voltage range is under consideration.					

SECTION 4: STANDARD RATINGS

4.1 Standard rated voltages

Standard values of rated voltages for arresters (in kilovolts 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 r.m.s.	Steps of rated voltage kV r.m.s.
<3	Under consideration
3 – 30	1
30 – 54	3
54 – 96	6
96 – 288	12
288 – 396	18
396 – 756	24

NOTE Other values of rated voltage may be accepted, provided they are multiples of 6.

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: 20 000 A, 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 which 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 $+40^{\circ}\text{C}$.
- b) Solar radiation.

NOTE The effects of maximum solar radiation ($1,1\text{ kW/m}^2$) 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 not 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.

SECTION 5: REQUIREMENTS

5.1 Insulation withstand of the arrester housing

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

- The lightning impulse protection level of the arresters (see 2.39) multiplied by 1,3.
NOTE The 1,3 factor covers variations in atmospheric conditions and discharge currents higher than nominal.
- For 10 000 A and 20 000 A arresters with rated voltages of 200 kV and above, switching impulse protection level of the arrester (see 2.39) multiplied by 1,25.
NOTE The 1,25 factor covers variations in atmospheric conditions and discharge currents higher than the maximum values of table 3, see 7.3.3.
- 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 and high lightning duty arresters (annex C) shall withstand a power frequency voltage with a peak value equal to the lightning impulse protection level multiplied by 0,88 for a duration of 1 minute.

Housings of 10 000 A and 20 000 A arresters with rated voltages less than 200 kV 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 minute.

5.2 Reference voltage

The reference voltage of each arrester shall be measured by the manufacturer at the reference current selected by the manufacturer, see 6.2. The minimum reference voltage of the arrester at the reference current used for routine tests shall be specified and published in the manufacturer's data.

5.3 Residual voltages

The purpose of the measurement of residual voltages is to obtain the maximum residual voltages for a given design for all specified currents and waveshapes. These are derived from the type test data and from the maximum residual voltage at a lightning impulse current used for routine tests as specified and published by the manufacturer.

The maximum residual voltage of a given arrester design for any current and waveshape is calculated from the residual voltage of sections tested during type tests multiplied by a specific scale factor. This scale factor is equal to the ratio of the declared maximum residual voltage, as checked during the routine tests, to the measured residual voltage of the sections at the same current and waveshape.

NOTE For some arresters with a rated voltage less than 36 kV (see 8.1b) the reference voltage may be used for this calculation instead of the residual voltage.

5.4 Internal partial discharge

The internal partial discharges in the arrester energised at 1,05 times the continuous operating voltage shall be ≤ 10 pC.

5.5 Seal leak rate

For arresters having an enclosed gas volume and a separate sealing system, seal leak rates shall be specified as defined in 8.1 d) and 13.7.4.

5.6 Current distribution in a multi-column arrester

The manufacturer shall specify the highest value of the current in a column of a multi-column arrester, see 8.1e.

5.7 Thermal stability

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

5.8 Long duration current impulse withstand

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

For 20 000 A and 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.

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.

The residual voltage measured before and after the long duration current test shall not have changed by more than 5 %.

5.9 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 and High Lightning Duty arresters (see annex C), this is demonstrated by the high current impulse operating duty test, see 7.5.4 and figure 1 or C.1.

For 10 000 A line discharge classes 2 and 3 and 20 000 A line discharge classes 4 and 5 arresters, this is demonstrated by the switching surge operating duty test, see 7.5.5 and figure 2.

The arrester has passed the test if thermal stability is achieved, if the residual voltage measured before and after the test is not changed by more than 5 %, and if examination of the test samples after the test reveals no evidence of puncture, flashover or cracking of the non-linear metal-oxide resistors.

5.10 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 as power frequency voltage versus time curves with the impulse energy consumption prior to this power frequency voltage application stated on the above mentioned 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 D shall be used.

5.11 Short-circuit

An arrester for which a short-circuit rating is claimed by the manufacturer shall not fail in a manner that causes violent shattering; see annex O.

5.12 Disconnectors

5.12.1 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.

5.12.2 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.

5.13 Requirements for auxiliary equipment such as grading components

No requirement at this time.

5.14 Mechanical loads

The manufacturer shall specify the maximum permissible terminal loads relevant for installation and service, such as cantilever, torque and tensile loads. The cantilever load (bending moment) shall be tested according to 13.7.2.

SECTION 6: GENERAL TESTING PROCEDURE

6.1 Measuring equipment and accuracy

The measuring equipment shall meet the requirements of IEC 60060-3. 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 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 $20\text{ °C} \pm 15\text{ °C}$ 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 nearly as possible to simulate the conditions in service.

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 line discharge test (see 7.4.2) and operating duty test (see 7.5) shall have a reference voltage value at the lowest end of the variation range declared by the manufacturer. Furthermore, in case of multi-column arresters the highest value of uneven current distribution shall be considered. 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 .
- b) The reference voltage of the test section should be equal to $k U_r/n$ where k is the ratio between the minimum reference voltage of the arrester and its rated voltage. In case $U_{\text{ref}} > k U_r/n$ for an available test sample, the factor n has to be reduced correspondingly. (In case $U_{\text{ref}} < k U_r/n$ the arrester may absorb too much energy. Such a section can be used only after agreement from the manufacturer.)
- c) For multi-column arresters the distribution of the current between the columns shall be measured at the impulse current used for current distribution test, see 8.1e. The highest current value shall not be higher than an upper limit specified by the manufacturer.

SECTION 7: TYPE TESTS (DESIGN TESTS)

7.1 General

The following type tests shall be made as far as required in table 1 and table C.1 of annex C:

- 1) 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.
- 2) Residual voltage tests, see 5.3 and 7.3.
These tests demonstrate the protective levels of the arrester.
- 3) Long duration current impulse withstand test, see 5.8 and 7.4.
These tests demonstrate the ability of the resistor elements to withstand possible dielectric and energy stresses without puncture or flashover.
- 4) Operating duty tests, see 5.9 and 7.5.
These tests demonstrate the thermal stability of the arrester under defined conditions.
- 5) Short-circuit tests: see 5.11 and annex O.
These tests demonstrate the ability of the arrester to withstand short-circuit currents without violent shattering under specified test conditions. For polymer housed arresters the tests also demonstrate the ability of the arrester to self-extinguish any fire caused by the arc.
- 6) Tests of arrester disconnectors, see 5.12 and 7.6.
For arresters fitted with disconnectors these tests demonstrate the correct operation of the disconnector.
- 7) Artificial pollution test for porcelain-housed multi-unit surge arresters (see annex F)
This test is made to evaluate the temperature rise of the internal parts due to a non-linear and transient voltage grading caused by the pollution layer on the surface of the arrester housing.
A preliminary calculation of the maximum theoretical temperature rise shall be performed according to clause F.5. If the result of the calculation is less than 40 K, no test is required. If the result of the calculation is 40 K or higher, a test according to annex F shall be performed unless, by agreement between user and manufacturer (for example, based on service experience in specified environments), the test can be omitted.
- 8) Internal partial discharge test: see 5.4 and 7.8.
This test measures the internal partial discharges.
- 9) Seal leak rate test: see 5.5 and 13.7.4.
This test demonstrates the gas/water-tightness of the complete system. It applies to all arresters employing porcelain housings and to arresters with polymer housings having seals and associated components essential for the maintenance of a controlled atmosphere within the housing (arresters with enclosed gas volume and a separate sealing system).
- 10) Current distribution test for multi-column arrester, see 5.6 and 8.1e.
This test determines the current through each column of parallel resistors when there is no electrical connection between columns.

11) Bending moment test: see 13.7.2.

This test demonstrates the ability of the arrester to withstand the manufacturer's declared values for bending loads.

12) Environmental tests: see 13.7.3.

These tests demonstrate by accelerated test procedures that the sealing mechanism and the exposed metal combinations of the arrester are not impaired by environmental conditions.

The required numbers of samples and their conditions are specified in the individual clauses. Arresters which differ only in methods of mounting or arrangement of the supporting structure and which are otherwise based on the same components and similar construction resulting in the same performance characteristics including their heat dissipation conditions and internal atmosphere, are considered to be of the same design.

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. For other designs the test has to be agreed upon between the manufacturer and the purchaser.

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 linear voltage distribution along the arrester axis.

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 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 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 Switching impulse voltage test

The 10 000 A and 20 000 A arresters with rated voltages of 200 kV and above shall be subjected to a standard switching impulse voltage test according to IEC 60060. Arresters for outdoor use shall be tested in wet conditions, arresters for indoor use in dry conditions.

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 switching impulse protection level of the arrester multiplied by 1,25.

7.2.8 Power frequency voltage test

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

Housings of 1 500 A, 2 500 A and 5 000 A arresters and High Lightning Duty arresters (annex C) shall withstand a power frequency voltage with a peak value equal to the lightning impulse protection level multiplied by 0,88 for a duration of 1 minute.

Housings of 10 000 A and 20 000 A arresters with rated voltages less than 200 kV 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 minute.

7.3 Residual voltage tests

The purpose of the residual voltage type test is to obtain the data necessary to derive the maximum residual voltage as explained in 5.3. It includes the calculation of the ratio between voltages at specified impulse currents and the voltage level checked in routine tests. The latter voltage can be either the reference voltage 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 wave-shapes 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.

For arresters with rated voltages below 36 kV (see 8.1b), the manufacturer may choose to check only the reference voltage by routine test. The maximum reference voltage shall then be specified. The measured residual voltages of the test sections are multiplied by the ratio of this maximum arrester reference voltage to the measured reference voltage of the test sections to obtain maximum residual voltages for all specified currents and wave shapes.

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 approximately ambient temperature. For multi-column arresters the test may be performed on sections made of only one column; the residual voltages are then measured for currents obtained from the total currents in the complete arrester divided by the number of columns.

7.3.1 Steep current impulse residual voltage test

One steep current impulse in accordance with 2.16 with a peak value equal to the nominal discharge current of the arrester $\pm 5\%$ shall be applied to each of the three samples. The peak value and the impulse shape of the voltage appearing across the three samples shall be recorded and, if necessary, corrected for inductive effects of the voltage measuring circuit as well as the geometry of the test sample and the test circuit.

The following procedure shall be used to determine if an inductive correction is required. A steep current impulse as described above shall be applied to a metal block having the same dimensions as the resistor samples being tested. The peak value and the shape of the voltage appearing across the metal block shall be recorded. If the peak voltage on the metal block is less than 2 % of the peak voltage of the resistor samples, no inductive correction to the resistor measurements is required. If the peak voltage on the metal block is between 2 % and 20 % of the peak voltage on the resistor sample, then the impulse shape of the metal block voltage shall be subtracted from the impulse shape of each of the resistor voltages and the peak values of the resulting impulse shapes shall be recorded as the corrected resistor voltages. If the peak voltage on the metal block is greater than 20 % of the peak voltage on the resistor samples, then the test circuit and the voltage measuring circuit shall be improved.

NOTE A possible way to achieve identical current wave shapes during all measurements is to perform them with both the test sample and the metal block in series in the test circuit. Only their positions relative to each other need to be interchanged for measuring the voltage drop on the metal block or on the test sample.

The sample impulse voltage wave shape (corrected if necessary) with the highest peak value shall be used to determine the steep current impulse residual voltage of the arrester according to one of the following procedures a) or b):

Procedure a)

- 1) multiply the sample impulse voltage waveshape by the scale factor (see 5.3);
- 2) from the waveshape of the steep current impulse, determine the rate of change of current (di/dt) over the entire waveshape and multiply it by the inductance in order to determine the inductive voltage drop:

$$u(t) = L \, di/dt = L' \, h \, di/dt$$

where

$u(t)$ is the inductive voltage drop as a function of time (kV);

L' is the inductivity per unit length ($\mu\text{H}/\text{m}$);

$L' = 1$ for outdoor arresters;

$L' = 0,3$ for GIS arresters;

h is the terminal-to-terminal length of the arrester (m);

di/dt is the rate of change of current with time ($\text{kA}/\mu\text{s}$);

- 3) add results of 1) and 2) on a waveshape basis; the peak value of the resulting waveshape is the steep current impulse residual voltage of the arrester.

Procedure b):

- 1) multiply the peak value of the sample impulse voltage by the scale factor (see 5.3);
- 2) determine the inductive voltage drop between the arrester terminals using the following formula:

$$U_L = L \, di/dt = L' \, h \, I_n / T_f$$

where

U_L is the peak value of the inductive voltage drop (kV);

L' is the inductivity per unit length ($\mu\text{H}/\text{m}$);

$L' = 1$ for outdoor arresters;

$L' = 0,3$ for GIS arresters;

h is the terminal-to-terminal length of the arrester (m);

T_f is the front time of the steep current impulse; equal to $1 \, \mu\text{s}$;

I_n is the nominal discharge current (kA);

- 3) add the results of 1) and 2); the resulting value is the steep current impulse residual voltage of the arrester.

7.3.2 Lightning impulse residual voltage test

One lightning current impulse in accordance with 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. Virtual front time shall be within 7 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 versus discharge current curve. The residual voltage read on such a curve corresponding to the nominal discharge current is defined as the lightning impulse protection level 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 nominal discharge current for comparison to the complete arrester.

7.3.3 Switching impulse residual voltage test

One switching current impulse in accordance with 2.32 of each specified value in table 3 shall be applied to each of the three samples with peak values according to table 3 with a tolerance of $\pm 5 \, \%$. 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 at the respective current. The switching impulse protection level of the arrester is defined as the highest voltage measured at the currents specified in table 3.

Table 3 – Peak currents for switching impulse residual voltage test

Arrester classification	Peak currents A
20 000 A, line discharge classes 4 and 5	500 and 2 000
10 000 A, line discharge class 3	250 and 1 000
10 000 A, line discharge classes 1 and 2	125 and 500

7.4 Long duration current impulse withstand test

7.4.1 General

Before the tests the lightning impulse residual voltage at nominal discharge current 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 or resistor elements which have not been subjected previously to any test except that specified above for evaluation purposes. The non-linear metal-oxide resistors may be exposed to the open air at a still air temperature of $20\text{ }^{\circ}\text{C} \pm 15\text{ }^{\circ}\text{C}$ 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 near ambient temperature.

Following the long duration current test and after the sample has cooled to near ambient temperature the residual voltage tests which were made before the long duration current test shall be repeated for comparison with the values obtained before the test and the values shall not have changed by more than 5 %.

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.

7.4.2 Line discharge test requirements for 20 000 A and 10 000 A arresters

This test consists in 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
on 20 000 A and 10 000 A arresters**

Arrester classification	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 A	1	$4,9 U_r$	2 000	$3,2 U_r$
10 000 A	2	$2,4 U_r$	2 000	$3,2 U_r$
10 000 A	3	$1,3 U_r$	2 400	$2,8 U_r$
20 000 A	4	$0,8 U_r$	2 800	$2,6 U_r$
20 000 A	5	$0,5 U_r$	3 200	$2,4 U_r$

U_r is the rated voltage of the test sample in kilovolts r.m.s.

NOTE The classes 1 to 5 of the preceding table correspond to increasing discharge requirements. The selection of the appropriate discharge class is based on system requirements and is dealt with in annex E.

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

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

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 later than one time and earlier than two times the virtual total duration of the current impulses after passing through zero.

An example of a suitable test circuit is described in annex J.

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	Peak current A	Virtual duration of peak <i>T</i> μs
5 000 A	75	1 000
2 500 A	50	500

7.5 Operating duty tests

7.5.1 General

As explained in 5.9 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 should be measured with an accuracy of ± 1 % and its peak value is not allowed to vary by more than 1 % from no load to full load condition. The ratio of peak voltage to r.m.s. value should not deviate from $\sqrt{2}$ by more than 2 %. During the operating duty tests the power frequency voltage should not deviate from the specified values by more than ± 1 %.

The main requirement to pass these tests is that the arrester is able to cool down during the power frequency voltage application, i.e. thermal runaway does not occur. 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.

The test sequence comprises:

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

This sequence is illustrated in figures 1, 2 and C.1.

The test shall be made on three samples of complete arresters or arrester sections in accordance with 6.2, 6.3 and 7.1 at an ambient temperature of $20\text{ }^{\circ}\text{C} \pm 15\text{ }^{\circ}\text{C}$. The rated voltage of the test samples shall be at least 3 kV if the rated voltage of the arrester is not lower than this and need not exceed 12 kV. If an arrester disconnector is built into the design of 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. The operating duty test shall, therefore, be carried out on new resistors at elevated test voltages U_c^* and U_r^* that give the same power losses as aged resistors 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 (see 2.9) and rated (see 2.8) voltages 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 The established preheat temperature of $60\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ specified in figures 1 and 2 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 figures 1, 2 and table C.1) which will allow those tests to be carried out on new resistors.

NOTE An alternate test procedure for resistors stressed close to or above the reference voltage U_{ref} is under consideration.

7.5.2.1 Test procedure

Three resistor samples shall be stressed at a voltage equal to the corrected maximum continuous operating voltage U_{ct} (see below) of the sample for 1 000 h, during which the temperature shall be controlled to keep the surface temperature of the resistor at $115\text{ }^{\circ}\text{C} \pm 4\text{ K}$.

All material (solid or liquid) in direct contact with the resistors shall be present during the ageing test with the same design as used in the complete arrester.

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

NOTE 1 The medium surrounding the resistor within the arrester may be subject to a modification during the normal life of the arrester due to internal partial discharges. Possible change of the medium surrounding the resistor in the field can significantly increase the power losses.

A suitable test procedure taking into account such modifications is under consideration. During this time an alternative procedure consists in performing the test in N_2 or SF_6 (for GIS-arresters) with a low oxygen concentration (less than 0,1 %, in volume). This ensures that even in the total absence of oxygen, the arrester will not age.

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. The relevant voltage for this procedure is the corrected maximum continuous operating voltage (U_{ct}), which the resistors support in the arrester including voltage unbalance effects. This voltage should be determined by voltage distribution measurements or computations.

NOTE 2 Information on procedures for voltage distribution calculations are given in annex M.

For arresters with a length H of less than 1 m, except for arresters with conductive, grounded enclosures such as GIS-arresters, liquid-immersed, deadfront or separable arresters, the voltage may be determined from the following formula:

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

where H is the total length of the arrester (m).

The ageing procedure described above shall be carried out on three typical samples of resistor elements 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 $115\text{ °C} \pm 4\text{ K}$ and the resistor power losses P_{1ct} shall be measured at a voltage of U_{ct} 1 h to 2 h after the voltage application. The resistor power losses shall be measured once in every 100 h time span after the first measurement giving P_{1ct} . Finally, the resistor power losses P_{2ct} shall be measured after $1\,000^{+100}_0$ h of ageing under the same conditions. Accidental intermediate de-energising of the test samples, not exceeding a total duration of 24 h during the test period is permissible. The interruption will not be counted in the duration of the test. The final measurement should be performed after not less than 100 h of continuous energising. Within the temperature range allowed, all measurements shall be made at the same temperature $\pm 1\text{ K}$.

The minimum power losses value among those measured at least every 100 h time span shall be called P_{3ct} . This is summarised in figure 5.

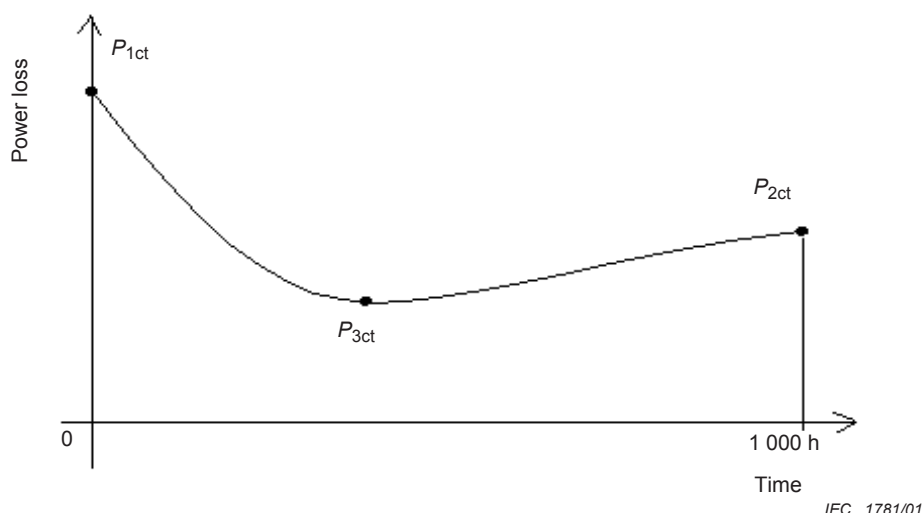


Figure 5 – Power losses of arrester at elevated temperatures versus time

- If P_{2ct} is equal to or below 1,1 times P_{3ct} , then the test according to 7.5.4.2 and 7.5.5.2 shall be performed on new resistors:
 - 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 resistors 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:

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

U_c^* and U_r^* are the highest of the three increased voltages obtained. As an alternative, aged resistors may also be used after agreement between the user and the manufacturer.

- If P_{2ct} is greater than 1,1 times P_{3ct} , and P_{2ct} is greater than or equal to P_{1ct} then aged resistors shall be used for the following tests of 7.5.4.2 and 7.5.5.2. New resistors with corrected values U_c^* and U_r^* can be used, but only after agreement between the user and the manufacturer.

Aged resistors are, by definition, resistors tested according to 7.5.2.1.

The following table 7 summarises these cases:

Table 7 – Determination of elevated rated and continuous operating voltages

Power losses measured	Test samples and test voltage for the operating duty test
$P_{2ct} \leq 1,1 \times P_{3ct}$ and $P_{2ct} \leq P_{1ct}$	New samples at U_{sc} and U_{sr}
$P_{2ct} \leq 1,1 \times P_{3ct}$ and $P_{2ct} > P_{1ct}$	New samples at U_{sc}^* and U_{sr}^*
$P_{2ct} > 1,1 \times P_{3ct}$ and $P_{2ct} < P_{1ct}$	Aged samples at U_{sc} and U_{sr}
$P_{2ct} > 1,1 \times P_{3ct}$ and $P_{2ct} \geq P_{1ct}$	Aged samples at U_{sc} and U_{sr} (or new samples at U_{sc}^* and U_{sr}^* after agreement between the user and the manufacturer)

Where aged resistors are used in the operating duty test, it is recommended that the time delay between the ageing test and the operating duty test be not more than 24 h

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

7.5.3 Heat dissipation behaviour of test sample

7.5.3.1 General

In the operating duty tests the behaviour of the test sample is to a great extent dependent on the ability of the sample to dissipate heat, i.e. to cool down after being stressed by a discharge.

Consequently, the test samples shall have a transient and a steady state heat dissipation capability and heat capacity equivalent to the complete arrester if correct information is to be obtained from the test. For the same ambient conditions the non-linear metal-oxide resistors in the sample and in the complete arrester should in principle reach the same temperature when subjected to the same voltage stress.

7.5.3.2 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 a sliced portion of the active part of the arrester being modeled.
- 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 $\pm 5\%$.
 - 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.

7.5.4 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 and High Lightning Duty arresters in annex C, according to 5.9.

The complete test sequence is illustrated in figure 1 or C.1.

Before the conditioning test, as the first part of the operating duty test, the lightning impulse residual voltage at nominal discharge current of each of the three test samples (resistor elements) is determined at ambient temperature, see 7.3.2.

7.5.4.1 Conditioning

The samples are exposed to a conditioning test consisting of twenty 8/20 lightning current impulses according to 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 1,2 times the continuous operating voltage of the sample. The twenty 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 60 ± 15 electrical degrees before the peak of the power frequency voltage.

This conditioning test may be carried out on the resistor elements in open air at a still air temperature of $20\text{ °C} \pm 15\text{ °C}$. 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 are stored for future use in the operating duty tests, see figures 1 and C.1 in annex C.

7.5.4.2 Application of impulses

At the beginning of the operating duty test the temperature of the complete section shall be $20\text{ °C} \pm 15\text{ °C}$.

The section is subjected to two high current impulses with peak value and impulse shape as specified in table 6. High Lightning Duty arresters specified in annex C are subjected to three 30/80 impulses with a peak value of 40 kA.

Table 6 – Requirements for high current impulses

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

NOTE 1 According to service conditions other values (lower or higher) may be adopted for the peak current.

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

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 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) shall be applied for a time period of 10 s and 30 min respectively to prove thermal stability or thermal runaway.

NOTE 2 To reproduce actual system conditions the second high current impulse is preferably applied while the sample is energized at U_r^* . The 100 ms are permitted in view of practical limitations in the test circuit.

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

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 7.5.6.

Following the complete test sequence and after the test sample has cooled to near ambient temperature, the residual voltage tests which were made at the beginning of the test sequence are repeated.

The arrester has passed the test if thermal stability is achieved, if the change in residual voltage measured before and after the test is not changed by more than 5 % and if examination of the test samples after the test reveals no evidence of puncture, flashover or cracking of the non-linear metal-oxide resistors.

7.5.5 Switching surge operating duty test

This test applies to 10 000 A line discharge classes 2 and 3 and 20 000 A line discharge classes 4 and 5 arresters according to 5.9.

The complete test sequence is illustrated in figure 2.

Before the switching surge operating duty test the lightning impulse residual voltage at nominal discharge current of each of the three test samples (resistor elements) is determined at ambient temperature, see 7.3.2.

The test samples shall be suitably marked to ensure the correct polarity of application in the following subclauses.

7.5.5.1 Conditioning

The samples are exposed to a conditioning test the first part of which consisting of twenty 8/20 current impulses according to 2.17 and a peak value equal to the nominal discharge current of the arrester. The impulses are applied while the test sample is energized at 1,2 times the continuous operating voltage of the sample. The twenty 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 shall 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 60 ± 15 electrical degrees before the peak of the power frequency voltage.

This first part of the conditioning may be carried out on the resistor elements in open air at a still air temperature of $20\text{ }^{\circ}\text{C} \pm 15\text{ }^{\circ}\text{C}$.

The second part of the conditioning is the application of two high current impulses 100 kA 4/10, see 2.31. The measured peak value of the current impulses shall be within 90 % and 110 % of the specified peak value.

After this conditioning the sections are stored for future use in the switching surge operating duty test.

7.5.5.2 Application of impulses

At the beginning of the switching surge operating duty test, that is before the application of two long duration current impulses, the temperature of the complete section shall be $60\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ at the ambient temperature of $20\text{ }^{\circ}\text{C} \pm 15\text{ }^{\circ}\text{C}$.

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

The arrester section shall be subjected to two long duration current impulses as specified in 7.4.2 table 4 for the relevant line discharge classes. The time interval between the impulses shall be 50 s to 60 s. The conditioning impulses and the long duration current impulses shall be applied with the same polarity.

After the second long duration current impulse the section shall be disconnected from the line and connected to the power frequency source as soon as possible but not later than 100 ms after the impulse. The elevated rated voltage (U_r^*) and the elevated continuous operating voltage (U_c^*), determined from the accelerated ageing procedure described in 7.5.2, shall be applied for a time period of 10 s and 30 min respectively to prove thermal stability or thermal runaway.

NOTE To reproduce actual system conditions the second long duration current impulse should be applied while the sample is energized at U_r^* . The 100 ms are permitted in view of practical limitation in the test circuit.

Oscillographic records of the voltage across and current through the test sample shall be made at the second long duration current impulse. The energy dissipated by the test sample during the second operation shall be determined from the voltage and current oscillograms, and the energy value shall be reported in the type test report. The current and voltage 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.