มาตรฐานผลิตภัณฑ์อุตสาหกรรม

THAI INDUSTRIAL STANDARD

มอก. 2366 – 2551

IEC 60099 – 4

Edition 2.1(2006 – 07)

กับดักเสิร์จ
เล่มที่ 4 : กับดักเสิร์จออกไซด์โลหะไม่มีช่องว่าง สำหรับระบบไฟฟ้ากระแสสลับ

METAL-OXIDE SURGE ARRESTERS WITHOUT GAPS FOR A.C. SYSTEMS

สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม

กระทรวงอุตสาหกรรม

ICS 29.240.10 ISBN 978-974-292-606-9

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สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม
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ประกาศในราชกิจจานุเบกษา ฉบับประกาศและงานทั่วไป เล่ม 126 ตอนพิเศษ 17ง
วันที่ 2 กุมภาพันธ์ พุทธศักราช 2552

กับดักเสิร์จออกไซด์โลหะไม่มีช่องว่างสำหรับระบบไฟฟ้ากระแสสลับ เป็นอุปกรณ์ที่ใช้ป้องกันอุปกรณ์ไฟฟ้าจากเสิร์จในระบบไฟฟ้าแรงดันสูง ปัจจุบันโรงงานในประเทศมีการผลิตหลายโรงงานเพื่อใช้ในประเทศและมีการส่งออก

เพื่อเป็นการส่งเสริมอุตสาหกรรม จึงกำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรมกับดักเสิร์จออกไซด์โลหะไม่มีช่องว่างสำหรับระบบไฟฟ้ากระแสสลับ เล่มที่ 4 ขึ้น

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้นโดยรับ IEC 60099-4 (2006-07) Surge arresters-Part 4 : Metal-oxide surge arresters without gaps for a.c. systems มาใช้ในระดับเหมือนกันทุกประการ (identical) โดยใช้ IEC ฉบับภาษาอังกฤษเป็นหลัก

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้นเพื่อใช้ในการอ้างอิง และเพื่อให้ทันกับความต้องการของผู้ใช้มาตรฐาน ซึ่งจะได้แปลเป็นภาษาไทยในโอกาสอันสมควรต่อไป หากมีข้อสงสัยโปรดติดต่อสอบถามสำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม

ประกาศกระทรวงอุตสาหกรรม

ฉบับที่ 3864 (พ.ศ. 2551)

ออกตามความในพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม

พ.ศ. 2511

เรื่อง กำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม

กับดักเสิร์จ เล่มที่ 4 : กับดักเสิร์จออกไซด์โลหะไม่มีช่องว่างสำหรับระบบไฟฟ้ากระแสสลับ

อาศัยอำนาจตามความในมาตรา 15 แห่งพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ. 2511 รัฐมนตรีว่าการกระทรวงอุตสาหกรรมออกประกาศกำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม กับดักเสิร์จ เล่มที่ 4 : กับดักเสิร์จออกไซด์โลหะไม่มีช่องว่างสำหรับระบบไฟฟ้ากระแสสลับ มาตรฐานเลขที่ มอก. 2366- 2551 ไว้ ดังมีรายละเอียดต่อท้ายประกาศนี้

ประกาศ ณ วันที่ 8 พฤษภาคม พ.ศ. 2551

สุวิทย์ คุณกิตติ

รัฐมนตรีว่าการกระทรวงอุตสาหกรรม

มาตรฐานผลิตภัณฑ์อุตสาหกรรม
กับดักเสิร์จ เล่มที่ 4 :
กับดักเสิร์จออกไซด์โลหะไม่มีช่องว่าง
สำหรับระบบไฟฟ้ากระแสสลับ

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้น โดยรับ IEC 60099-4 Edition 2.1 (2006-07) Surge Arresters - Part 4 : Metal-oxide surge arresters without gaps for a.c. systems มาใช้ในระดับเหมือนกันทุกประการ (identical) โดยใช้ฉบับภาษาอังกฤษเป็นหลัก

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้น สำหรับตัวต้านทานออกไซด์โลหะไม่เป็นเชิงเส้น ไม่มีช่องว่าง ออกแบบสำหรับจำกัดแรงดันเสิร์จในวงจรไฟฟ้ากำลังกระแสสลับ

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SURGE ARRESTERS –

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

FOREWORD

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International Standard 60099-4 has been prepared by IEC technical committee 37: Surge arresters.

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

- Clauses 1, 2 and 3 contain common subclauses that cover all arrester types. Clauses 4 to 9 contain subclauses that apply to porcelain-housed arresters. To a great extent, the content of Clauses 4 to 9 also applies to arrester types other than porcelain- housed. Any exceptions that apply to polymer-housed, GIS, separable and dead-front, and liquid-immersed arresters are included in Clauses 10 to 13 as entire subclauses, not as parts of subclauses. That is, if any subclause of Clauses 4 to 9 does not apply in its entirety to a particular type of arrester, then a replacement subclause is given in its entirety in the appropriate Clauses 10, 11, 12, or 13. This avoids the necessity for the user of the document to judgewhich part of a clause has been amended.

- Table 1 has been modified. The previous Table 1 included references to subclauses for type testing. Such references are really not appropriate in Clause 4 and have been transferred to a new table in Clause 8.
- Clauses 6, 8, 11, 12 and 13: modifications have been made to short-circuit requirements.
- Requirements of Clause 13 (mechanical considerations) have been incorporated into Clauses 5, 6, 8, 10, 11, 12 and 13, and Annex A of this new edition.

This consolidated version of IEC 60099-4 is based on the second edition (2004) [documents 37/298/FDIS and 37/300/RVD] and its amendment 1 (2006) [documents 37/324/FDIS and 37/325/RVD].

It bears the edition number 2.1.

A vertical line in the margin shows where the base publication has been modified by amendment 1.

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

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

- 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 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.

SURGE ARRESTERS –

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

1 Scope

This part of IEC 60099 applies to non-linear metal-oxide resistor type surge arresters without spark gaps designed to limit voltage surges on a.c. power circuits.

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 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 60068-2-42:2003, *Environmental testing – Part 2-42: Tests – Test Kc: Sulphur dioxide test for contacts and connections*

IEC 60071-1:1993, *Insulation co-ordination – Part 1: Definitions, principles and rules*

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

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

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

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*

IEC 62271-200:2003, *High-voltage switchgear and controlgear – Part 200: A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

IEC 62271-203:2003, *High-voltage switchgear and controlgear – Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV*

CISPR 16-1:1999, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1: Radio disturbance and immunity measuring apparatus*

CISPR 18-2:1986, *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 2: Methods of measurement and procedure for determining limits*

3 Terms and definitions

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

3.1
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

3.2
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

3.3
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

3.4
grading ring of an arrester
metal part, usually circular in shape, mounted to modify electrostatically the voltage distribution along the arrester

3.5
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.

3.6
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.

3.7
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

3.8
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 8.5)

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 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 established rating do not necessarily produce equivalent values (a resolution to this discrepancy is under consideration).

3.9
continuous operating voltage of an arrester
U_c
designated permissible r.m.s. value of power-frequency voltage that may be applied continuously between the arrester terminals in accordance with 8.5

3.10
rated frequency of an arrester
frequency of the power system on which the arrester is designed to be used

3.11
disruptive discharge
phenomenon 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.

3.12
puncture
breakdown
disruptive discharge through a solid

3.13
flashover
disruptive discharge over a solid surface

3.14
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.

3.15
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)

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

3.16
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 is 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 8.3).

3.17
lightning current impulse
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 8.3).

3.18
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

NOTE The parameters which define a rectangular impulse are polarity, peak value, virtual duration of the peak and virtual total duration.

3.19
peak (crest) value of an impulse
maximum value of a voltage or current impulse

NOTE Superimposed oscillations may be disregarded (see 8.4.2c and 8.5.4.2e).

3.20
front of an impulse
part of an impulse which occurs prior to the peak

3.21
tail of an impulse
part of an impulse which occurs after the peak

3.22
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 shall be 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.

3.23
virtual front time of a current impulse
T_1
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.

3.24
virtual steepness of the front of an impulse
quotient of the peak value and the virtual front time of an impulse

3.25
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 microseconds

3.26
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

3.27
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.

3.28
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

3.29
discharge current of an arrester
impulse current which flows through the arrester

3.30
nominal discharge current of an arrester
I_n
peak value of lightning current impulse (see 3.17) which is used to classify an arrester

3.31
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

3.32
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

3.33
continuous current of an arrester
current flowing through the arrester when energized at the continuous operating voltage

NOTE 1 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.

NOTE 2 The continuous current is, for comparison purposes, expressed either by its r.m.s. or peak value.

3.34
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 will 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 is to 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.

3.35
reference voltage of an arrester
U_{ref}
peak value of power-frequency voltage divided by $\sqrt{2}$ which is applied to the arrester to obtain the reference current

NOTE 1 The reference voltage of a multi-unit arrester is the sum of the reference voltages of the individual units.

NOTE 2 Measurement of the reference voltage is necessary for the selection of a correct test sample in the operating duty test (see 8.5).

3.36
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.

3.37
power-frequency withstand voltage versus time characteristic of an arrester
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 6.10.

3.38
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

3.39
protective characteristics of an arrester
combination of the following:

a) residual voltage for steep current impulse according to 8.3.1;

b) residual voltage versus discharge current characteristic for lightning impulses according to 8.3.2;

NOTE 1 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 8.3.3

NOTE 2 The switching impulse protection level of the arrester is the maximum residual voltage at the specified switching impulse currents.

3.40
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

3.41
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

3.42
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 Clearing of the fault current through the arrester during disconnection generally is not a function of the device.

3.43
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.

3.44
routine tests
tests made on each arrester, or on parts and materials, as required, to ensure that the product meets the design specifications

3.45
acceptance tests
tests made on arresters or representative samples after agreement between manufacturer and purchaser

3.46
housing and sheds

3.46.1

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

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

3.46.2
shed
insulating part projecting from the housing, intended to increase the creepage distance

3.47
polymer housed surge arrester
NOTE See definition 3.60.

3.48
fault indicator
device intended to provide an indication that the arrester is faulty and which does not disconnect the arrester from the system

3.49
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 3.6.

3.50
mechanical unit
portion of an arrester in which the resistors within the unit are mechanically restrained from moving in an axial direction

3.51
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 = 10^5Pa.

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

3.52
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 dead-break arresters

NOTE The use of separable arresters is common in Europe.

3.53
arrester – dead-front type
dead-front 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 dead-front arresters are load-break arresters.

NOTE 2 The use of dead-front arresters is common in the USA.

3.54
dead-break arrester
arrester which can be connected and disconnected from the circuit only when the circuit is de-energized

3.55
load-break arrester
arrester which can be connected and disconnected when the circuit is energized

3.56
arrester – liquid-immersed type
liquid-immersed arrester
arrester designed to be immersed in an insulating liquid

3.57
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

3.58
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 3.57 and 3.58 are preliminary and may be superseded by more general definitions.

3.59
porcelain-housed arrester
arrester using porcelain as housing material, with fittings and sealing systems

3.60
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.

3.61
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

3.62
terminal line force
force perpendicular to the longitudinal axis of the arrester measured at the centre line of the arrester

3.63
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

3.64
breaking load
force perpendicular to the longitudinal axis of a porcelain-housed arrester leading to mechanical failure of the arrester housing

3.65
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

3.66
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

3.67
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 (for example, short-circuit current forces, seismic stress) without causing any mechanical damage to the arrester

3.68
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

3.69
internal parts
metal-oxide resistor elements with supporting structure

3.70
seal (gas/watertightness)
ability of an arrester to avoid ingress of matter affecting the electrical and/or mechanical behaviour into the arrester

4 Identification and classification

4.1 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 5.2);
– 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 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).

4.2 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 3.

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 5).

Table 1 – Arrester classification

	Standard nominal discharge current [a]				
	20 000 A	**10 000 A**	**5 000 A**	**2 500 A**	**1 500 A**
Rated voltage U_r (kV_{rms})	$360 < U_r \leq 756$	$3 \leq U_r \leq 360$	$U_r \leq 132$	$U_r \leq 36$	[b]

[a] In some countries it is customary to classify arresters as follows:
– station for 10 000 A and 20 000 A arresters;
– intermediate or distribution for 5 000 A arresters;
– secondary for 1 500 A arresters.

[b] This low-voltage range is under consideration.

5 Standard ratings and service conditions

5.1 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.

5.2 Standard rated frequencies

The standard rated frequencies are 50 Hz and 60 Hz.

5.3 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 3.30).

5.4 Service conditions

5.4.1 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 °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 should 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);

h) wind speeds ≤ 34 m/s;

i) vertical erection.

5.4.2 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.

6 Requirements

6.1 Insulation withstand of the arrester housing

The arrester housing shall withstand the following voltages when tested according to 8.2:

– The lightning impulse protection level of the arresters (see 3.39) multiplied by 1,3.

  NOTE 1 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 3.39) multiplied by 1,25.

  NOTE 2 The 1,25 factor covers variations in atmospheric conditions and discharge currents higher than the maximum values of Table 4 (see 8.3.3).

– 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 min.

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 min.

6.2 Reference voltage

The reference voltage of each arrester shall be measured by the manufacturer at the reference current selected by the manufacturer (see 7.2). 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.

6.3 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 of less than 36 kV (see item b) of 9.1), the reference voltage may be used for this calculation instead of the residual voltage.

6.4 Internal partial discharges

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

6.5 Seal leak rate

For arresters having an enclosed gas volume and a separate sealing system, seal leak rates shall be specified as defined in 8.11 and item d) of 9.1.

6.6 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 item e) of 9.1.

6.7 Thermal stability

When agreed between manufacturer and purchaser, a special thermal stability test may be performed according to 9.2.2.

6.8 Long-duration current impulse withstand

Arresters shall withstand long-duration currents as checked during type tests (see 8.4).

For 20 000 A and 10 000 A arresters the long-duration withstand is demonstrated by a line discharge test (see 8.4.2) 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 8.4.3).

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 %.

6.9 Operating duty

Arresters shall be able to withstand the combination of stresses arising in service as demonstrated by the operating duty tests (see 8.5). 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 8.5.4 and Figure 1 or Figure 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 8.5.5 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.

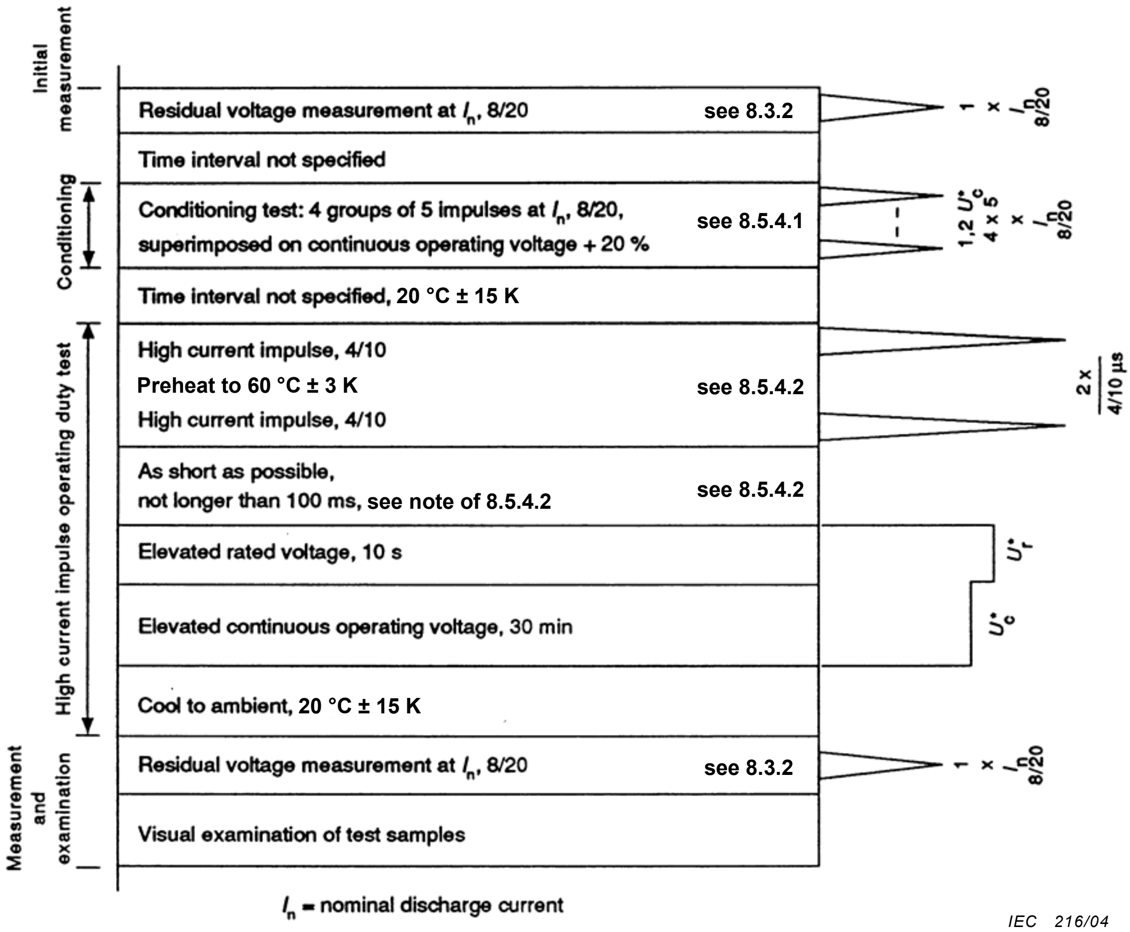


Figure 1 – Operating duty test on 10 000 A line discharge Class 1, 5 000 A, 2 500 A and 1 500 A arresters (see 8.5.4)

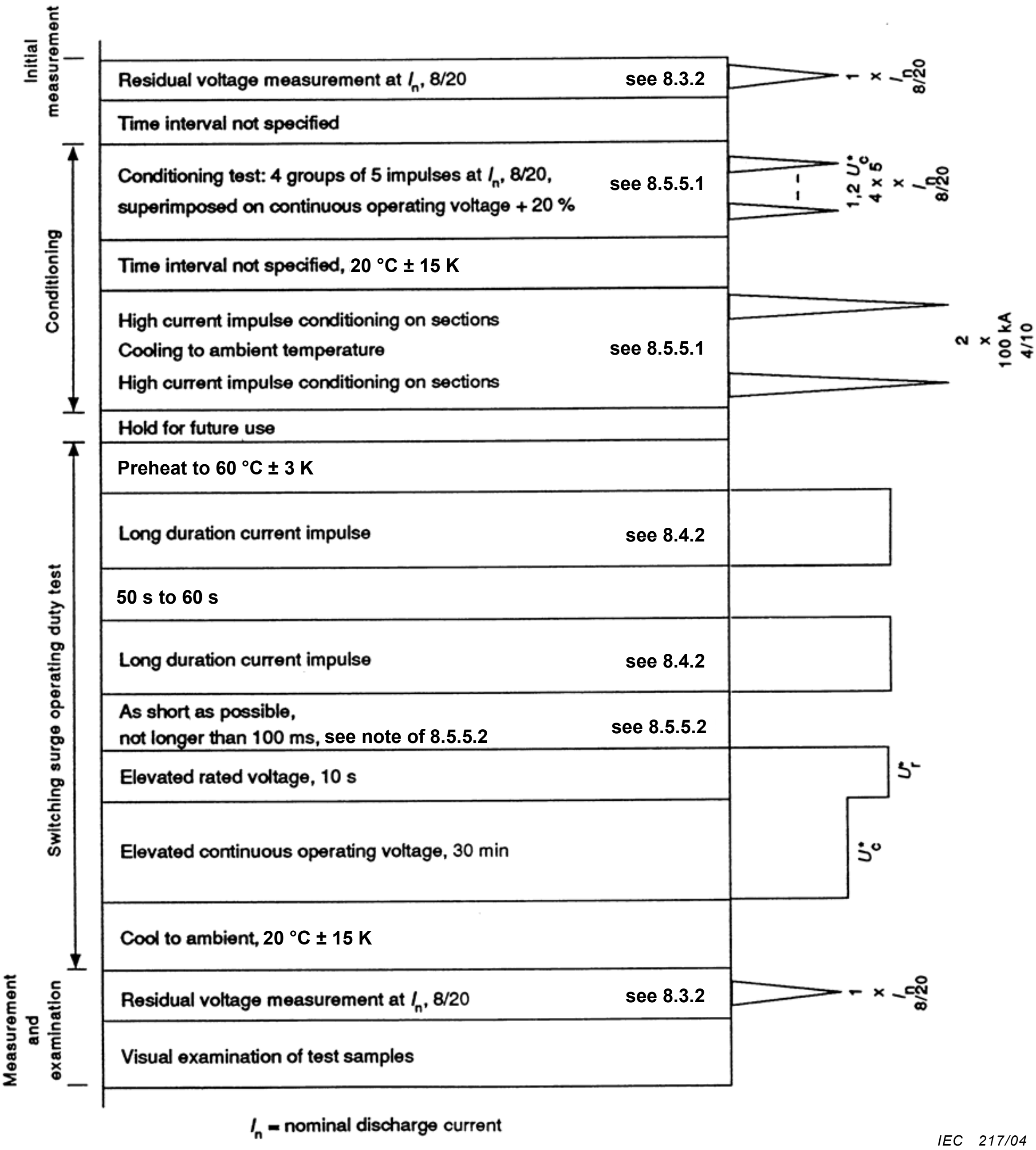


Figure 2 – Operating duty test on 10 000 A arresters line discharge Classes 2 and 3 and 20 000 A arresters line discharge Classes 4 and 5 (see 8.5.5)

6.10 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.

6.11 Short-circuit

An arrester for which a short-circuit rating is claimed by the manufacturer shall be subjected to a short-circuit test according to 8.7 to show that the arrester will not fail in a manner that causes violent shattering of the housing and that self-extinguishing of open flames (if any) occurs within a defined period of time.

6.12 Disconnector

6.12.1 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 8.6.2.1);
– operating duty test (see 8.6.2.2);
– for surge arresters to be installed in overhead lines with system voltages exceeding 52 kV, test of the lightning impulse discharge capability (see Annex N).

6.12.2 Disconnector operation

The time delay for the operation of the disconnector is determined for three values of current according to 8.6.3. There shall be clear evidence of effective and permanent disconnection by the device.

6.13 Requirements for auxiliary equipment such as grading components

No requirement at this time.

6.14 Mechanical loads

The manufacturer shall specify the maximum permissible terminal loads relevant for installation and service, such as cantilever, torque and tensile loads.

6.14.1 Bending moment

The arrester shall be able to withstand the manufacturer's declared values for bending loads (see 8.9).

NOTE 1 When determining the dynamic load applied to a surge arrester, the user should consider, for example, wind, ice and electromagnetic forces likely to affect the installation.

NOTE 2 Surge arresters enclosed within their package should withstand the transportation loads specified by the user in accordance with IEC 60721-3-2, but not less than Class 2M1.

NOTE 3 Unlike porcelain-housed arresters, polymer-housed arresters may show mechanical deflections in service.

6.14.2 Resistance against environmental stresses

The arrester shall be able to withstand environmental stresses as defined in 8.10.

6.14.3 Insulating base

When an arrester is fitted with an insulating base, this device shall withstand each of the following tests without any damage, which could affect its normal function:

– test of the bending moment (see 8.9);
– environmental tests (see 8.10).

6.15 Electromagnetic compatibility

Arresters are not sensitive to electromagnetic disturbances and therefore no immunity test is necessary.

In normal working operating conditions, surge arresters shall not emit significant disturbances. A radio interference voltage test (RIV) shall be applied to arresters having a rated voltage of 77 kV and above (see 8.12). The maximum radio interference level of the arrester energized at 1,05 times its continuous operating voltage shall not exceed 2 500 µV.

6.16 End of life

On request from users, each manufacturer shall give enough information so that all the arrester components may be scrapped and/or recycled in accordance with international and national regulations.

6.17 Lightning impulse discharge capability

For surge arresters to be installed in overhead lines with system voltages exceeding 52 kV, the lightning impulse discharge capability shall be demonstrated by the tests and procedures of Annex N.

7 General testing procedure

7.1 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 stated elsewhere, 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.

7.2 Reference voltage measurements

The reference voltage of an arrester (see 3.35) is measured at the reference current (see 3.34) on sections and units when required. The measurement shall be performed at an ambient temperature of 20 °C ± 15 K 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.

7.3 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 (for example, with grading rings if applicable) and arranged to simulate as closely as possible 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 8.4.2) and operating duty test (see 8.5) 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 the 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. If $U_{ref} > k\ U_r/n$ for an available test sample, the factor *n* shall be reduced correspondingly. (If $U_{ref} < k\ U_r/n$ 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 item e) of 9.1). The highest current value shall not be higher than an upper limit specified by the manufacturer.

8 Type tests (design tests)

8.1 General

Type tests defined in this clause apply to porcelain-housed arresters. The tests also apply to other types of arrester (polymer-housed, GIS, dead-front and separable, and liquid-immersed) unless otherwise noted in 10.8 for polymer-housed arresters, 11.8 for GIS arresters, 12.8 for dead-front and separable arresters, or 13.8 for liquid-immersed arresters.

Type tests shall be made as indicated in Table 3, except for 20 000 A arresters especially applicable for high lightning intensity areas with highest system voltage in the range 1 kV to 52 kV (see Table C.1).

Table 3 – Arrester type tests[a]

	Standard nominal discharge current				
	20 000 A	**10 000 A**	**5 000 A**	**2 500 A**	**1 500 A**
Rated voltage U_r (kV_{rms})	360 < U_r ≤ 756	3 ≤ U_r ≤ 360	U_r ≤ 132	U_r ≤ 36	Under consideration
1 Insulation withstand tests on the arrester housing[b]	8.2.6, 8.2.7	8.2.6, 8.2.7, 8.2.8	8.2.6, 8.2.8	8.2.6, 8.2.8	8.2.6, 8.2.8
2 Residual voltage test[c]	Table J.1	Table J.1	Table J.2	Table J.2	Table J.2
a) Steep current impulse residual voltage test	8.3.1	8.3.1	8.3.1	8.3.1	8.3.1
b) Lightning impulse residual voltage test	8.3.2	8.3.2	8.3.2	8.3.2	8.3.2
c) Switching impulse residual voltage test	8.3.3	8.3.3	Not required	Not required	Not required
3 Long-duration current impulse withstand test[d]	8.4.2	8.4.2	8.4.3	8.4.3	Not required
4 Operating duty test[e]					
a) High-current impulse operating duty test	Not required	8.5.4 Table 8	8.5.4 Table 8	8.5.4 Table 8	8.5.4 Table 8
b) Switching surge operating duty test	8.5.5 Table 5	8.5.5 Table 5	Not required	Not required	Not required
5 Short circuit[f]	8.7	8.7	8.7	8.7	8.7
6 Arrester disconnector/fault indicator (when fitted)[g]	8.6	8.6	8.6	8.6	8.6
7 Polluted housing test[h]	Annex F				
8 Internal partial discharge test[i]	8.8	8.8	8.8	8.8	–
9 Bending moment[j]	8.9	8.9	8.9	8.9	8.9
10 Environmental tests[k]	8.10	8.10	8.10	8.10	8.10
11 Seal leak rate[l]	8.11	8.11	8.11	8.11	8.11
12 Radio interference voltage (RIV)[m]	8.12	8.12	8.12	8.12	8.12

[a] Numbers in rows 1-12 refer to clauses and subclauses in this standard.

[b] Insulation withstand tests, see also 6.1.

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

[c] Residual voltage tests, see also 6.3.

These tests demonstrate the protective levels of the arrester.

[d] For long-duration current impulse withstand test, see also 6.8.

These tests demonstrate the ability of the resistor elements to withstand possible dielectric and energy stresses without puncture or flashover.

[e] Operating duty tests, see also 6.9.

These tests demonstrate the thermal stability of the arrester under defined conditions.

[f] Short-circuit tests: see also 6.11.

[g] Tests of arrester disconnectors, see also 6.12.

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

[h] Artificial pollution test for porcelain-housed multi-unit surge arresters.

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.

[I] Internal partial discharge test: see also 6.4.

This test measures the internal partial discharges.

Table 3 *(continued)*

j	Bending moment test. This test demonstrates the ability of the arrester to withstand the manufacturer's declared values for bending loads.
k	Environmental tests 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.
l	Seal leak rate test, see also 6.5. 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).
m	Radio interference voltage test : see also 6.15.

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.

8.2 Insulation withstand tests on the arrester housing

8.2.1 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 6.1 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.

8.2.2 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 (for example, grading elements) to provide linear voltage distribution along the arrester axis.

8.2.3 Tests on complete arrester housing assemblies

Under consideration.

8.2.4 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.

8.2.5 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.

8.2.6 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.

8.2.7 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 60060-1. 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.

8.2.8 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 min.

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 min.

8.3 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 6.3. 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 item b) of 9.1), 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.

8.3.1 Steep current impulse residual voltage test

One steep current impulse in accordance with 3.16 with a peak value equal to the nominal discharge current of the arrester ±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 6.3).
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 (μH/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 (kA/μs).

3) Add the 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 6.3).
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 (μH/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 μs;

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.

8.3.2 Lightning impulse residual voltage test

One lightning current impulse in accordance with 3.17 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 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 6.3. 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 should 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.

8.3.3 Switching impulse residual voltage test

One switching current impulse in accordance with 3.32 of each specified value in Table 4 shall be applied to each of the three samples with peak values according to Table 4 with a tolerance of ±5 %. The residual voltages are determined in accordance with 6.3. 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 4.

Table 4 – 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

8.4 Long-duration current impulse withstand test

8.4.1 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 7.3 and 8.1 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 °C ± 15 K 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/fault indicator is built into the design of the arrester under consideration, these tests shall be made with the disconnector/fault indicator in operable condition (see 8.6).

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.

8.4.2 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 5.

Table 5 – 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 Classes 1 to 5 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 5 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 4.

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 5.

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 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 I.

8.4.3 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 6.

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 6 for the first impulse and between 100 % and 110 % of this value for the following impulses.

Table 6 – 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 *T*** µs
5 000 A	75	1 000
2 500 A	50	500

8.5 Operating duty tests

8.5.1 General

As explained in 6.9, 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 8.5.3).

The test sequence comprises

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

This sequence is illustrated in Figures 1 and 2 and in Figure C.1.

The test shall be made on three samples of complete arresters or arrester sections in accordance with 7.2, 7.3 and 8.1 at an ambient temperature of 20 °C ± 15 K. 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/fault indicator is built into the design of arrester under consideration, these tests shall be made with the disconnector/fault indicator in operable condition, see 8.6.

For arresters rated above 12 kV it is usually necessary to make this test on an arrester section because of the 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 8.5.2.2.

The power-frequency test voltages to be applied to the test arrester section shall be the continuous operating (see 3.9) and rated (see 3.8) voltages of the complete arrester divided by the total number of similar arrester sections n (see 7.3). These voltages, U_{sc} equal to U_c/n and U_{sr} equal to U_r/n are modified according to 8.5.2.2 to establish the elevated test voltages U_c^* and U_r^*.

NOTE The established preheat temperature of 60 °C ± 3 K 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.

8.5.2 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 and 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.

8.5.2.1 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 °C ± 4 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 the open air is equivalent to that carried out in the actual medium, the ageing procedure can be carried out in the 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 L.

For arresters with a length H of less than 1 m, except for arresters with conductive, grounded enclosures such as GIS-arresters, liquid-immersed, dead-front 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 7.3. The power frequency voltage shall fulfil the requirements stated for the operating duty test (see 8.5.1).

8.5.2.2 Determination of elevated rated and continuous operating voltages

The three test samples shall be heated to 115 °C ± 4 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-energizing 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 energizing. Within the temperature range allowed, all measurements shall be made at the same temperature ±1 K.

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

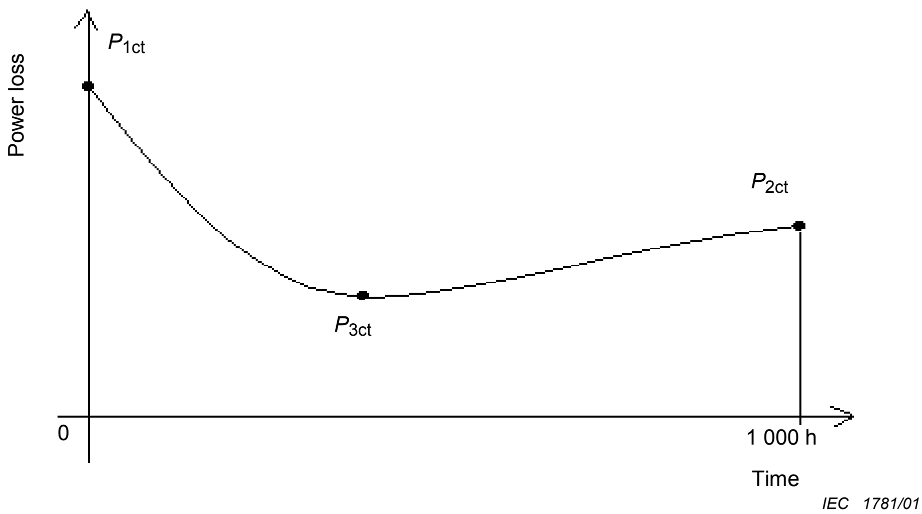


Figure 3 – Power losses of the arrester at elevated temperatures versus time

- If P_{2ct} is equal to, or below, 1,1 times P_{3ct}, then the test according to 8.5.4.2 and 8.5.5.2 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:

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

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 8.5.4.2 and 8.5.5.2. 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 8.5.2.1.

Table 7 summarizes 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.

8.5.2.3 Test procedure for resistor elements stressed at or above the reference voltage

If U_{ct} is close to or above the reference voltage, it may not be possible to perform an accelerated ageing test at U_{ct}, due to the extreme voltage dependence for the power losses and stability of available voltage source. If $U_{ct} \geq 0{,}95 {*} U_{ref}$ and if it is not possible to perform an accelerated ageing test according to 8.5.2.1, this alternative test procedure shall apply and replaces 8.5.2.1 and 8.5.2.2.

NOTE To provide an overview and to serve as an aid to understanding the procedure, the steps required are as follows.

1) Calculate power loss, P_{ct}, for the highest stressed resistor (at T_a = 40 °C and $U = U_c$).

2) Determine the steady-state temperature, T_{st}, for the highest stressed part of the arrester by using one of the three alternative procedures of 8.5.2.3.1.

3) At a voltage U_{ct}, determine the ratio, k_x, of power loss at 115 °C to power loss at T_{st} for the type of resistor elements used.

4) Perform an accelerated ageing test at constant power loss, $k_x * P_{ct}$.

5) Interrupt the test for a short time and take measurements of power loss at specified time intervals.

6) If T_{st} > 60 °C, increase test temperature or test time.

7) Evaluate the power losses of step 5) according to 8.5.2.3.3.

8.5.2.3.1 Determination of test parameters

Calculate the power losses, P_{ct}, per resistor element at the maximum ambient temperature of 40 °C with the arrester energized at U_c, for the highest voltage stressed resistor according to Annex L including the effect of the resistive current.

NOTE 1 For dead-front and liquid-immersed arresters, 65 °C and 95 °C, respectively, apply as maximum ambient temperatures.

Select one of the three following test procedures to determine the steady-state temperature, T_{st}, of the most stressed part of the arrester at maximum ambient temperature.

NOTE 2 The test procedures are considered to be conservative in increasing order from 1 to 3.

1. At an ambient temperature of 25 °C ± 10 K, energize the complete arrester at the claimed U_c until steady-state temperature conditions have been attained. The temperature shall be measured on resistor elements, at five points as evenly spaced as possible over the most highly stressed 20 % portion of the length of each column of the arrester. If this 20 % portion contains less than five resistor elements, the number of measuring points may be limited to one point on each resistor element. The average temperature rise above ambient of the resistor elements shall be added to the maximum ambient temperature to obtain the temperature T_{st}.
2. At the maximum ambient temperature, energize a thermally pro-rated section representative for the arrester type at a voltage level, which results in the same power losses per resistor element as determined above. Keep the power losses constant by adjusting the voltage if necessary. Measure the temperature of the resistors in steady-state condition and calculate the average steady-state temperature, which is set equal to $T_{st.}$
3. At an ambient temperature of 25 °C ± 10 K, energize a thermally pro-rated section representative for the arrester type at a voltage level which results in the same power losses per resistor element as determined above. Keep the power losses constant by adjusting the voltage if necessary. Measure the temperature of the resistors in steady-state condition and calculate the average steady-state temperature rise, ΔT_{st}, above ambient. Determine the temperature, T_{st} ,by adding ΔT_{st} to the maximum ambient temperature.

The prorated section shall represent the steady-state thermal behaviour of the complete arrester.

NOTE 3 The section may not necessarily be the same as that used for the operating duty test.

At a voltage U_{ct}, determine the ratio, k_x, of power losses at 115 °C to power losses at T_{st} for the type of resistor elements used. For this test the voltage source shall fulfil the requirements according to 8.5.1.

8.5.2.3.2 Test procedure

Three resistor samples shall be subjected to constant power losses equal to k_x*P_{ct} (tolerance $^{+30}_{\ 0}$%) for 1 000 h. During the test, the temperature shall be controlled to keep the surface temperature of the resistor at the required test temperature T_t ± 4 K. The applied test voltage at the start of the test shall be not less than 0,95*U_{ct}.

If the temperature, T_{st}, is equal to or below 60 °C, T_t shall be 115 °C. If T_{st} is above 60 °C, either the test temperature or the testing time shall be increased as follows.

a) Increase of the test temperature

$$T_t = 115 + (T_{st} - T_{a,max} - \Delta T_n)$$

where

T_t is the test temperature in °C;

T_{st} is the steady-state temperature of the resistors in °C;

$T_{a,max}$ is the maximum ambient temperature in °C;

ΔT_n = 20 K.

NOTE 1 For liquid-immersed arresters ΔT_n = 25 K, which results from the requirement that the operating duty test starting temperature for these arresters (120 °C) is 25 K above the maximum ambient temperature (95 °C), while for other arresters the difference between the operating duty test starting temperature and the maximum ambient temperature is 20 K.

b) Increase of the testing time

$$t = t_0 * 2{,}5^{\Delta T/10}$$

where

t is the testing time in h;

t_0 = 1 000 h;

ΔT is the temperature above 60 °C.

NOTE 2 For dead-front and liquid-immersed arresters, t_0 is 2 000 h and 7 000 h, respectively, and ΔT is the temperature above 85 °C and 120 °C, respectively.

8.5.2.3.3 Determination of elevated rated and continuous operating voltages

The three test samples shall be heated to T_t ± 4 K and subjected to the constant power losses k_x*P_{ct}. One to two hours after the voltage application, the voltage is adjusted to a voltage in the range 0,95* U_{ct} to U_{ct} and the power losses, P_{1ct}, are measured. During the test, after 30 %, 50 % and 70 % of the testing time, the measurement of power losses is repeated under the same conditions with respect to temperature and voltage. The minimum power loss values at these times are designated as P_{3ct}. At the end of the ageing test, under the same conditions with regard to block temperature and at the same voltage, the power losses P_{2ct} are determined.

- If P_{2ct} is equal to or below 1,1 times P_{3ct}, then the test according to 8.5.4 and 8.5.5 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 $P_{2ct} > P_{1ct}$, the ratio P_{2ct}/P_{1ct} is determined for each sample. The highest of these 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:

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

  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 test of 8.5.4 and 8.5.5. 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 8.5.2.3.2.

These cases are summarized in Table 7.

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.

8.5.3 Heat dissipation behaviour of test sample

8.5.3.1 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.

8.5.3.2 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 modelled.
b) The housing shall meet the following requirements:
   1) the material shall be the same as that of the arrester housing;
   2) the inside diameter shall be the same as that of the arrester ±5 %;
   3) 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;
   4) 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 a copper wire of 3 mm in diameter .

8.5.4 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 6.9.

The complete test sequence is illustrated in Figure 1 or in Figure 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 8.3.2).

8.5.4.1 Conditioning

The samples are exposed to a conditioning test consisting of 20 8/20 lightning current impulses according to 3.17 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 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 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 °C ± 15 K. 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 Figure 1 and Figure C.1).

8.5.4.2 Application of impulses

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

The section is subjected to two high current impulses with peak value and impulse shape as specified in Table 8. High lightning duty arresters specified in Annex C are subjected to three 30/80 impulses with a peak value of 40 kA.

Table 8 – 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 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 °C ± 3 K. The tests shall be carried out at an ambient temperature of 20 °C ± 15 K.

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 8.5.2) 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 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 8.5.6).

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 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.

8.5.5 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 6.9.

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 8.3.2).

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

8.5.5.1 Conditioning

The samples are exposed to a conditioning test, the first part of which consists of 20 8/20 current impulses according to 3.17 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 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 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 °C ± 15 K.

The second part of the conditioning is the application of two high current impulses 100 kA 4/10 (see 3.31). 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.

8.5.5.2 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 °C ± 3 K at the ambient temperature of 20 °C ± 15 K.

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 Table 5 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 8.5.2, 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 run-away.

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 (see 8.5.6), if the change in residual voltage measured before and after the test is not more than 5 %, and if visual examination of the test samples after the test reveals no evidence of puncture, flashover or cracking of the non-linear metal-oxide resistors.

8.5.6 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 pass 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 in the procedures shown in Figures 1, 2 and C.1 for the respective types of arresters.

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, the judgement 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.

8.6 Tests of arrester disconnectors/fault indicators

8.6.1 General

In this procedure, the term "disconnector/fault indicator" shall mean either a disconnector or a fault indicator, whichever type of device is used with the arrester.

These tests shall be made on arresters which are fitted with arrester disconnectors/fault indicators or on the disconnector/fault indicator 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 be hard-drawn bare copper approximately 5 mm in diameter and 30 cm long, arranged to allow freedom of movement of the disconnector/fault indicator when it operates.

8.6.2 Current impulse and operating duty withstand tests

As noted in 8.4 and 8.5, these tests will be made at the same time as the tests on the arrester, for arresters with built-in disconnector/fault indicators. In the case of disconnector/fault indicators 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/fault indicator shall withstand without operating each of the following tests. Three new samples shall be used for each different test.

8.6.2.1 Long-duration current impulse test

This test shall be made in accordance with 8.4 with the peak current and duration corresponding to the highest classification of arrester with which the disconnector/fault indicator is designed to be used, see Tables 4 and 5.

8.6.2.2 Operating duty test

This test shall be made in accordance with 8.5 with the sample disconnector/fault indicator 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.

8.6.3 Disconnector operation

8.6.3.1 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 8.6.1.

For tests on disconnectors affected by internal heating of the associated arresters, the non-linear resistors 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 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 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 durations 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.

8.6.3.2 Evaluation of disconnector performance

There shall be clear evidence of effective and permanent disconnection by the device. If there is no clear evidence of effective and permanent disconnection by the device, 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 1mA r.m.s.

8.6.4 Fault indicator operation

Under consideration.

8.7 Short-circuit tests

8.7.1 General

Arresters, for which a short-circuit rating is claimed by the manufacturer, shall be tested in accordance with this subclause. The test shall be performed in order to show that an arrester failure does not result in a violent shattering of the arrester housing, and that self-extinguishing of open flames (if any) occurs within a defined period of time. Each arrester type is tested with four values of short-circuit currents. If the arrester is equipped with some other arrangement as a substitute for a conventional pressure relief device, this arrangement shall be included in the test.

The frequency of the short-circuit test current supply shall be between 48 Hz and 62 Hz.

With respect to the short-circuit current performance, it is important to distinguish between two designs of surge arresters.

– “Design A” arresters have a design in which a gas channel runs along the entire length of the arrester unit and fills ≥50 % of the internal volume not occupied by the internal active parts.
– “Design B” arresters are of a solid design with no enclosed volume of gas or having an internal gas volume filling <50 % of the internal volume not occupied by the internal active parts.

NOTE 1 Typically, “Design A” arresters are porcelain-housed arresters, or polymer-housed arresters with a composite hollow insulator which are equipped either with pressure-relief devices, or with prefabricated weak spots in the composite housing which burst or flip open at a specified pressure, thereby decreasing the internal pressure.

Typically, “Design B” arresters do not have any pressure relief device and are of a solid type with no enclosed volume of gas. If the resistors fail electrically, an arc is established within the arrester. This arc causes heavy evaporation and possibly burning of the housing and/or internal material. These arresters’ short-circuit performance is determined by their ability to control the cracking or tearing-open of the housing due to the arc effects, thereby avoiding violent shattering.

NOTE 2 "Active parts" in this context are the non-linear, metal-oxide resistors and any metal spacers directly in series with them.

Depending on the type of arrester and test voltage, different requirements apply with regard to the number of test samples, initiation of short-circuit current and amplitude of the first short-circuit current peak. Table 14 shows a summary of these requirements which are further explained in the following subclauses.

NOTE 3 After agreement between the manufacturer and the purchaser, the test procedure can be modified to include, for example, a number of reclosing operations. For such special tests, the procedure and acceptance criteria should be agreed upon between the manufacturer and the purchaser.

8.7.2 Preparation of the test samples

For the high-current tests, the test samples shall be the longest arrester unit used for the design with the highest rated voltage of that unit used for each different arrester design.

For the low-current test, the test sample shall be an arrester unit of any length with the highest rated voltage of that unit used for each different arrester design.

NOTE 1 Figure 13 shows different examples of arrester units.

In case a fuse wire is required, the fuse wire material and size shall be selected so that the wire will melt within the first 30 electrical degrees after initiation of the test current.

NOTE 2 In order to have melting of the fuse wire within the specified time limit and create a suitable condition for arc ignition, it is generally recommended that a fuse wire of a low resistance material (for example copper, aluminium or silver) with a diameter of about 0,2 mm to 0,5 mm be used. Higher fuse-wire cross-sections are applicable to surge arrester units prepared for higher short-circuit test currents. When there are problems in initiating the arc, a fuse wire of larger size but with a diameter not exceeding 1,5 mm, may be used since it will help arc establishment. In such cases, a specially prepared fuse wire, having a larger cross-section along most of the arrester height with a short thinner section in the middle, may also help.

8.7.2.1 "Design A" arresters

The samples shall be prepared with means for conducting the required short-circuit current using a fuse wire. The fuse wire shall be in direct contact with the MO resistors and be positioned within, or as close as possible to, the gas channel and shall short-circuit the entire internal active part. The actual location of the fuse wire in the test shall be reported in the test report.

No differences with regard to polymer housings or porcelain housings are made in the preparation of the test samples. However, differences partly apply in the test procedure (see 8.7.4.2). In this case, "Design A" arresters with polymeric sheds which are not made of porcelain or other hollow insulators, and which are as brittle as ceramics, shall be considered and tested as porcelain-housed arresters.

8.7.2.2 "Design B" arresters

"Design B" arresters with polymeric sheds which are not made of porcelain or other mechanically supporting structures, and which are as brittle as ceramics, shall be considered and tested as porcelain-housed arresters.

8.7.2.2.1 Polymer-housed arresters

No special preparation is necessary. Standard arrester units shall be used. The arrester units shall be electrically pre-failed with a power frequency overvoltage. The overvoltage shall be run on completely assembled test units. No physical modification shall be made to the units between pre-failing and the actual short-circuit current test.

The overvoltage given by the manufacturer shall be a voltage exceeding 1,15 times U_c. The voltage shall cause the arrester to fail within (5 ± 3) min. The resistors are considered to have failed when the voltage across the resistors falls below 10 % of the originally applied voltage. The short-circuit current of the pre-failing test circuit shall not exceed 30 A.

The time between pre-failure and the rated short-circuit current test shall not exceed 15 min.

NOTE The pre-failure can be achieved by either applying a voltage source or a current source to the samples.

– Voltage source method: the initial current should typically be in the range 5-10 mA/cm^2. The short-circuit current should typically be between 1 A and 30 A. The voltage source need not be adjusted after the initial setting, although small adjustments might be necessary in order to fail the resistors in the given time range.

– Current source method: Typically a current density of around 15 mA/cm^2 with a variation of ±50 %, will result in failure of the resistors in the given time range. The short-circuit current should typically be between 10 A and 30 A. The current source need not be adjusted after the initial setting, although small adjustments might be necessary in order to fail the resistors in the given time range.

8.7.2.2.2 Porcelain-housed arresters

The samples shall be prepared with means for conducting the required short-circuit current using a fuse wire. The fuse wire shall be in direct contact with the MO resistors and be located as far away as possible from the gas channel and shall short-circuit the entire internal active part. The actual location of the fuse wire in the test shall be reported in the test report.

8.7.3 Mounting of the test sample

For a base-mounted arrester, the mounting arrangement is shown in Figures 14a and 14b. The distance to the ground from the insulating platform and the conductors shall be as indicated in Figures 14a and 14b.

For non-base-mounted arresters (for example, pole-mounted arresters), the test sample shall be mounted on a non-metallic pole using mounting brackets and hardware typically used for real service installation. For the purpose of the test, the mounting bracket shall be considered as a part of the arrester base. In cases where the foregoing is at variance with the manufacturer's instructions, the arrester shall be mounted in accordance with the installation recommendations of the manufacturer. The entire lead between the base and the current sensor shall be insulated for at least 1 000 V. The top end of the test sample shall be fitted with the base assembly of the same design of an arrester or with the top cap.

For base-mounted arresters, the bottom end fitting of the test sample shall be mounted on a test base that is at the same height as a surrounding circular or square enclosure. The test base shall be of insulating material or may be of conducting material if its surface dimensions are smaller than the surface dimensions of the arrester bottom end fitting. The test base and the enclosure shall be placed on top of an insulating platform, as shown in Figures 14a and 14b. For non-base-mounted arresters, the same requirements apply to the bottom of the arrester. The arcing distance between the top end cap and any other metallic object (floating or grounded), except for the base of the arrester, shall be at least 1,6 times the height of the sample arrester, but not less than 0,9 m. The enclosure shall be made of non-metallic material and be positioned symmetrically with respect to the axis of the test sample. The height of the enclosure shall be 40 cm ± 10 cm, and its diameter (or side, in case of a square enclosure) shall be equal to the greater of 1,8 m or D in Equation (1) below. The enclosure shall not be permitted to open or move during the test.

$$D = 1{,}2 \times (2 \times H + D_{arr}) \qquad (1)$$

where

H is the height of tested arrester unit;

D_{arr} is the diameter of tested arrester unit.

Porcelain-housed arresters shall be mounted according to Figure 14a. Polymer housed arresters shall be mounted according to Figure 14b.

Test samples shall be mounted vertically unless agreed upon otherwise between the manufacturer and the purchaser.

NOTE 1 The mounting of the arrester during the short-circuit test and, more specifically, the routing of the conductors should represent the most unfavourable condition in service.

The routing shown in Figure 14a is the most unfavourable to use during the initial phase of the test before venting occurs (especially in the case of a surge arrester fitted with a pressure relief device). Positioning the sample as shown in Figure 14a, with the venting ports facing in the direction of the test source, may cause the external arc to be swept in closer proximity to the arrester housing than otherwise. As a result, a thermal shock effect may cause excessive chipping and shattering of porcelain weather sheds, as compared to the other possible orientations of the venting ports. However, during the remaining arcing time, this routing forces the arc to move away from the arrester, and thus reduces the risk of the arrester catching fire. Both the initial phase of the test as well as the part with risk of catching fire are important, especially for arresters where the external part of the housing is made of polymeric material.

For all polymer-housed arresters, the ground conductor should be directed to the opposite direction as the incoming conductor, as described in Figure 14b. In this way, the arc will stay close to the arrester during the entire duration of the short-circuit current, thus creating the most unfavourable conditions with regards to the fire hazard.

NOTE 2 In the event that physical space limitations of the laboratory do not permit an enclosure of the specified size, the manufacturer may choose to use an enclosure of lesser diameter.

8.7.4 High-current short-circuit tests

Three samples shall be tested at currents based on selection of a rated short-circuit current selected from Table 15. All three samples shall be prepared according to 8.7.2 and mounted according to 8.7.3.

Tests shall be made in a single-phase test circuit, with an open-circuit test voltage of 77 % to 107 % of the rated voltage of the test sample, as outlined in 8.7.4.1. However, it is expected that tests on high-voltage arresters will have to be made at laboratories which might not have the sufficient short-circuit power capability to carry out these tests at 77 % or more of the test sample rated voltage. Accordingly, an alternative procedure for making the high-current, short-circuit tests at a reduced voltage is given in 8.7.4.2. The measured total duration of test current flowing through the circuit shall be ≥0,2 s.

NOTE Experience from porcelain-housed arresters has shown that tests at the rated current do not necessarily demonstrate acceptable behaviour at lower currents.

8.7.4.1 High-current tests at full voltage (77 % to 107 % of rating)

The prospective current shall first be measured by making a test with the arrester short-circuited or replaced by a solid link of negligible impedance.

The duration of such a test may be limited to the minimum time required to measure the peak and symmetrical component of the current waveform.

For “Design A” arresters tested at the rated short-circuit current, the peak value of the first half-cycle of the prospective current shall be at least 2,5 times the r.m.s. value of the symmetrical component of the prospective current. The following r.m.s. value of the symmetrical component shall be equal to the rated short-circuit current or higher. The peak value of the prospective current, divided by 2,5, shall be quoted as the test current, even though the r.m.s. value of the symmetrical component of the prospective current may be higher. Because of the higher prospective current, the sample arrester may be subjected to more severe duty, and, therefore, tests at X/R ratio lower than 15 shall only be carried out with the manufacturer’s consent.

For “Design B” arresters tested at rated short-circuit current, the peak value of the first half-cycle of the prospective current shall be at least √2 times the r.m.s. value.

For all the reduced short-circuit currents, the r.m.s. value shall be in accordance with Table 15 and the peak value of the first half-cycle of the prospective current shall be at least √2 times the r.m.s. value of this current.

The solid shorting link shall be removed after checking the prospective current and the arrester sample(s) shall be tested with the same circuit parameters.

NOTE 1 The resistance of the restricted arc inside the arrester may reduce the r.m.s. symmetrical component and the peak value of the measured current. This does not invalidate the test, since the test is being made with at least normal service voltage and the effect on the test current is the same as would be experienced during a fault in service.

NOTE 2 The X/R ratio of the test circuit impedance, without the arrester connected, should preferably be at least 15. In cases where the test circuit impedance X/R ratio is less than 15, the test voltage may be increased or the impedance may be reduced, in such a way that,

– for the rated short-circuit current, the peak value of the first half-cycle of the prospective current is equal to, or greater than, 2,5 times the required test current level;
– for the reduced current level tests, the tolerances in Table 15 are met.

8.7.4.2 High-current test at less than 77 % of rated voltage

When tests are made with a test circuit voltage <77 % of the rated voltage of the test samples, the test circuit parameters shall be adjusted in such a way that the r.m.s. value of the symmetrical component of the actual arrester test current shall equal or exceed the required test current level of 8.7.4.

For "Design A" arresters tested at the rated short-circuit current, the peak value of the first half-cycle of the actual arrester test current shall be at least 2,5 times the r.m.s. value of the symmetrical component of the actual arrester test current. The following r.m.s. value of the symmetrical component shall be equal to the rated short-circuit current or higher. The peak value of the actual arrester test current, divided by 2,5 shall be quoted as the test current, even though the r.m.s. value of the symmetrical component of the actual arrester test current may be higher.

The following exception for the test at rated short-circuit current is valid for "Design A" polymer-housed arresters only (see 8.7.2.1 for the definition of polymer- and porcelain-housed arresters): if the rated voltage of the test sample is more than 150 kV and a first peak value of ≥2,5 times the rated short-circuit current cannot be achieved, an additional test sample shall be tested. This additional test sample shall be tested according to either 8.7.4.1 or 8.7.4.2. It shall have a rated voltage of ≥150 kV and shall also not be shorter than the shortest arrester unit used for the actual arrester design. The rated short-circuit current value shall be the lowest of the r.m.s. current from the test on the longest unit and the r.m.s. current defined according to testing with either 8.7.4.1 or 8.7.4.2 from the test on the minimum 150 kV rated unit. Both tests shall be reported.

For "Design B" arresters tested at rated short-circuit current, the peak value of the first half-cycle of the actual arrester test current shall be at least √2 times the r.m.s. value.

For all the reduced short-circuit currents the r.m.s. value shall be in accordance with Table 15 and the peak value of the first half-cycle of the actual arrester test current shall be at least √2 times the r.m.s. value of this current.

NOTE 1 Especially for tall arresters that are tested at a low percentage of their rated voltage, the first asymmetric peak current of 2,5 is not easily achieved unless special test possibilities are considered. It is thus possible to increase the test r.m.s voltage or reduce the impedance so that, for the rated short-circuit current, the peak value of the first half-cycle of the test current is equal to, or greater than, 2,5 times the required test current level. In case of testing with a generator, the first peak of 2,5 times the required test current can also be achieved by varying the generator's excitation. The current should then be reduced, not less than 2,5 cycles after initiation, to the required symmetrical value. The actual peak value of the test current, divided by 2,5, should be quoted as the test current, even though the r.m.s. value of the symmetrical component of the actual arrester test current may be higher. Because of the higher test current, the sample arrester may be subjected to more severe duty and, therefore, tests at X/R ratio lower than 15 should only be carried out with the manufacturer's consent.

NOTE 2 For "Design B" polymer-housed arresters, even the first current peak of √2 may not be easily achieved unless special test facilities are considered. Pre-failed arresters can build up considerable arc resistance, which limits the symmetrical current through the arrester. It is therefore recommended to perform the short-circuit tests as soon as possible after the pre-failure, preferably before the test samples have cooled down.

For pre-failed arresters, therefore, it is recommended to ensure that the arrester represents a sufficiently low impedance prior to applying the short-circuit current by reapplying the pre-failing, or similar, circuit during a maximum of 2 s immediately before applying the short-circuit test current (see Figure 15). It is acceptable to increase the short-circuit current of the pre-applied circuit up to 300 A (r.m.s). If so, its maximum duration, which depends on the current magnitude, shall not exceed the following value:

$$t_{rpf} \leq Q_{rpf} / I_{rpf}$$

where

t_{rpf} is the re-pre-failing time in s;

Q_{rpf} is the re-pre-failing charge = 60 As;

I_{rpf} is the re-pre-failing current in A (r.m.s.).

8.7.5 Low-current short-circuit test

The test shall be made by using any test circuit that will produce a current through the test sample of 600 A ± 200 A r.m.s., measured at approximately 0,1 s after the start of the current flow. The current shall flow for 1 s or, for "Design A" porcelain-housed surge arresters, until venting occurs.

Refer to Note 2 of 8.7.6 with regard to handling an arrester that fails to vent.

8.7.6 Evaluation of test results

The test is considered successful if the following three criteria are met.

a) No violent shattering

NOTE 1 Structural failure of the sample is permitted as long as criteria 2 and 3 are met.

b) No parts of the test sample shall be allowed to be found outside the enclosure, except for
   - fragments, less than 60 g each, of ceramic material such as MOV or porcelain;
   - pressure relief vent covers and diaphragms;
   - soft parts of polymeric materials.

c) The arrester shall be able to self-extinguish open flames within 2 min after the end of the test. Any ejected part (in or out of the enclosure) must also self-extinguish open flames within 2 min.

NOTE 2 If the arrester has not visibly vented at the end of the test, caution should be exercised, as the housing may remain pressurized after the test. This note is applicable to all levels of test current, but is of particular relevance to the low-current, short-circuit tests.

NOTE 3 A shorter duration of self-extinguishing open flames for ejected parts may be agreed upon between the purchaser and the manufacturer.

NOTE 4 For arresters to be used in applications where mechanical integrity and a strength is required after failure, different test procedures and evaluations may be established between the manufacturer and the user (as an example, it may be required that after the tests the arrester should still be able to be lifted and removed by its top end).

Table 14 – Test requirements

	Required number of test samples	Initiation of short-circuit current	Ratio of first current peak value to r.m.s. value of required short-circuit current according to to Table 15					
			Test voltage: 77 % to 107 % of U_r			Test voltage: < 77 % of U_r		
			Rated short-circuit current	Reduced short-circuit current	Low short-circuit current	Rated short-circuit current	Reduced short-circuit current	Low short-circuit current
"Design A" Porcelain	4	Fuse wire along surface of MO resistors; within, or as close as possible to, the gas channel	Prosp.: ≥ 2,5 Actual: no requirement	Prosp.: $\geq \sqrt{2}$ Actual: no requirement	Actual: $\geq \sqrt{2}$	Actual: ≥ 2,5	Actual: $\geq \sqrt{2}$	Actual: $\geq \sqrt{2}$
"Design A" Polymer-housed	4 or 5	Fuse wire along surface of MO resistors; within, or as close as possible to, the gas channel	Prosp.: ≥ 2,5 Actual: no requirement	Prosp.: $\geq \sqrt{2}$ Actual: no requirement	Actual: $\geq \sqrt{2}$	Actual: ≥ 2,5 *or*: Actual: $\geq \sqrt{2}$ on longest unit and Actual: ≥ 2,5 on a unit with $U_r \geq 150$ kV	Actual: $\geq \sqrt{2}$	Actual: $\geq \sqrt{2}$
"Design B" Porcelain-housed	4	Fuse wire along surface of MO resistors; located as far away as possible from the gas channel	Prosp.: $\geq \sqrt{2}$ Actual: no requirement	Prosp.: $\geq \sqrt{2}$ Actual: no requirement	Actual: $\geq \sqrt{2}$	Actual: $\geq \sqrt{2}$	Actual: $\geq \sqrt{2}$	Actual: $\geq \sqrt{2}$
"Design B" Polymer housed	4	Pre-failing by constant voltage or constant current source	Prosp.: $\geq \sqrt{2}$ Actual: no requirement	Prosp.: $\geq \sqrt{2}$ Actual: no requirement	Actual: $\geq \sqrt{2}$	Actual: $\geq \sqrt{2}$	Actual: $\geq \sqrt{2}$	Actual: $\geq \sqrt{2}$

Table 15 – Required currents for short-circuit tests

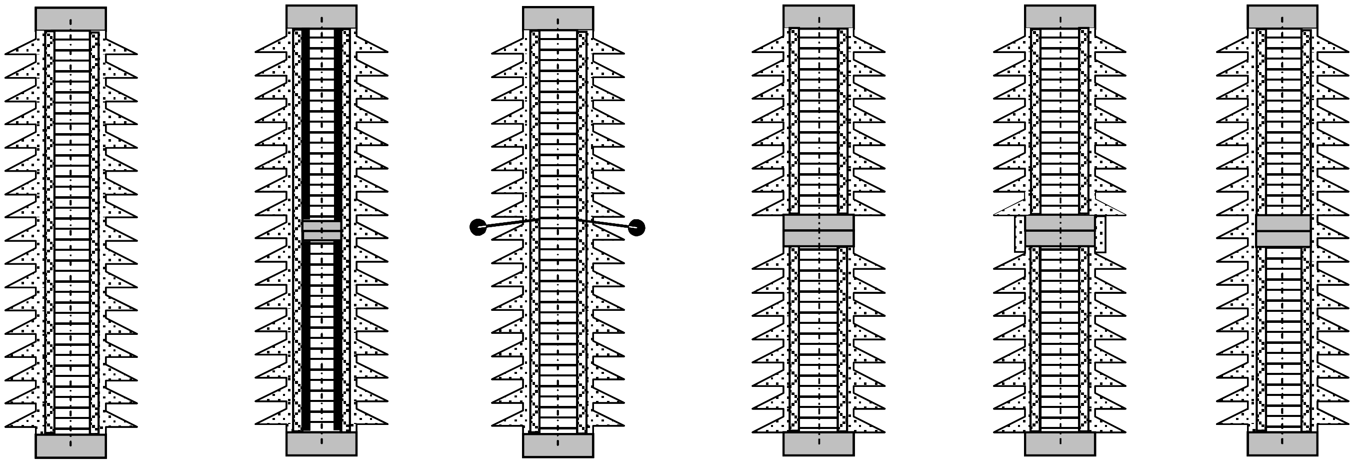
Arrester class = nominal discharge current	Rated short-circuit current I_S	Reduced short-circuit currents ±10 %		Low short-circuit current with a duration of 1 s 1)
A	A	A		A
20 000 or 10 000	80 000	50 000	25 000	600±200
20 000 or 10 000	63 000	25 000	12 000	600±200
20 000 or 10 000	50 000	25 000	12 000	600±200
20 000 or 10 000	40 000	25 000	12 000	600±200
20 000 or 10 000	31 500	12 000	6 000	600±200
20 000, 10 000 or 5 000	20 000	12 000	6 000	600±200
10 000 or 5 000	16 000	6 000	3 000	600±200
10 000, 5 000, 2 500 or 1 500	10 000	6 000	3 000	600±200
10 000, 5 000, 2 500 or 1 500	5 000	3 000	1 500	600±200

1) For surge arresters to be installed in resonant earthed or unearthed neutral systems, the increase of the test duration to longer than 1 s, up to 30 min, may be permitted after agreement between the manufacturer and the purchaser. In this case the low short-circuit current shall be reduced to 50 A ± 20 A, and the test sample and acceptance criteria shall be agreed between the manufacturer and the purchaser.

NOTE 1 If an existing type of arrester, already qualified for one of the rated currents in Table 15, is being qualified for a higher rated-current value available in this table, it should be tested only at the new rated value. Any extrapolation can only be extended by two steps of rated short-circuit current.

NOTE 2 If a new arrester type is to be qualified for a higher rated current value than available in this table, it shall be tested at the proposed rated current, at 50 % and at 25 % of this rated current.

NOTE 3 If an existing arrester is qualified for one of the rated short-circuit currents in this table, it is deemed to have passed the test for any value of rated current lower than this one.



Case a)	Case b)	Case c)	Case d)	Case e)	Case f)
n = 1	n = 1	n = 1	n = 2	n = 1	n = 1

Case a) One mechanical and electrical unit
Case b) Two mechanical internal assemblies covered by one common housing providing final mechanical strength
Case c) One mechanical unit covered by a housing with an intermediate potential grading element
Case d) Two mechanical units covered by individual housings each and assembled afterwards
Case e) Two mechanical units of final mechanical strength, intermediate flanges covered by soft insulating material after assembly
Case f) Two mechanical units covered by individual housings each and assembled afterwards
n … number of units

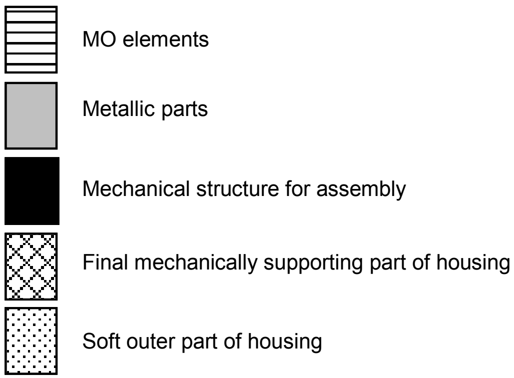


Figure 13 – Examples of arrester units

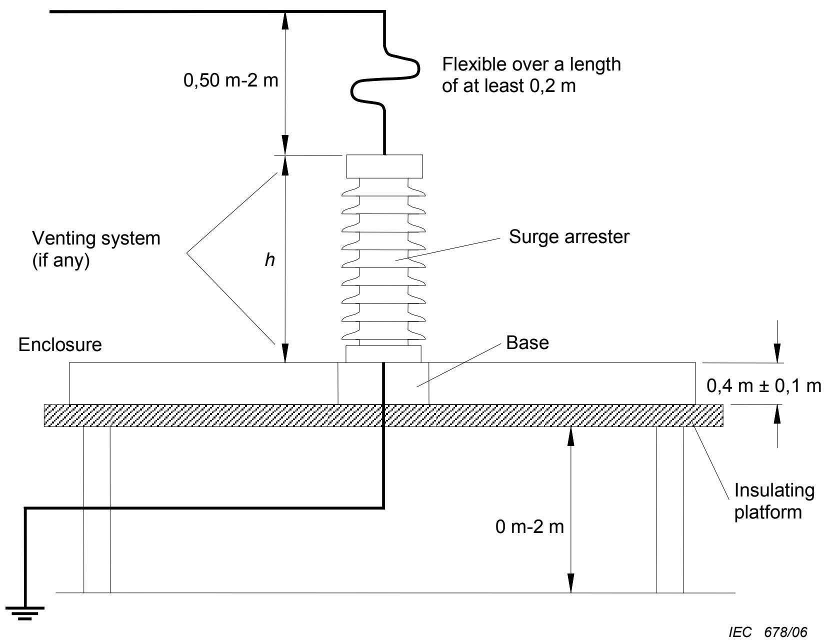


Figure 14a – Circuit layout for porcelain-housed arresters

(all leads and venting systems in the same plane)

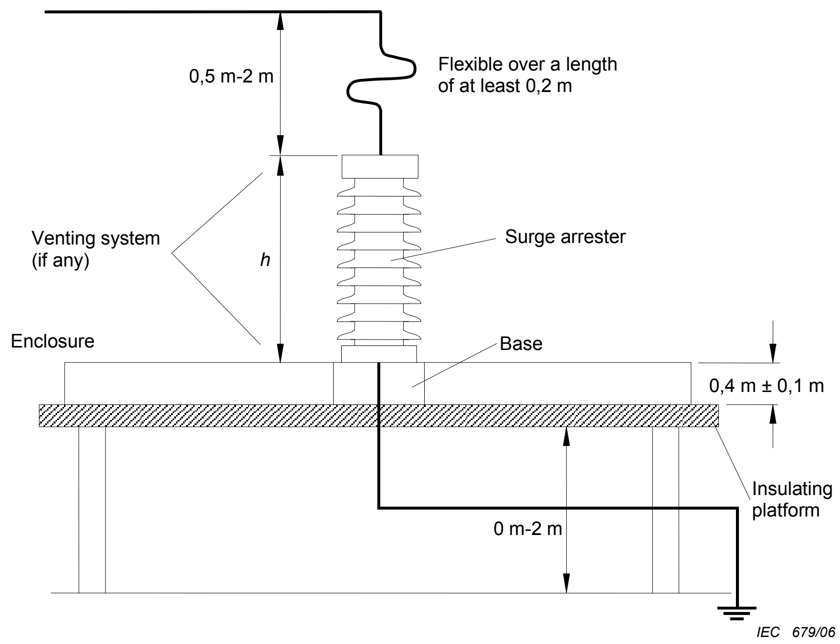
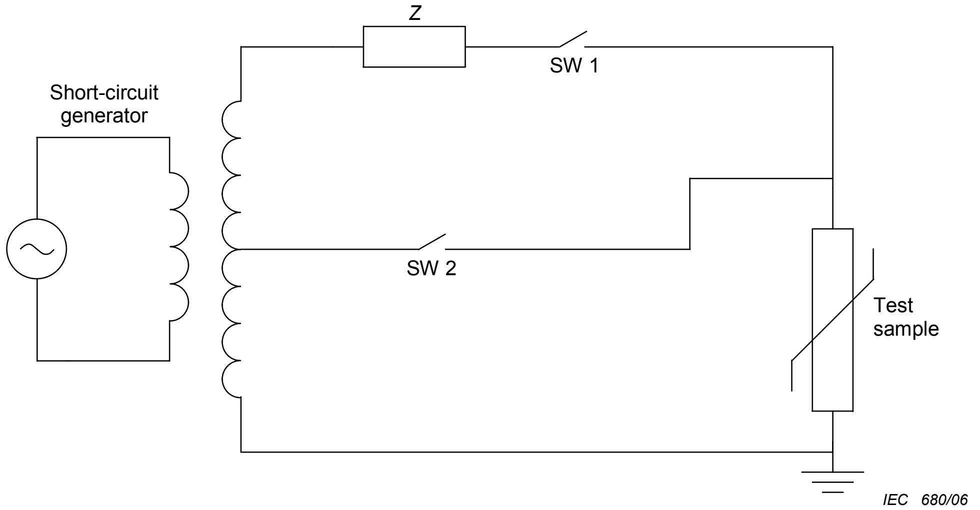


Figure 14b – Circuit layout for polymer-housed arresters

(all leads and venting systems in the same plane)

Figure 14 – Short-circuit test setup



NOTE SW 1 is closed and SW 2 is opened to apply pre-failing level of current (maximum of 30 A, limited by impedance *Z*). After a maximum of 2 s, SW 2 is closed to cause the specified short-circuit current to flow through the test sample.

Figure 15 – Example of a test circuit for re-applying pre-failing circuit immediately before applying the short-circuit test current

8.8 Internal partial discharge tests

The test shall be performed on the longest electrical unit of the arrester. If this does not represent the highest specific voltage stress per unit length, additional tests shall be performed on the unit having the highest specific voltage stress. The test sample may be shielded against external partial discharges.

NOTE Shielding against external partial discharges should have negligible effects on the voltage distribution.

The power-frequency voltage shall be increased to the rated voltage of the sample, held for 2 s to 10 s, and then decreased to 1,05 times the continuous operating voltage of the sample. At that voltage, the partial discharge level shall be measured according to IEC 60270. The measured value for the internal partial discharge shall not exceed 10 pC.

8.9 Test of the bending moment

8.9.1 General

This test demonstrates the ability of the arrester to withstand the manufacturer's declared values for bending loads. Normally, an arrester is not designed for torsional loading. If an arrester is subjected to torsional loads, a specific test may be necessary by agreement between manufacturer and user.

The test is applicable to all surge arresters designated with a line discharge class and which are base-mounted. These arresters consist of one or several units. They are applied up to the highest system voltages.

The test shall be performed on complete arresters or arrester units. The test samples shall be mounted in the upright position. They shall be attached to the mounting surface of the testing machine by their normal method of mounting. The load shall be applied to the free end of the arrester. The direction of the load shall pass through the longitudinal axis of the arrester and shall be perpendicular to it in the direction of the lowest mechanical strength (initial arrester position: longitudinal axis in the vertical direction). The manufacturer shall give information concerning the lowest mechanical strength.

Where an arrester contains more than one unit or where the arrester has different specified bending moments in both ends, tests shall be performed to evaluate each different specified bending moment with loads determined according to Clause M.1.

The test load shall be the maximum permissible dynamic service load (MPDSL), i.e. the 100 % value of Clause M.3.

The tests shall be carried out without internal pressure.

NOTE Polymer-housed arresters are additionally subjected to the moisture ingress test (see 10.8.13), where the maximum continuous cantilever load is applied in different directions and under different temperatures.

8.9.2 Sample preparation

The test samples shall contain the internal parts.

Prior to the tests, each test sample shall be subjected to a leakage check (see item d) of 9.1) and an internal partial discharge test (see item c) of 9.1).

8.9.3 Test procedure

The bending load shall be increased smoothly to the test load within 30 s to 90 s. When the test load is reached, it shall be maintained for 60 s to 90 s. During this time the deflection shall be measured. Then the load shall be released smoothly and the residual deflection shall be recorded.

NOTE Care should be taken because the housing of an arrester can break and splinter while tension is applied.

8.9.4 Test evaluation

The arrester shall be considered satisfactory if the following is demonstrated:

– no visible mechanical damage;
– a force-deflection curve without discontinuity;
– the strain condition of the housing after removal of the bending load is within ±5 % of the strain condition before application of the bending load;

  NOTE The value of ±5 % is given for guidance and is still under consideration.
– a successful leakage check in accordance with item d) of 9.1;
– internal partial discharge level not exceeding the value specified in item c) of 9.1.

8.10 Environmental tests

8.10.1 General

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

Arresters, which differ only in terms of their dimensions, and which are otherwise based on the same design and material, are considered to be the same type of arrester.

For arresters with an enclosed gas volume and a separate sealing system, the internal parts may be omitted.

The tests specified below (see 8.10.3) shall be performed one after the other on one sample.

The temperature cycling test shall be carried out first.

8.10.2 Sample preparation

Prior to the tests, the test sample shall be subjected to the leakage check of item d) of 9.1.

8.10.3 Test procedure

8.10.3.1 Temperature cycling test

The test shall be performed according to test Nb of IEC 60068-2-14.

The hot period shall be at a temperature of at least +40 °C, but not higher than +70 °C. The cold period shall be at least 85 K below the value actually applied in the hot period; however, the lowest temperature in the cold period shall not be lower than –50 °C:

– temperature change gradient: 1 K/min;
– duration of each temperature level: 3 h;
– number of cycles: 10.

8.10.3.2 Sulphur dioxide test

The test shall be performed according to Clauses 4 and 6, as applicable, of IEC 60068-2-42:

– sulphur dioxide concentration : 25×10^{-6} ($\pm 5 \times 10^{-6}$) (vol./vol.);
– test duration : 21 days (20 cycles of 24 h each).

8.10.3.3 Salt mist test

The test shall be performed according to Clause 4 and to 7.6, as applicable, of IEC 60068-2-11:

– salt solution concentration: 5 % ± 1 % by weight;
– test duration: 96 h.

8.10.4 Test evaluation

The measurements performed before the test shall be repeated. The arrester shall be considered satisfactory if the results demonstrate the following:

– no visible mechanical damage;
– a successful leakage check according to item d) of 9.1.

8.11 Seal leak rate test

8.11.1 General

This test demonstrates the gas/watertightness of the complete system.

The test shall be performed on one complete arrester unit. The internal parts may be omitted. If the arrester contains units with differences in their sealing system, the test shall be performed on one unit each, representing each different sealing system.

8.11.2 Sample preparation

The test sample shall be new and clean.

8.11.3 Test procedure

The manufacturer may use any sensitive method suitable for the measurement of the specified seal leak rate.

NOTE Some test procedures are specified in IEC 60068-2-17.

8.11.4 Test evaluation

The maximum seal leak rate (see Clause M.4) shall be lower than

$$1\ \mu W = 1\times10^{-6}\ Pa.m^3/s$$

NOTE This type test provides information concerning the efficiency of the sealing system and is therefore very sensitive. For routine tests, which are performed to verify correct assembly of the arrester, higher values of the seal leak rate may be adopted in order to reduce test efforts during production (see item d) of 9.1).

8.12 Radio interference voltage (RIV) test

These tests apply to open-air surge arresters having a rated voltage of 77 kV and above. The test shall be performed on the longest arrester, with the highest rated voltage used for a particular arrester type.

NOTE 1 A test on an element, part or unit of an arrester cannot be considered adequate because of the non-linearity of the potential distribution along a complete arrester.

NOTE 2 For this test, particular arrester type means also to have identical grading rings configurations.

Surge arresters under test shall be fully assembled, and shall include the fittings (line and earth terminals, grading rings, etc.) that the manufacturer offers as standard equipment for the arrester.

The test voltage shall be applied between the terminals and the earthed base.

Earthed parts of the arrester shall be connected to earth. Care should be taken to avoid influencing the measurements by earthed or unearthed objects near to the surge arresters and to the test and measuring circuit.

The test connections and their ends shall not be a source of radio interference voltage of higher values than those indicated below.

The measuring circuit shall comply with CISPR 16-2 of the International Special Committee on Radio Interference (CISPR). The measuring circuit should preferably be tuned to a frequency within 10 % of 0,5 MHz but other frequencies in the range 0,5 MHz to 2 MHz may be used, the measuring frequency being recorded. The results shall be expressed in microvolts.

If measuring impedances different from those specified in the CISPR publications are used, they shall be not more than 600 Ω; in any case, the phase angle shall not exceed 20°. The equivalent radio interference voltage referred to 300 Ω can be calculated, assuming the measured voltage to be directly proportional to the resistance.

The filter F shall have a high impedance so that the impedance between the high-voltage conductor and earth is not appreciably shunted as seen from the surge arrester under test. This filter also reduces circulating radiofrequency currents in the test circuit, generated by the high-voltage transformer or picked up from extraneous sources. A suitable value for its impedance has been found to be 10 000 Ω to 20 000 Ω at the measuring frequency.

Means shall be employed to ensure that the radio interference background level (radio interference level caused by external field and by the high-voltage transformer when magnetized at the full test voltage) is at least 6 dB and preferably 10 dB below the specified radio interference level of the surge arrester to be tested. Calibration methods for the measuring instrument are given in CISPR 18-2.

As the radio interference level may be affected by fibres or dust settling on the insulators, it is permitted to wipe the insulators with a clean cloth before taking a measurement. The atmospheric conditions during the test shall be recorded. It is not known what correction factors apply to radio interference testing but it is known that test may be sensitive to high relative humidity and the results of test may be open to doubt if the relative humidity exceeds 80 %.

The following test procedure shall be followed.

The test voltage is increased to 1,15 U_c and then lowered to 1,05 U_c, where it shall be maintained for 5 min, U_c being the continuous operating voltage of the arrester. The voltage shall then be decreased by steps to 0,5 times U_c, raised again by steps to 1,05 U_c for 5 min and finally decreased by steps to 0,5 times U_c. At each step, a radio interference measurement shall be taken and the radio interference level, as recorded during the last series of voltage reductions, shall be plotted versus the applied voltage; the curve so obtained is the radio interference characteristic of the surge arrester. The amplitude of voltage steps shall be approximately 0,1 U_c.

The surge arrester shall have passed the test if the radio interference level at 1,05 times U_c and all lower voltage steps does not exceed 2 500 μV.

This RIV test may be omitted, if the same arrester has passed the partial discharge test (in this case, internal and external discharges shall be measured, i.e. with no shielding devices used for the connections or the grading rings or other parts of the arresters).

9 Routine tests and acceptance tests

9.1 Routine tests

The minimum requirement for routine tests to be made by the manufacturer shall be

a) measurement of reference voltage (U_{ref}) (see 3.35 and 6.2). The measured values shall be within a range specified by the manufacturer;

b) 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 the 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 1 When 5 000 A and 2 500 A arresters below 36 kV rating are supplied in volume, the residual voltage test may be omitted in the routine tests if agreed between manufacturer and purchaser.

c) internal partial discharge test. This test shall be performed on each arrester unit. The test sample may be shielded against external partial discharges.

The power-frequency voltage shall be increased to the rated voltage of the sample, held for 2 s to 10 s, and then decreased to 1,05 times the continuous operating voltage of the sample. At that voltage, the partial discharge level shall be measured according to IEC 60270. The measured value for the internal partial discharge shall not exceed 10 pC. Alternatively, the manufacturer may carry out the partial discharge measurement at the rated voltage or at a higher value without reducing the test voltage afterwards;

d) for arrester units with sealed housing, a leakage check shall be made on each unit by any sensitive method adopted by the manufacturer;

e) current distribution test for multi-column arrester. This test shall be carried out on all groups of parallel resistors. A group of parallel resistors means a part of the assembly where no intermediate electrical connection between the columns is used. The manufacturer shall specify a suitable impulse current in the range 0,01 to 1 times the nominal discharge current at which the current through each column shall be measured.

The highest current value shall not be higher than an upper limit specified by the manufacturer. The current impulse shall have a virtual front time of not less than 7 μs and the half-value time may have any value.

NOTE 2 If the rated voltage of the groups of parallel resistors used in the design is too high compared to available test facilities, the rated voltage of the group of parallel resistors used in this test can be reduced by introducing intermediate electrical connections between the columns, thereby establishing several artificial groups of parallel resistors. Each such artificial group will then pass the current distribution test specified.

9.2 Acceptance tests

9.2.1 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) Measurement of power-frequency voltage on the complete arrester at the reference current measured at the bottom of the arrester. The measured value shall be within a range specified by the manufacturer. For multi-unit arresters, the value may deviate from the reference voltage of the arrester.

b) Lightning impulse residual voltage on the complete arrester or arrester unit (see 8.3), at nominal discharge current if possible or at a current value chosen according to 8.3. In this case, the virtual time to half-value on the tail is less important and need not be complied with.

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 shall not be higher than a value specified by the manufacturer.

c) Internal partial discharge test

The test shall be performed on the complete arrester or the arrester units. The test sample may be shielded against external partial discharges.

The power-frequency voltage shall be increased to the rated voltage of the sample, held for 2 s to 10 s, and then decreased to 1,05 times the continuous operating voltage of the sample. At that voltage, the partial discharge level shall be measured according to IEC 60270. The measured value for the internal partial discharge shall not exceed 10 pC.

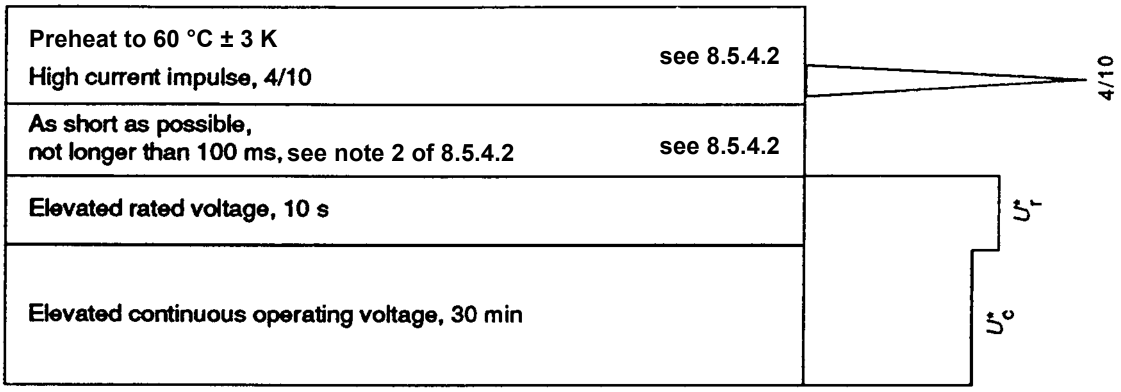
Any alteration in the number of test samples or type of test shall be negotiated between the manufacturer and the purchaser.

9.2.2 Special thermal stability test

The following test requires additional agreement between manufacturer and purchaser prior to the commencement of arrester assembly (see 6.7).

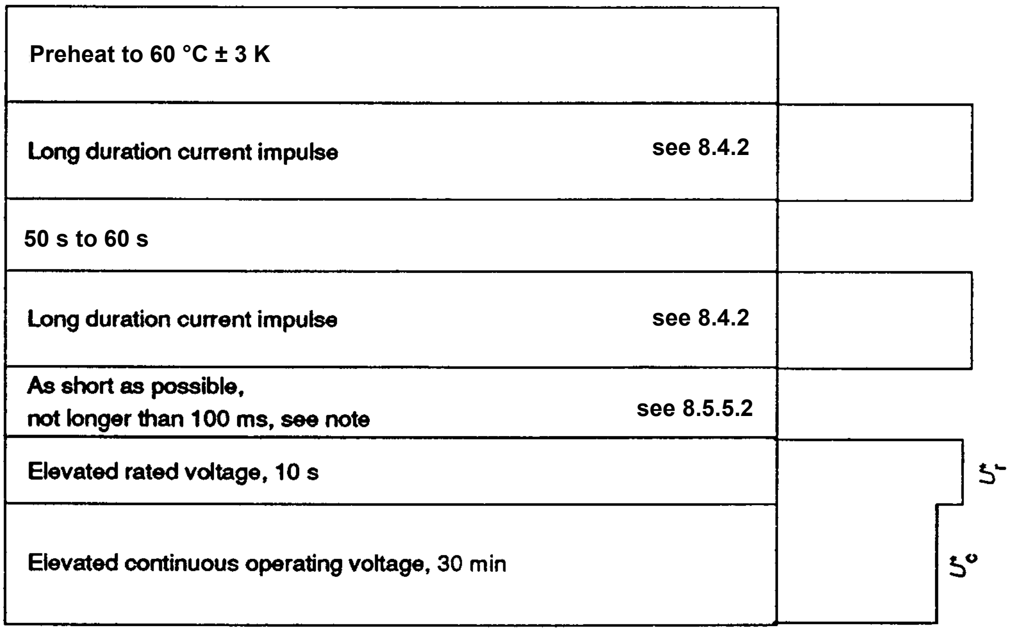
This test shall be performed on three totally different test sections consisting of metal-oxide resistors taken from current routine production and having the same dimensions and characteristics as those of the arresters under test. The test consists of a part of the operating duty test relevant to the type of arrester as indicated in Figures 4, 5 and C.2.

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 8.5.6). If one sample fails, agreement shall be reached between the manufacturer and the purchaser regarding any further tests.



IEC 218/04

Figure 4 – Thermal stability test on 10 000 A line discharge Class 1, 5 000 A, 2 500 A and 1 500 A arresters



IEC 219/04

Figure 5 – Thermal stability test on 10 000 A arresters line discharge Classes 2 and 3 and 20 000 A arresters line discharge Classes 4 and 5

10 Test requirements on polymer-housed surge arresters

10.1 Scope

See Clause 1.

10.2 Normative references

See Clause 2.

10.3 Terms and definitions

See Clause 3

10.4 Identification and classification

See Clause 4.

10.5 Standard ratings and service conditions

See Clause 5.

10.6 Requirements

The requirements of Clause 6 apply except for the following:

6.1 Insulation withstand of the arrester housing – modified by 10.8.2.

6.8 Long-duration current impulse withstand – modified by 10.8.4.

6.9 Operating duty – modified by 10.8.5.

Additional requirements are imposed for moisture ingress (see 10.8.13) and weather ageing (see 10.8.14)

10.7 General testing procedure

See Clause 7.

10.8 Type tests (design tests)

10.8.1 General

Type tests defined in Clause 8 shall be performed, except as indicated below:

1) Insulation withstand tests on the arrester housing – see 10.8.2.
3) Long-duration current impulse withstand test – see 10.8.4.
4) Operating duty tests – see 10.8.5.
6) Tests of arrester disconnectors/fault indicators – see 10.8.6.
7) Artificial pollution tests of Annex F do not apply.

In addition, the following tests are to be made

13) Moisture ingress test (see 10.8.13)

    This test demonstrates the ability of the arrester to resist ingress of moisture after being subjected to specified mechanical stresses.

14) Weather ageing test (see 10.8.14)

    This test demonstrates the ability of the arrester to withstand specified climatic conditions.

NOTE This test does not apply to polymer-housed arresters intended for indoor use only.

10.8.2 Insulation withstand tests on the arrester housing

Subclause 8.2 applies, except as follows:

10.8.2.2 Tests on individual electrical section

This subclause replaces 8.2.2.

The applicable tests shall be run on the longest electrical section. If this does not represent the highest specific voltage stress per unit length, additional tests shall be performed on the electrical section having the highest specific voltage stress. The internal parts may be replaced by an equivalent arrangement (for example, grading elements) to provide linear voltage distribution along the arrester axis.

In design cases where the external insulation is moulded directly onto the resistors or some insulating material substrate, these tests may be performed with the housing moulded on to a suitable insulating substrate.

10.8.3 Residual voltage tests

Subclause 8.3 applies without modification.

10.8.4 Long-duration current impulse withstand test

Subclause 8.4 applies, except as follows:

10.8.4.1 General

This subclause replaces 8.4.1.

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 7.3 and 8.1 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 °C ± 15 K 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/fault indicator is built into the design of the arrester under consideration, these tests shall be made with the disconnector/fault indicator in operable condition (see 8.6).

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 %.

If the manufacturer declares that the resistors may be removed from the test sample, 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. In the other cases, visual inspection applies only to external parts. To check the integrity of the internal parts, an additional long-duration current impulse shall be performed after the sample has cooled down to ambient temperature to verify that no damage occurred. If the sample has withstood this 19th long-duration current impulse with no damage (checked by the oscillographic records), then the sample has passed the test.

10.8.5 Operating duty tests

Subclause 8.5 applies, except as follows:

10.8.5.3.2 Arrester section requirements

This subclause replaces 8.5.3.2.

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 modelled.

b) The housing shall meet the following requirements:
   1) the material shall be the same as that of the arrester housing;
   2) the inside diameter shall be the same as that of the arrester ±5 %;
   3) 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.
   4) the housing shall be long enough to enclose the arrester section.
   5) the internal arrangement shall be the same as that of the complete arrester. This means that the section should represent a slice of the surge arrester;
   6) insulation may be added at the end and, if necessary, around the housing to meet the thermal requirement of Annex B.

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

10.8.5.4.1 Conditioning

This subclause replaces 8.5.4.1.

The samples are exposed to a conditioning test consisting of 20 8/20 lightning current impulses according to 3.17 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 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 60 ± 15 electrical degrees before the peak of the power frequency voltage.

If the resistors are not in direct contact with a solid material, the conditioning test can be performed in the open air. In the other cases, this conditioning test shall be carried out on the section at a still air temperature of 20 °C ± 15 K.

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).

10.8.5.4.2 Application of impulses

This subclause replaces 8.5.4.2.

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

The section is subjected to two high current impulses with peak value and impulse shape as specified in Table 8. High lightning duty arresters specified in Annex C are subjected to three 30/80 impulses with a peak value of 40 kA.

Table 8 – 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 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 °C ± 3 K. The tests shall be carried out at an ambient temperature of 20 °C ± 15 K.

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 8.5.2) 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 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 8.5.6.

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 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.

After this conditioning test, the resistors are stored for future use in the operating duty tests (see Figures 1 and C.1).

If the manufacturer declares that the resistors may be removed from the test sample, a visual examination of the resistors shall be made to verify that the test has not caused puncture, flashover or cracking of the resistors. Otherwise, additional tests shall be performed to be sure that no damage occurred during the test as follows.

– Before the tests, the residual voltage at the nominal discharge current I_n is measured on the samples.
– After the tests, two impulses at I_n are applied on the sample. The first impulse is applied after sufficient time to allow the cooling of the sample to ambient temperature. The second impulse is applied between 50 s to 60 s after the first one.
– During the two impulses, the oscillograms of both voltage and current should not reveal any breakdown. The variation of the residual voltage between the initial measurement and the last impulse should not be greater than 5 %.

10.8.5.5.1 Conditioning

This subclause replaces 8.5.5.1

The samples are exposed to a conditioning test the first part of which consists of 20 8/20 current impulses according to 3.17 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 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 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.

If the resistors are not in direct contact with a solid material, the conditioning test can be performed in the open air. In other cases, this conditioning test shall be carried out on the section at a still air temperature of 20 °C ± 15 K.

The second part of the conditioning is the application of two high current impulses 100 kA 4/10 (see 3.31). 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.

10.8.5.5.2 Application of impulses

This subclause replaces 8.5.5.2.

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 °C ± 3 K at the ambient temperature of 20 °C ± 15 K.

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 Table 5 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 8.5.2, 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.

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 (see 8.5.6), if the change in residual voltage measured before and after the test is not more than 5 %. Also, if the manufacturer declares that the resistors may be removed from the test sample, visual examination of the test samples after the test reveals no evidence of puncture, flashover or cracking of the non-linear metal-oxide resistors. In other cases, visual inspection applies only to external parts. To check the integrity of the internal parts, an additional long-duration current impulse shall be performed after the sample has cooled to ambient temperature to be sure that no damage occurred. If the sample has withstood this third long-duration current impulse with no damage, checked by the oscillographic records, then the sample has passed the test.

10.8.6 Tests of arrester disconnectors and fault indicators

Subclause 8.6 applies without modification.

10.8.7 Short-circuit tests

Subclause 8.7 applies without modification.

10.8.8 Internal partial discharge tests

Subclause 8.8 applies without modification.

10.8.9 Test of the bending moment

10.8.9.1 General

This test demonstrates the ability of the arrester to withstand the manufacturer's declared values for bending loads. Normally, an arrester is not designed for torsional loading. If an arrester is subjected to torsional loads, a specific test may be necessary by agreement between manufacturer and user.

The test is applicable to all surge arresters designated with a line discharge class and which are base-mounted. These arresters consist of one or several units. They are applied up to the highest system voltages.

The test shall be performed on complete arresters or arrester units. The test samples shall be mounted in the upright position. They shall be attached to the mounting surface of the testing machine by their normal method of mounting. The load shall be applied to the free end of the arrester. The direction of the load shall pass through the longitudinal axis of the arrester and shall be perpendicular to it in the direction of the lowest mechanical strength (initial arrester position: longitudinal axis in the vertical direction). The manufacturer shall give information concerning the lowest mechanical strength.

Where an arrester contains more than one unit or where the arrester has different specified bending moments in both ends, tests shall be performed to evaluate each different specified bending moment with loads determined according to Clause M.1.

For arresters with polymer (except cast resin) housing, the test load shall be the maximum permissible service load (MPSL), i.e. the 100 % value of Clause M.3.

The tests shall be carried out without internal pressure.

NOTE Polymer-housed arresters are additionally subjected to the moisture ingress test (see 10.8.13), where the maximum continuous cantilever load is applied in different directions and under different temperatures.

10.8.9.2 Polymer-housed arresters with enclosed gas volume and a separate sealing system

10.8.9.2.1 Sample preparation

The test samples shall contain the internal parts.

Prior to the tests, each test sample shall be subjected to the following tests:

– electrical tests of 10.8.13.1;
– leakage check in accordance with item d) of 9.1.

10.8.9.2.2 Test procedure

The bending load shall be increased smoothly to the test load within 30 s to 90 s. When the test load is reached, it shall be maintained for 60 s to 90 s. During this time, the deflection shall be measured. Then the load shall be released smoothly and the residual deflection shall be recorded.

NOTE Care should be taken because the housing of an arrester can break and splinter while tension is applied.

10.8.9.2.3 Test evaluation

The arrester shall be considered satisfactory if the following is demonstrated:

– no visible mechanical damage;

– a force-deflection curve without discontinuity;

– the strain condition of the housing after removal of the bending load is within ±5 % of the strain condition before the application of the bending load;

NOTE The value of ±5 % is given for guidance and is still under consideration. Reversibility depends on the weakest load-carrying material. If strain gauges are used, even if the ±5 % value is fulfilled, there might be cracks not affecting the surfaces where strain gauges are fastened (for example, inner laminar cracks).

– a successful leakage check in accordance with item d) of 9.1.

The test sample shall then be subjected to the water immersion test (see 10.8.13.3). It shall be considered satisfactory if the following is then successfully demonstrated:

– electrical tests of 10.8.13.4.

10.8.9.3 Polymer housed arresters without enclosed gas volume

10.8.9.3.1 Sample preparation

The test samples shall contain the internal parts.

Prior to testing, each test sample shall be subjected to the electrical tests of 10.8.13.1.

10.8.9.3.2 Test procedure

The bending load shall be increased smoothly to the test load within 30 s to 90 s. When the test load is reached, it shall be maintained for 60 s to 90 s. During this time, the deflection shall be measured. Then the load shall be released smoothly and the residual deflection shall be recorded.

NOTE Care should be taken because the housing of an arrester can break and splinter while tension is applied.

10.8.9.3.3 Test evaluation

The arrester shall be considered satisfactory if the following is demonstrated:

– no visible mechanical damage;

– a force-deflection curve without discontinuity;

– the strain condition of the housing after removal of the bending load is within ±5 % of the strain condition before the application of the bending load;

NOTE The value of ±5 % is given for guidance and is still under consideration. Reversibility depends on the weakest load carrying material. If strain gauges are used, even if the ±5 % value is fulfilled, there might be cracks not effecting the surfaces where strain gauges are fastened (e.g. inner laminar cracks).

The test sample shall then be subjected to the water immersion test (see 10.8.13.3) . It shall be considered satisfactory if the following is then successfully demonstrated:

– electrical tests of 10.8.13.4.

10.8.10 Environmental tests

Subclause 8.10 applies, except as follows:

10.8.10.2 Sample preparation

This subclause replaces 8.10.2.

Prior to the tests, the test sample shall be subjected to the internal partial discharge test of item c) of 9.1. If the arrester has enclosed gas volume, the leakage check of item d) of 9.1 shall also be performed.

10.8.10.3.1 Temperature cycling test

This subclause replaces 8.10.3.1.

This test does not apply to polymer arresters.

10.8.10.3.4 Test evaluation

This subclause replaces 8.10.3.4.

The measurements performed before the test shall be repeated. The arrester shall be considered satisfactory if the results demonstrate the following:

– no visible mechanical damage;
– internal partial discharge level not exceeding the value specified in item c) of 9.1;
– a successful leakage check according to item d) of 9.1 (only for arresters with enclosed gas volume and a separable sealing system).

10.8.11 Seal leak rate test

Subclause 8.11 applies, except as follows:

10.8.11.1 General

This subclause replaces 8.11.1.

This test demonstrates the gas/watertightness of the complete system. It applies to arresters with polymer housings having seals and associated components essential for maintaining a controlled atmosphere within the housing (arresters with enclosed gas volume and a separate sealing system).

NOTE The resistance of the various interfaces of polymer-housed arresters against moisture ingress are tested in the moisture ingress test (see 10.8.13).

The test shall be performed on one complete arrester unit. The internal parts may be omitted. If the arrester contains units with differences in their sealing system, the test shall be performed on one unit each, representing each different sealing system.

10.8.12 Radio interference voltage (RIV) test

Subclause 8.12 applies without modification.

10.8.13 Moisture ingress test

In general, the sample under test should be the longest mechanical unit. If the length of the longest mechanical unit is greater than 800 mm, a shorter length section may be tested, provided it is not less than three times the outside diameter of the housing at the bottom flange excluding the sheds or 800 mm long, whichever is greater.

NOTE 1 For non-circular profiles, an equivalent diameter should be defined.

NOTE 2 This value of three times the outside diameter of the housing at the bottom flange is under consideration.

The same sample of arrester is submitted to the various mechanical and climatic stresses described in 10.8.13.2 to 10.8.13.4.

10.8.13.1 Initial measurements

Before tests, the following measurements shall be made in the following sequence:

– watt losses measured at a value in the range between 80 % to 100 % of U_c and at an ambient temperature of 20 °C ± 15 K;
– internal partial discharge according to 8.8;
– residual voltage at the nominal discharge current or a lower value in accordance with the acceptance test.

10.8.13.2 Preconditioning

10.8.13.2.1 Terminal torque preconditioning

The arrester terminal torque specified by the manufacturer shall be applied to the test sample for a duration of 30 s.

10.8.13.2.2 Thermomechanical preconditioning

The arrester is then submitted to the maximum continuous cantilever load specified by the manufacturer in four directions and in thermal variations as described in Figures 6 and 7.

NOTE If, in particular applications, other loads are dominant, the relevant loads should be applied instead. The total test time and temperature cycle should remain unchanged.

If the sample has no cylindrical symmetry, the load direction shall be chosen in such a manner as to achieve the maximum mechanical stress.

The thermal variations consist of two 48 h cycles of heating and cooling as described in Figure 6. The temperature of the hot and cold periods shall be maintained for at least 16 h. The tests shall be conducted in air.

The continuous static mechanical load corresponds to the maximum continuous bending moment defined by the manufacturer. Its direction changes every 24 h as defined in Figure 7.

The test may be interrupted for maintenance for a total duration of 4 h and restarted after interruption. The cycle then remains valid.

Any permanent deformation measured from the initial no-load position shall be reported.

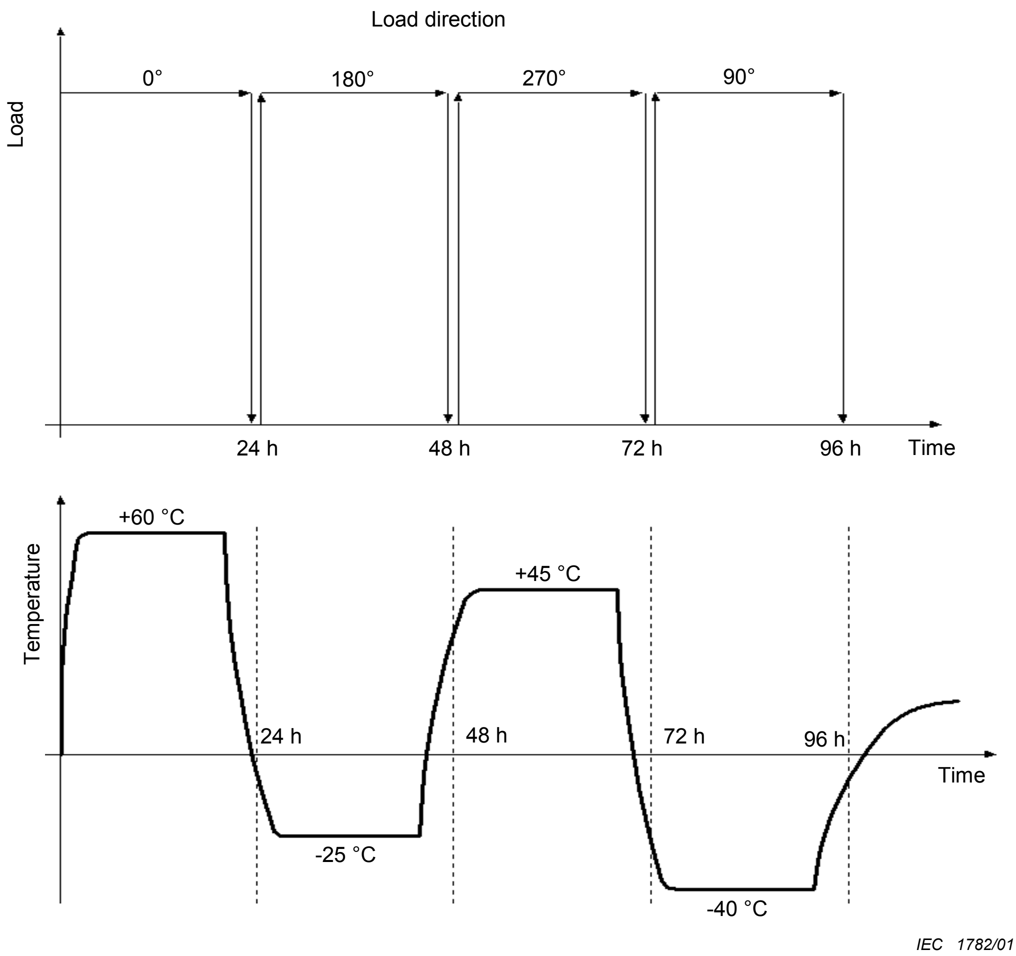


Figure 6 – Thermomechanical test

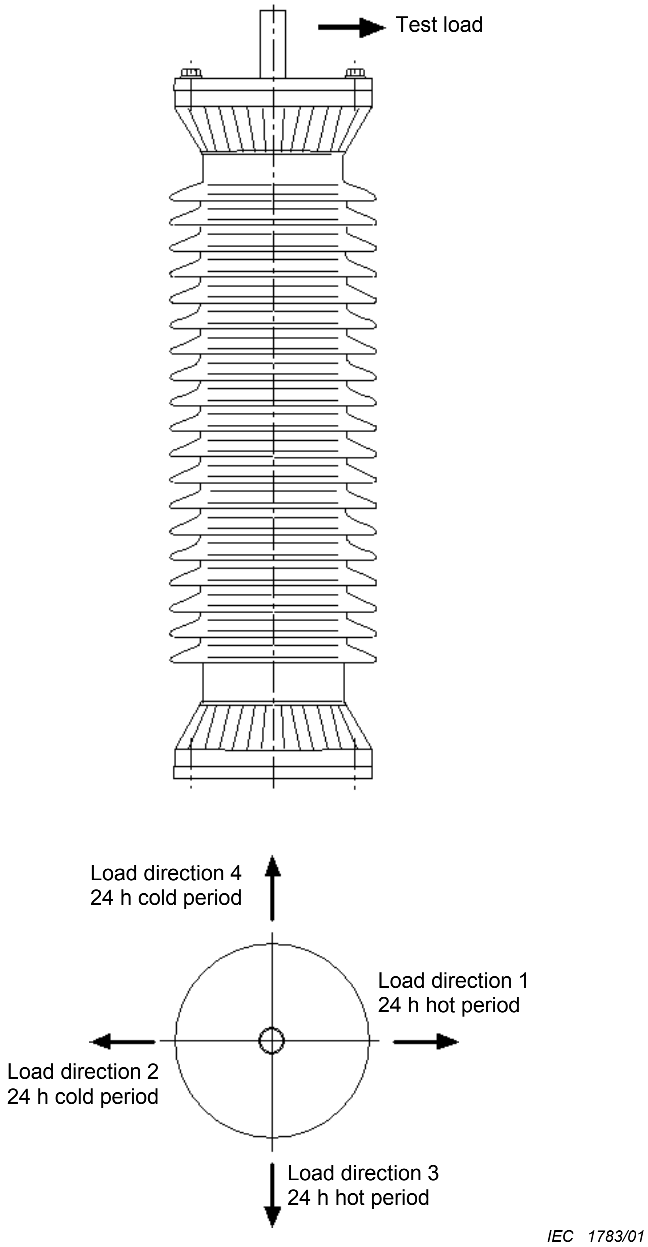


Figure 7 – Example of the test arrangement for the thermomechanical test and direction of the cantilever load

10.8.13.3 Water immersion test

The arrester shall be kept immersed in a vessel, in boiling deionized water with 1 kg/m^3 of NaCl, for 42 h.

NOTE 1 The characteristics of the water described above are those measured at the beginning of the test.

NOTE 2 This temperature (boiling water) can be reduced to 80 °C (with a minimum duration of 52 h) by agreement between the user and the manufacturer, if the manufacturer claims that its sealing material is not able to withstand the boiling temperature for a duration of 42 h. This value of 52 h can be expanded up to 168 h (i.e. one week) after agreement between the manufacturer and the user.

At the end of the boiling, the arrester shall remain in the vessel until the water cools to approximately 50 °C and shall be maintained at this temperature until verification tests are performed in the following sequence. These verification tests are performed on samples having cooled to ambient temperature. The 50 °C holding temperature is necessary only if it is necessary to delay the verification tests until after the end of the water immersion test as shown in Figure 8.

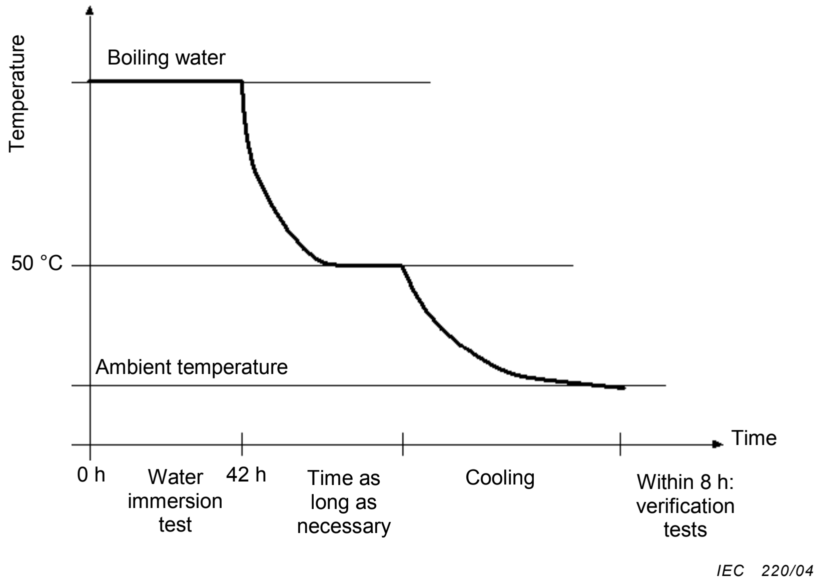


Figure 8 – Water immersion

10.8.13.4 Verification tests

All verification tests shall be completed within 8 h in the following sequence:

– visual inspection: any mechanical change should be reported;
– watt losses measured at the same voltage as the one used in 10.8.13.1: the increase from the initial measurement shall be less than 20 %.

The measurement of the watt losses shall be performed at an ambient temperature that does not deviate by more than 3 K from the initial measurements:

– partial discharge measurement: the value shall not exceed 10 pC at 1,05 times U_c;
– residual voltage at the same discharge current as the one used in 10.8.13.1: the deviation from the initial measurement shall not exceed 5 % and in addition the oscillograms of both voltage and current should not reveal any breakdown.

NOTE Alternative tests are under consideration.

10.8.14 Weather ageing test

10.8.14.1 Test specimens

This test has a duration of 1 000 h under salt fog conditions according to test series A described below. In case of severe environmental conditions (intense solar radiation, frequent temperature inversion with condensation, heavy or very heavy pollution as defined by IEC 60815) and after agreement between the manufacturer and the user, a test with a duration of 5 000 h according to test series B may be performed in addition.

Test series A:

A 1 000 h test (see 10.8.14.2.1) shall be performed. This shall be performed on the longest electrical unit with the minimum specific creepage distance and the highest rated voltage recommended by the manufacturer for this unit.

Test series B:

A 5 000 h test (see 10.8.14.2.2) is performed after agreement between the user and the manufacturer. If the arrester U_c is greater than 14 kV, the 5 000 h test may be performed on any pro-rated sample with the minimum specific creepage distance and the highest rated voltage recommended by the manufacturer, provided that the U_c of the sample is not less than 14 kV. If the arrester U_c is equal to, or less than, 14 kV, the 5 000 h test shall be performed on the complete arrester.

If the test is performed on the longest electrical unit with the minimum specific creepage distance and the highest rated voltage, test series A may be omitted after agreement between the user and the manufacturer.

The test samples shall be representative of the most critical design relevant for a given arrester type.

NOTE Criteria for the comparison of different types of arrester are under consideration.

10.8.14.2 Test procedure

10.8.14.2.1 Test series A: 1 000 h

The test is a time-limited continuous test under salt fog at constant power-frequency voltage equal to U_c. The test is carried out in a moisture-sealed corrosion-proof chamber. An aperture of not more than 80 cm^2 shall be provided for the natural evacuation of exhaust air. A turbo sprayer or room humidifier of constant spraying capacity shall be used as a water atomizer.

The fog shall fill up the chamber and not be directly sprayed onto the test specimen. The salt water prepared with NaCl and deionized water will be supplied to the sprayer. The power-frequency test voltage shall be obtained with a test transformer. The test circuit, when loaded with a resistive current of 250 mA (r.m.s.) on the high-voltage side, shall experience a maximum voltage drop of 5 %.

The protection level shall be set at 1 A (r.m.s.). The test specimen shall be cleaned with deionized water before starting the test.

The test specimen shall be tested when mounted vertically. There shall be enough clearance between the roof and walls of the chamber and the test specimen in order to avoid electrical field disturbance. These data shall be found in the manufacturer’s installation instructions.

Duration of the test	1 000 h
Water flow rate	0,4 $l/h/m^3$ ± 0,1 $l/h/m^3$
Size of droplets	5 μm to 10 μm
Temperature	20 °C ± 5 K
NaCl content of water	between 1 kg/m^3 to 10 kg/m^3

The manufacturer shall state the starting value of the salt content of the water. The water flow rate is defined in litres per hour per cubic metre of the test chamber. It is not permitted to recirculate the water. Interruptions due to flashovers are permitted. If more than one flashover occurs, the test voltage is interrupted. However, the salt fog application shall continue until the washing of the arrester with tap water is started. Interruptions of salt fog application shall not exceed 15 min. The test shall then be re-started at a lower value of the salt content of the water. If again more than one flashover occurs, this procedure shall be repeated. Interruption times shall not be counted as part of the test duration.

The NaCl content of the water, the number of flashovers and the duration of the interruptions shall be noted.

NOTE 1 Within this range of salinity, lower salt content may increase test severity. Higher salt content increases flashover probability, which makes it difficult to run the test on larger diameter housings.

NOTE 2 The number of overcurrent trip-outs should be noted and taken into account in the evaluation of the duration of the test.

10.8.14.2.2 Test series B: 5 000 h

This test consists of applying, in addition to U_c, various stresses in a cyclic manner:

– solar radiation simulation;
– artificial rain;
– dry heat;
– damp heat (near saturation);
– high dampness at room temperature (saturation shall be obtained);
– salt fog at low concentration.

Furthermore, temperature variations may cause some degree of mechanical stress, especially at the level of insulator interfaces and also give rise to condensation phenomena, which are repeated several times in the course of a cycle.

The power-frequency test voltage shall be obtained with a test transformer. The test circuit, when loaded with a resistive current of 250 mA (r.m.s.) on the high-voltage side, shall experience a maximum voltage drop of 5 %.

The protection level shall be set at 1 A (r.m.s.).

A cycle example including all these stresses is shown in Figure 9 and is described below.

– Each cycle lasts 24 h and a programme change takes place every 2 h.
– During the time when the humidification and heating are not in operation, the arresters are submitted to room temperature (15 °C to 25 °C) and relative humidity (30 % to 60 %).
– The rise from ambient temperature to 50 °C shall take less than 15 min.
– The humidification shall take less than 15 min to reach a relative humidity of 95 % and less than another 10 min to reach the required value of at least 98 %.
– Saturation, which causes the samples to drip, is obtained by a natural cooling of the test room after a sequence with 50 °C and 98 % relative humidity. The fan shall be stopped for this operation. The time to return to ambient temperature is approximately 2 h.
– The rain and salt fog are in accordance with IEC 61109.

– The solar radiation simulation is obtained with a xenon arc lamp giving about 90 mW/cm^2 on the housing. A filter system makes it possible to approximately reproduce the power and the solar spectrum received in a moderate climatic area at noon on a summer's day.

NOTE 1 The surface of the housing to be taken into account is obtained by taking the equivalent diameter as described in IEC 60815 and the length of the housing.

– A duration of 5 000 h is required for the whole test.

Another example is proposed as shown in Figure 10.

This cycle is, in principle, identical with the following distinctions.

– A salinity value of 40 kg/m^3 is adopted during the salt fog period, the fog shall not be sprayed direct onto the specimen. The water flow is between 0,1 l/h/m^3 and 0,15 l/h/m^3.

– The weekly total time of application of each ambient stress is nearly the same, but each type of stress is concentrated in only one period per day, in order to limit the interventions in the test chamber.

– The UV radiation is applied continuously during a single period of about 48 h every weekend.

– Heating is obtained by the same lamps providing the UV radiation. The lamps are chosen and positioned in such a way that they obtain the required radiation power on the surface of the surge arrester housing, without exceeding a surface temperature of 60 °C.

NOTE 2 Applicable to test series A and B: for surge arresters intended for installation in systems for which very high continuous operating voltage is required during shorter periods, the test voltage may be reduced to 1,05 × $U_m/\sqrt{3}$ by agreement between manufacturer and user, where U_m is the highest voltage of equipment.

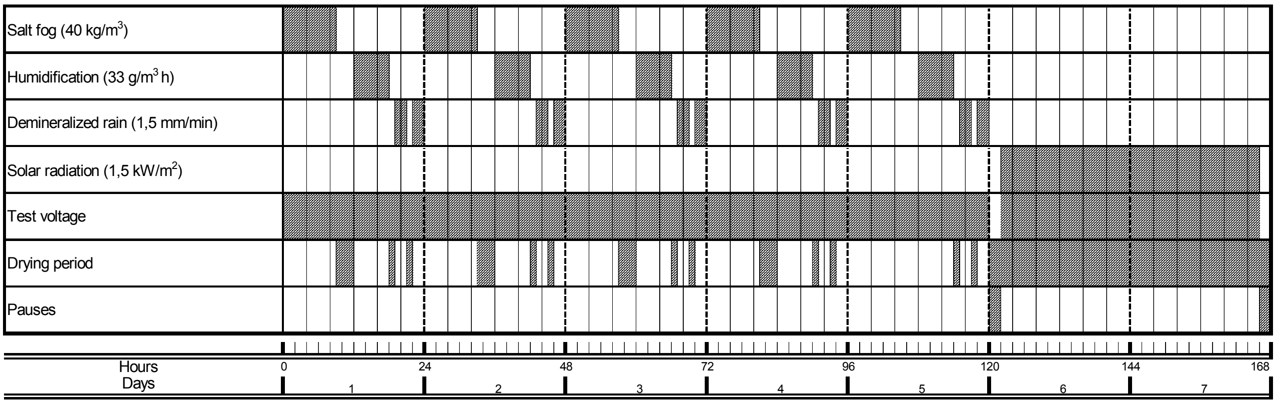
NOTE 3 Applicable to test series B, cycle according to Figure 10: if U_c of the test sample is greater than 14 kV, and if electrical clearance prevents voltage from being applied during UV radiation, it is acceptable to de-energize the sample during the application of UV radiation.

Time (h)	2	4	6	8	10	12	14	16	18	20	22	24
Test voltage	■	■	■	■	■	■	■	■	■	■	■	■
Demineralized rain	■											
Heating (50 °C)		■	■				■	■				■
Relative humidity (95 %)			■					■				
Salt fog (7 kg/m^3)				■	■				■	■		
Solar radiation (UV)	■	■				■	■				■	■

■ In operation □ Out of operation

IEC 1785/01

Figure 9 – Example of an accelerated weather ageing cycle under operating voltage
(according to IEC 61109)



IEC 1786/01

Figure 10 – Another example of an accelerated weather ageing cycle

10.8.14.3 Evaluation of the test

The test is regarded as passed, if no tracking occurs (see IEC 61109), if erosion does not occur through the entire thickness of the external coating up to the next layer of material, if the sheds and housing are not punctured, if the reference voltage measured before and after the test has not decreased by more than 5 %, and if the partial discharge measurement performed before and after the test is satisfactory, i.e. the partial discharge level shall not exceed 10 pC according to 8.8.

11 Test requirements on gas-insulated metal enclosed arresters (GIS-arresters)

11.1 Scope

See Clause 1.

11.2 Normative references

See Clause 2.

11.3 Terms and definitions

See Clause 3.

11.4 Identification and classification

Subclause 4.1 applies with the following addition:

– rated gas pressure for insulation at 20 °C.

11.5 Standard ratings and service conditions

See Clause 5.

11.6 Requirements

The requirements of Clause 6 apply except for the following:

6.1 Insulation withstand of the arrester housing – replaced by 11.6.1
6.5 Seal leak rate test – does not apply
6.9 Operating duty – modified by 11.8.5
6.11 Short circuit – replaced by 11.6.11
6.12 Disconnector/fault indicators – does not apply
6.13 Mechanical load – does not apply

11.6.1 Withstand voltages

This subclause replaces 6.1.

a) Single-phase arrester

The insulation between the internal parts and the metal housing shall withstand the following voltages when tested according to 11.8.2.

– The lightning impulse withstand voltage of the equipment to be protected or the lightning impulse protection level of the arrester multiplied by 1,3 whichever is lower.

  NOTE 1 The 1,3 factor covers discharge currents higher than nominal. Variations in atmospheric conditions, as given for porcelain-housed arresters, are not relevant for GIS-arresters. Nevertheless, the factor of 1,3 is retained to provide additional security.

– For 10 000 A and 20 000 A arresters with rated voltages of 200 kV and above, the switching impulse withstand voltage of the equipment to be protected or the switching impulse protection level of the arrester multiplied by 1,25, whichever is lower.

  NOTE 2 The 1,25 factor covers discharge currents higher than the maximum values of Table 4. Variations in atmospheric conditions, as given for porcelain-housed arresters, are not relevant for GIS-arresters. Nevertheless, the factor 1,25 is retained to provide additional security.

– For 10 000 A and 20 000 A arresters with rated voltages of less than 200 kV, the power-frequency withstand voltage of the equipment to be protected or a power-frequency voltage with a peak value equal to the switching impulse protection level multiplied by 1,2 for a duration of 1 min, whichever is lower.

– For 1 500 A, 2 500 A and 5 000 A arresters, a power-frequency withstand voltage of the equipment to be protected or a power-frequency voltage with a peak value equal to the lightning impulse protection level for a duration of 1 min, whichever is lower.

b) Three-phase arrester

The withstand voltage for the insulation of three-phase arresters is given in Tables 9 and 10.

11.6.11 Requirements for the enclosures of GIS-arresters

This subclause replaces 6.11.

The design of the metallic enclosures of GIS-arresters shall meet the requirements of 5.103 of IEC 62271-203 or 5.102 of IEC 62271-200.

If the arrester has a separate internal enclosure with a pressure-relief device different from that of the metallic vessel, 8.7 applies. In this case, it is necessary that a test be performed only with the rated short-circuit current.

11.7 General testing procedures

See Clause 7.

11.8 Type tests (design tests)

11.8.1 General

Type tests defined in Clause 8 shall be performed, except as indicated below.

1) Insulation withstand tests on the arrester housing – see 11.8.2.

4) Operating duty tests – see 11.8.5.

6) Tests of arrester disconnectors/fault indicators – does not apply.

7) Artificial pollution tests of Annex F – does not apply.

9) Bending moment test – does not apply.

10) Environmental test – does not apply.

11) Seal leak rate test – does not apply.

11.8.2 Insulation withstand tests

This subclause replaces 8.2

11.8.2.1 General

These tests demonstrate the ability of the insulation to withstand the required voltage stresses between the internal parts and the metal housing and, in addition, between the phases for a three-phase arrester.

The insulation withstand tests shall also assure that all internal components are tested at least to the equivalent of the highest stresses in service. A separate test of single components may therefore be necessary to verify the required withstand voltage (see 11.8.2.5).

For single-phase arresters, the test shall be performed on the complete arrester with the metal oxide resistors replaced by insulating parts. Grading elements may be used instead of insulating parts in order to control the voltage distribution along the arrester axis.

In the case of a three-phase arrester, the phase(s) not energized during the test shall be connected to earth. For active parts connected to a voltage source, the metal oxide resistors shall be replaced by insulating parts. Grading elements may be used instead of insulating parts in order to control the voltage distribution along the arrester axis.

NOTE Due to the strong influence of earth capacitances in GIS arresters, it may be difficult or even impossible to achieve a linear voltage distribution by grading elements. Performing the test with an uneven voltage distribution or without any grading elements represents the worst case, and test results remain conservative.

During the tests, the insulating gas shall have the minimum functional density specified for the arrester.

Subclauses 8.2.4 and 8.2.5 are not applicable for GIS-arresters.

11.8.2.2 Lightning impulse voltage test

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

a) Single-phase arresters

The test voltage shall be as specified in 11.6.1.

Fifteen consecutive impulses at the test voltage value shall be applied for each polarity. The arrester has passed the test if no disruptive discharges occur. In the case of disruptive discharges, the pass criteria in IEC 62271-203 and IEC 62271-200 shall be observed.

b) Three-phase arrester

The test voltage shall be as specified in 11.6.1.

The test shall start with the phase-to-earth insulation test. The test voltage is applied to one phase, while the other phases are connected to earth.

After the phase-to-earth insulation test, the phase-to-phase insulation test shall be performed. This test can be made using only an impulse voltage or an impulse voltage and a power frequency voltage. The choice is made by the manufacturer.

If the test is made using only an impulse voltage, the same test arrangement as used for the phase-to-earth test shall be used.

If the test is made using an impulse voltage and a power-frequency voltage, only one phase is connected to earth. The impulse voltage is applied to the second phase, while the power-frequency voltage is applied to the third phase in such a way that, during application of the impulse voltage to the second phase, the power-frequency voltage reaches its peak value of the opposite polarity.

The phase-to-earth test and the phase-to-phase test shall be repeated for all possible combinations of the three active parts, unless proved unnecessary by considerations of electrical symmetry.

In both tests, 15 consecutive impulses at the test voltage value shall be applied for each polarity. The arrester has passed the test if no disruptive discharges occur. In the case of disruptive discharges, the pass criteria in IEC 62271-203 and IEC 62271-200 shall be observed.

11.8.2.3 Switching impulse voltage test

The arresters shall be subjected to a standard switching impulse voltage according to IEC 60060-1.

a) Single-phase arresters

The test voltage shall be as specified in 11.6.1.

Fifteen consecutive impulses at the test voltage value shall be applied for each polarity. The arrester has passed the test if no disruptive discharges occur. In case of disruptive discharges, the pass criteria in IEC 62271-203 and IEC 62271-200 shall be observed.

b) Three-phase arresters

The test voltage shall be as specified in 11.6.1.

The tests shall start with the phase-to-earth insulation test. The test voltage is applied to one phase, while the other two phases are connected to earth.

After this test, the phase-to-phase insulation test may be performed, without changing the test arrangement, by increasing the test voltage to the required level.

If flashovers occur or are expected, one of the following two test alternatives shall be adopted. The choice is made by the manufacturer:

– One phase of the arrester is earthed. Two switching impulses of equal amplitude and opposite polarity shall be applied to the two other phases. The impulses shall reach their crests at the same instant. The amplitude of each impulse shall be half the required switching impulse withstand voltage phase-to-phase (phase-to-phase test according to IEC 60071-1).
– One phase of the arrester is earthed. A switching impulse equal to the required value phase-to-earth is applied to the second phase. A power-frequency voltage is applied to the third phase such that the crest of the switching impulse is reached at the power-frequency voltage peak of opposite polarity. The difference between the voltages at the instant of the switching impulse crest shall be equal to the required switching impulse withstand voltage phase-to-phase (longitudinal insulation test according to IEC 60071-1).

The phase-to-earth test and the phase-to-phase test shall be repeated for all possible combinations of three active parts, unless proved unnecessary by considerations of electrical symmetry.

In both tests, 15 consecutive impulses at the test voltage value shall be applied for each polarity. The arrester has passed the test if no disruptive discharge occurs. In case of disruptive discharges, the pass criteria in IEC 62271-203 and IEC 62271-200 shall be observed.

11.8.2.4 Power-frequency voltage test

a) Single-phase arresters

The test voltage shall be as specified in 11.6.1.

The arrester has passed the test if no disruptive discharge occurs.

b) Three-phase arresters

The test voltage shall be as specified in 11.6.1.

The tests shall start with the phase-to-earth insulation test. The test voltage is applied to one phase, while the other phases are connected to earth.

After the phase-to-earth insulation test, the phase-to-phase insulation test shall be performed. If this test is made using only a power-frequency voltage, the same test arrangement shall be taken. The applied voltage shall be raised to the required phase-to-phase value.

The arrester has passed the test if no disruptive discharge occurs.

Alternatively, the following test procedure may be adopted. One phase of the arrester is connected to earth. The impulse voltage equal to 1,2 times the switching impulse protection level is applied to the second phase, while the power-frequency voltage equal to U_c is applied to the third phase. This is done in such a way that, during application of the impulse voltage to the second phase, the power-frequency voltage reaches its peak value of the opposite polarity.

The phase-to-earth test and the phase-to-phase test shall be repeated for all possible combinations of the three active parts, unless proved unnecessary by considerations of electrical symmetry.

Fifteen consecutive impulses at the test voltage shall be applied to each polarity. The arrester has passed the test if no disruptive discharge occurs. In case of disruptive discharges, the pass criteria in IEC 62271-203 and IEC 62271-200 shall be observed.

11.8.2.5 Withstand test on the active part of GIS-arresters

For a GIS-arrester with an active part containing the resistor elements electrically connected in series but geometrically arranged in parallel by using insulating material, the voltage withstand capability of the insulating material, the resistance of the supporting structure and the insulation between the resistor columns shall be tested.

The test shall be performed in such a way that all possible voltage stresses mentioned above are taken into consideration.

During the test, the samples may be surrounded by the actual gas of a density corresponding to the minimum density specified for the complete arrester.

11.8.3 Residual voltage tests

Subclause 8.3 applies without modification.

11.8.4 Long duration current impulse withstand test

Subclause 8.4 applies without modification.

11.8.5 Operating duty tests

Subclause 8.5 applies, except as follows:

11.8.5.1 General

This subclause replaces 8.5.1.

As explained in 6.9 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 shall be measured with an accuracy of ±1 % and its peak value shall not 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 8.5.3).

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 7.2, 7.3 and 8.1 at an ambient temperature of 20 °C ± 15 K. 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/fault indicator is built into the design of the arrester under consideration, these tests shall be made with the disconnector/fault indicator in operable condition (see 8.6).

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 8.5.2.2.

The power-frequency test voltages to be applied to the test arrester section shall be the continuous operating (see 3.9) and rated (see 3.8) voltages of the complete arrester divided by the total number of similar arrester sections n (see 7.3). These voltages, U_{sc} equal to U_c/n and U_{sr} equal to U_r/n, are modified according to 8.5.2.2 to establish the elevated test voltages U_c^* and U_r^*.

NOTE The established preheat temperature of 60 °C ± 3 K 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.

The voltage unbalance effects between varistors of the arresters shall be demonstrated by voltage distribution measurements or computations made at voltages not higher than the continuous operating voltage of the arresters. A performed calculation or measurement is valid for the considered rated voltage ±25 %.

To verify thermal equivalency between a complete arrester and an arrester section, a test according to Annex B is necessary.

The arrester section shall only represent the thermal behaviour of the complete arrester. It is not needed to meet the requirements of item b) of 8.5.3.2, and the active part of the section need not contain the elements of the supporting structure.

The operating duty test on this arrester section is valid for a single-phase arrester as well as for a three-phase arrester.

11.8.6 Tests of arrester disconnectors/fault indicators

Subclause 8.6 does not apply.

11.8.7 Short-circuit tests

Subclause 8.7 applies; depending upon the arrester type, see 11.6.11.

11.8.8 Internal partial discharge tests

Subclause 8.8 applies without modification.

11.9 Routine tests

The routine tests on GIS-arresters shall be carried out according to 9.1.

The reference voltage shall be measured on the complete arrester or on the active parts of the arrester.

The partial discharge test shall be performed on the complete arrester or on the active parts of the arrester and on the arrester housing, including supporting structure and grading elements.

11.10 Test after erection on site

If the arrester is delivered incompletely assembled to the site, it shall be checked for correct mounting by any appropriate method adopted by the manufacturer.

If the insulating capacity of gas-insulated switchgear equipped with arresters is to be tested with impulse or power-frequency voltages, the arresters shall be removed or rendered inoperative to permit these tests.

Table 9 – 10 000 A and 20 000 A three–phase GIS–arresters – Required withstand voltages

Voltage kV	Type of withstand voltage	Test	Comment
U_r < 200	Lightning impulse withstand voltage	Phase-to-earth and phase-to-phase: - withstand voltage of equipment to be protected (see IEC 60071-1) or - phase-to-earth: 1,3 × lightning impulse protection level - phase-to-phase: 1,3 × lightning impulse protection level + $U_c \times \sqrt{2}$	Whichever is lower
	Power-frequency withstand voltage	Phase-to-earth and phase-to-phase: - withstand voltage of equipment to be protected (see IEC 60071-1) or - phase-to-earth: $\hat{u}_{ac}$ = 1,2 x switching impulse protection level - phase-to-phase: $\hat{u}_{ac}$ = 1,2 x switching impulse protection level + U_c x √2	Whichever is lower
U_r ≥ 200	Lightning impulse withstand voltage	Phase-to-earth and phase-to-phase: - withstand voltage of equipment to be protected (see IEC 60071-1) or - phase-to-earth: 1,3 × lightning impulse protection level - phase-to-phase: 1,3 × lightning impulse protection level + $U_c \times \sqrt{2}$	Whichever is lower
	Switching impulse withstand voltage	Phase-to-earth and phase-to-phase: - withstand voltage of equipment to be protected (see IEC 60071-1) or - phase-to-earth: 1,25 × switching impulse protection level - phase-to-phase: 2,5 × switching impulse protection level	Whichever is lower

Table 10 – 1 500 A, 2 500 A and 5 000 A three – phase – GIS arresters – Required withstand voltages

Type of withstand voltage	Test	Comment
Lightning impulse withstand voltage	Phase-to-earth and phase-to-phase: -withstand voltage of equipment to be protected (see IEC 60071-1) or - phase-to-earth: 1,3 × lightning impulse protection level - phase-to-phase: 1,3 × lightning impulse protection level + $U_c \times \sqrt{2}$	Whichever is lower
Power-frequency withstand voltage	Phase-to-earth and phase-to-phase: - withstand voltage of equipment to be protected (see IEC 60071-1) or - phase-to-earth: $\hat{u}_{ac}$ = lightning impulse protection level - phase-to-phase: $\hat{u}_{ac}$ = lightning impulse protection level + $U_c \times \sqrt{2}$	Whichever is lower

12 Separable and dead-front arresters

12.1 Scope

This clause applies to arresters designed with insulating and/or shielded housings providing system insulation, intended to be installed in an enclosure for the protection of distribution equipment and circuits.

12.2 Normative references

See Clause 2.

12.3 Terms and definitions

See Clause 3.

12.4 Identification and classification

See Clause 4.

12.5 Standard ratings and service conditions

Clause 5 applies, except as follows.

12.5.4 Normal service conditions

This subclause replaces 5.4.

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

a) Ambient air temperature in the general vicinity of dead-front arresters shall be between –40 ˚C and +65 °C.
b) The maximum temperature of dead-front arresters due to external heat sources in the general vicinity of the arrester shall not exceed +85 °C.

   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 should 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).

12.6 Requirements

The requirements of Clause 6 apply except for the following.

12.6.11 Short circuit

This subclause replaces 6.11.

An arrester for which a short-circuit rating is claimed by the manufacturer shall not fail in a manner that causes violent shattering (see 12.8.7).

All separable and dead-front arresters shall be able to withstand resistor failures without ejecting arrester parts through the body of the housing except at places specifically designed for this purpose.

12.7 General testing procedure

See Clause 7.

12.8 Type tests (design tests)

12.8.1 General

Type tests defined in Clause 8 shall be performed, except as indicated below.

1) Insulation withstand tests on the arrester housing – see 12.8.2.
5) Short circuit test – see 12.8.7.
6) Tests of arrester disconnectors/fault indicators – does not apply.
7) Artificial pollution tests of Annex F – does not apply.

NOTE Suitable tests are under consideration.

9) Bending moment test – does not apply.
10) Environmental test – does not apply.
11) Seal leak rate test – does not apply.

12.8.2 Insulation withstand tests on the arrester housing

Subclause 8.2 applies with the addition of the following two subclauses.

12.8.2.9 Insulation withstand tests of unscreened separable arresters

For unscreened separable arresters where the clearances are smaller than that specified in IEC 60071-2, three samples shall be mounted in an earthed test terminal box, as shown in Figure 11. Provided that the test box is symmetrical, the test shall be performed on arresters 1 and 2. If the box is not symmetrical, all three arresters shall be tested. The minimum allowable clearances *a, b, c, d*, and *e* shall be stated in the literature included with the arrester. For screened separable arresters, a single-phase test is sufficient.

The insulation withstand tests may be carried out with arresters including the non-linear resistors. In this case, the tested unit shall be isolated from earth potential. During the impulse test, the arrester next to the tested arrester shall be earthed.

Insulation withstand values shall be in accordance with Table 11.

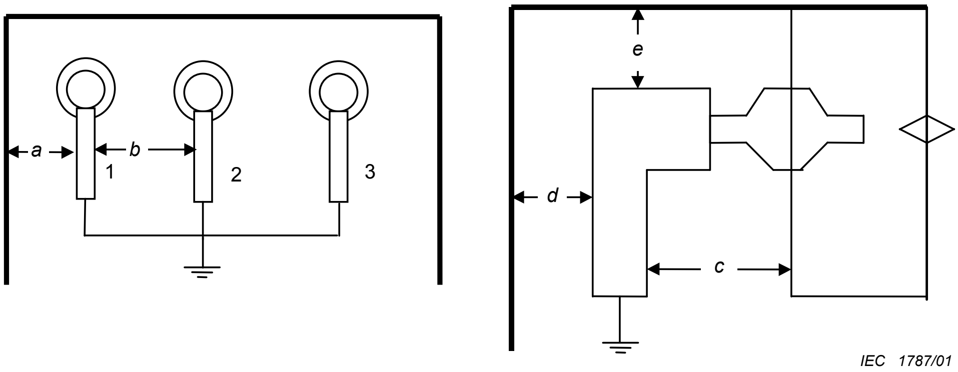


Figure 11 – Test set-up for insulation withstand test ofseparable arresters in insulating housings

Table 11 – Insulation withstand test voltages for unscreened separable arresters

Highest voltage for equipment kV	**Impulse test 1,2/50 full wave** kV (peak value)	**50/60 Hz test voltage** kV (r.m.s.)
12	75	28
17,5	95	38
24	125	50
36	170	70
NOTE Test values are in accordance with IEC 60694 and IEC 60071-1 and, for other values of the "highest voltage for equipment", use the test voltages in IEC 60071-1.		

12.8.2.10 Insulation withstand tests of dead-front or separable arresters in a screened housing

For dead-front or separable arresters in a screened housing, the non-linear resistors shall be removed and replaced by a metal rod of the same outer diameter as the resistors. The length of the metal rod shall be at least two-thirds of the total length of the resistor stack. The lower end of the rod shall be shaped in such a way as to minimize dielectric stress (for example, semi-spherical). To isolate the housing screen at the lower end, the remaining housing length shall be filled with insulating material (solid or liquid) to prevent interfacial breakdown during the test. The high-voltage terminal shall be energized and the screened housing earthed for the test.

Insulation withstand values shall be in accordance with Table 11 or Table 12, depending on the intended application.

Table 12 – Insulation withstand test voltages for dead-front arresters or separable arresters in a screened housing

System class rating kV	**Impulse test 1,2/50 full wave** kV (peak)	**50/60 Hz test voltage** kV (r.m.s.) applied for 1 min	**DC test voltage** kV applied for 15 min
15	95	34	53
25	125	40	78
35	150	50	103
NOTE Test values are in accordance with IEEE C62.11.			

12.8.3 Residual voltage tests

Subclause 8.3 applies without modification.

12.8.4 Long duration current impulse withstand test

Subclause 8.4 applies without modification.

12.8.5 Operating duty tests

Subclause 8.5 applies, except as follows.

12.8.5.2.1 Test procedure

This subclause replaces 8.5.2.1

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 °C ± 4 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 shall be equal to that of the highest stressed non-linear resistor. For screened arresters, the manufacturer shall establish this voltage value by calculations. Dead-front arresters shall be energized for 2 000 h.

NOTE 2 Information on procedures for voltage distribution calculations are given in Annex L.

For arresters with a length *H* of less than 1 m, except for arresters with conductive, grounded enclosures such as GIS-arresters, liquid-immersed, dead-front 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 7.3. The power-frequency voltage shall fulfil the requirements stated for the operating duty test (see 8.5.1).

12.8.5.4.2 Application of impulses

This subclause replaces 8.5.4.2.

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

The section is subjected to two high current impulses with peak value and impulse shape as specified in Table 8. High lightning duty arresters specified in Annex C are subjected to three 30/80 impulses with a peak value of 40 kA.

Table 8 – 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 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 °C ± 3 K for separable arresters and 85 °C ± 3 K for deadfront arresters. The tests shall be carried out at an ambient temperature of 20 °C ± 15 K.

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 8.5.2) 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 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 8.5.6).

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.

12.8.6 Tests of disconnectors/fault indicators

Subclause 8.6 applies without modification.

12.8.7 Short-circuit test procedure

An arrester for which a short-circuit rating is claimed by the manufacturer shall be subjected to a short-circuit test according to 8.7 to show that the arrester will not fail in a manner that causes violent shattering of the housing. Modifications to 8.7 that are applicable to separable and dead-front arresters are as follows.

12.8.7.1 General

This subclause replaces 8.7.1.

Arresters, for which a short-circuit rating is claimed by the manufacturer, should be tested in accordance with this annex. The test is conducted to show that an arrester failure is not likely to cause an explosive failure.

Each arrester design is tested with two groups of short-circuit currents:

– high short-circuit current values consisting of the rated short-circuit current and two reduced short-circuit currents;
– low short-circuit current.

NOTE Surge arresters may be of two principal designs with respect to short-circuit behaviour.

One design of surge arresters makes use of the internal overpressure, which is built up due to the internal arc coming from the short circuit of the arrester elements. The overpressure is created by heating an enclosed volume of gas or liquid, which expands, leading to bursting or flipping of a pressure-relief device (in this case, the tests are sometimes called "pressure-relief tests"). The arrester housing is not intended to break before the overpressure is relieved.

Another design, usually of a compact type with no enclosed volume of gas or liquid, does not have any pressure-relief device. The short-circuit performance of this design depends on the arc directly burning through or tearing the housing.

If the arrester is equipped with an arrangement other than a conventional pressure relief device, this arrangement should be included in the test.

For the rated and reduced short-circuit current, the methods of test sample preparation depend upon the arrester construction. For an arrester fitted with a pressure-relief device, the active resistors are externally bypassed by a fuse wire. For an arrester without a pressure-relief device, the active resistors may be pre-failed by overvoltage or may be bypassed with an internal fuse wire installed in a drilled hole through the resistors.

For the low-current short-circuit test, active resistors are pre-failed by overvoltage.

The frequency of the short-circuit current test supply should be not less than 48 Hz and not greater than 62 Hz.

Upon agreement between the manufacturer and the user, reclosing cycle tests may be performed using a mutually agreed upon test procedure and test criteria.

All separable and dead-front arresters shall be able to withstand resistor failures without ejecting arrester parts through the body of the housing except at places specifically designed for this purpose. The tests shall be made on the highest voltage rating of complete arrester units of a given type and design. These tests shall be considered to substantiate conformance to this standard of lower voltage ratings of the same type and design.

Samples shall be prepared according to 8.7.2.

12.8.7.3 Mounting of the test sample

This subclause replaces 8.7.3.

Dead-front arrester test specimens shall be mounted on a standard interface bushing to simulate normal service conditions.

Separable arrester short-circuit tests shall be carried out while installed in the individual compartment. Mounting shall be in accordance with 10.2.3 of IEC 61330.

12.8.7.4 Evaluation of test results

This subclause replaces 8.7.6.

Fracture of the housing with ejection of arrester parts through the body shall constitute failure of the arrester to pass this test. Ejection of arrester parts including non-linear resistors through the bottom with release of the bottom cap, or through other parts specifically designed for this purpose, is acceptable.

12.8.8 Internal partial discharge test

This subclause replaces 8.8.

The test shall be performed on the longest electrical unit of the arrester. If this does not represent the highest specific voltage stress per unit length, additional tests shall be performed on the unit having the highest specific voltage stress. The test sample may be shielded against external partial discharges.

NOTE Shielding against external partial discharges should have negligible effects on the voltage distribution.

Test voltages and extinction levels shall be according to Table 13.

Table 13 – Partial discharge test values for separable and dead-front arresters

Separable arresters		Dead-front arresters	
Highest voltage of equipment kV	Partial discharge test voltage (extinction level) kV (r.m.s.)[a]	System class rating kV	Partial discharge test voltage (extinction level) kV (r.m.s.)
12	12	15	11
17,5	17,5	25	19
24	24	35	26
36	36	-	-

[a] If U_c is lower than the highest voltage of equipment, the test voltage shall be 1,05 times U_c.

12.9 Routine tests and acceptance tests

Clause 9 applies without modification.

13 Liquid-immersed arresters

13.1 Scope

This clause applies to arresters designed to be used immersed in insulating liquid. It does not apply to devices not subjected to the operating voltage of the system (for example, devices on tap changers). Such devices are not arresters.

13.2 Normative references

See Clause 2.

13.3 Terms and definitions

See Clause 3.

13.4 Identification and classification

See Clause 4.

13.5 Standard ratings and service conditions

Clause 5 applies, except as follows.

13.5.4 Normal service conditions

This subclause replaces 5.4.1.

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

a) The ambient liquid temperature in the general vicinity of liquid-immersed arresters shall be between –40 °C and +95 ºC.

b) The daily average value of the maximum temperature of the ambient insulating liquid shall not exceed +120 ºC.

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 should 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).

13.6 Requirements

The requirements of Clause 6 apply except for the following.

13.6.11 Short-circuit

This subclause replaces 6.11.

An arrester for which a short-circuit rating is claimed by the manufacturer shall not fail in a manner that causes violent shattering (see 13.8.7).

If a fail-open current rating is claimed, the tests shall be conducted at the lowest current level claimed.

If a fail-short current rating is claimed, the tests shall include the highest current level claimed.

13.7 General testing procedure

Clause 7 applies without modification.

13.8 Type tests (design tests)

13.8.1 General

Type tests defined in Clause 8 shall be performed, except as indicated below.

The following type tests shall be carried out depending upon the arrester type.

1) Insulation withstand tests on the arrester housing – see 13.8.2.
5) Short-circuit tests – see 13.8.7.
6) Tests of arrester disconnectors/fault indicators – does not apply.
7) Artificial pollution tests of Annex F – does not apply.
9) Bending moment test – does not apply.
10) Environmental test – does not apply.
11) Seal leak rate test – does not apply.

For liquid-immersed arresters, when testing in insulating liquid is required, the liquid shall be that which is used in the protected equipment.

13.8.2 Insulation withstand test on the arrester housing

Subclause 8.2 applies except for the following.

13.8.2.1 General

This subclause replaces 8.2.1.

The voltage withstand tests demonstrate the voltage withstand capability of the external insulation of the arrester housing. For other designs the test shall be agreed upon between the manufacturer and the purchaser.

The tests shall be performed in the conditions and with the test voltages specified in 6.1 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.

The insulation withstand tests for liquid-immersed arresters shall be performed in insulating liquid at room temperature.

13.8.2.5 Wet test procedure

This subclause replaces 8.2.5.

Wet withstand tests under the procedure given in IEC 60060-1 do not apply to liquid-immersed arresters.

13.8.5 Operating duty tests

Subclause 8.5 applies except as follows.

13.8.5.2.1 Test procedure

This subclause replaces 8.5.2.1.

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 7 000 h, during which the temperature shall be controlled to keep the surface temperature of the resistor at 115 °C ± 4 K. Test time may be reduced to not less than 2 000 h by agreement between manufacturer and user. This can be accomplished by monitoring the resistor power losses at least once every 100 h period, then extrapolating to 7 000 h using a straight line on a plot of power losses versus the square root of time from the lowest measured value through to the highest measured value.

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 L.

For arresters with a length *H* of less than 1 m, except for arresters with conductive, grounded enclosures such as GIS-arresters, liquid-immersed, dead-front 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 7.3. The power-frequency voltage shall fulfil the requirements stated for the operating duty test (see 8.5.1).

13.8.5.2.2 Determination of elevated rated and continuous operating voltages

This subclause replaces 8.5.2.2.

The three test samples shall be heated to 115 °C ± 4 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 $7\,000^{+100}_{0}$ h of ageing under the same conditions. (Test time may be reduced to not less than 2 000 h by agreement between manufacturer and user as described in 13.8.5.2.1.) Accidental intermediate de-energizing 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 energizing. Within the temperature range allowed, all measurements shall be made at the same temperature ±1 K.

The minimum power losses value among those measured at least every 100 h time span shall be called P_{3ct}. This is summarized in Figure 12.

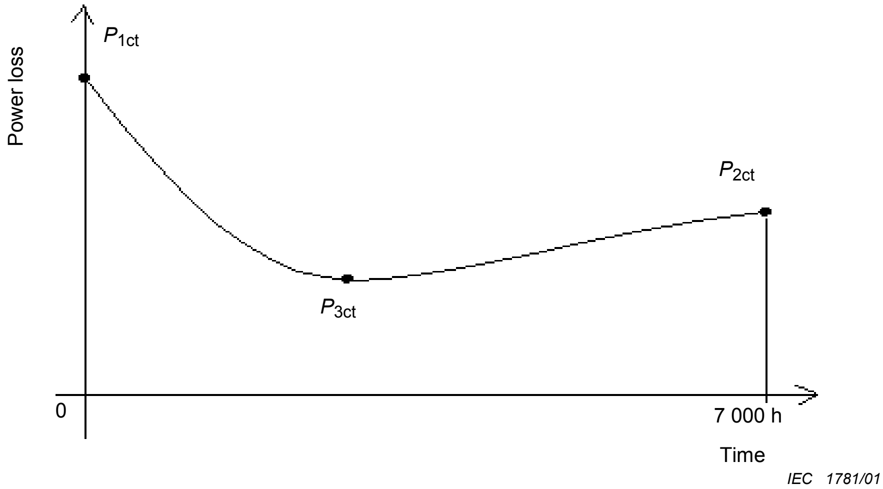


Figure 12 – Power losses of arrester at elevated temperatures versus time

- If P_{2ct} is equal to, or below, 1,1 times P_{3ct}, then the test according to 8.5.4.2 and 8.5.5.2 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:

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

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 8.5.4.2 and 8.5.5.2. 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 8.5.2.1.

Table 7 summarizes 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**
$P_{2ct} \le 1,1 \times P_{3ct}$ and $P_{2ct} \le P_{1ct}$	New samples at U_{sc} and U_{sr}
$P_{2ct} \le 1,1 \times P_{3ct}$ 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 $P_{2ct} \ge P_{1ct}$	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.

13.8.5.4.2 Application of impulses

This subclause replaces 8.5.4.2.

At the beginning of the operating duty test the arrester shall be immersed in insulating liquid at 120 °C ± 15 K.

The section is subjected to two high current impulses with peak value and impulse shape as specified in Table 8. High lightning duty arresters specified in Annex C are subjected to three 30/80 impulses with a peak value of 40 kA.

Table 8 – 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 According to service conditions other values (lower or higher) may be adopted for the peak current.	

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 8.5.2) 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 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 8.5.6).

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.

13.8.7 Short-circuit tests

An arrester for which a short-circuit rating is claimed by the manufacturer shall be subjected to a short-circuit test according to 8.7 to show that the arrester will not fail in a manner that causes violent shattering of the housing. Modifications to 8.7 that are applicable to liquid-immersed arresters are as follows.

13.8.7.1 General

This subclause replaces 8.7.1.

Arresters, for which a short-circuit rating is claimed by the manufacturer, should be tested in accordance with this annex. The test is conducted to show that an arrester failure is not likely to cause an explosive failure.

Each arrester design is tested with two groups of short-circuit currents:

– high short-circuit current values consisting of the rated short-circuit current and two reduced short-circuit currents;
– low short-circuit current.

NOTE Surge arresters may be of two principal designs with respect to short-circuit behaviour.

One design of surge arresters makes use of the internal overpressure, which is built up due to the internal arc coming from the short circuit of the arrester elements. The overpressure is created by heating an enclosed volume of gas or liquid, which expands, leading to bursting or flipping of a pressure-relief device (in this case, the tests are sometimes called "pressure-relief tests"). The arrester housing is not intended to break before the overpressure is relieved.

Another design, usually of a compact type with no enclosed volume of gas or liquid, does not have any pressure-relief device. The short-circuit performance of this design depends on the arc directly burning through or tearing the housing.

If the arrester is equipped with an arrangement other than a conventional pressure relief device, this arrangement should be included in the test.

For the rated and reduced short-circuit current, the methods of test sample preparation depend upon the arrester construction. For an arrester fitted with a pressure relief device, the active resistors are externally bypassed by a fuse wire. For an arrester without a pressure relief device, the active resistors may be pre-failed by overvoltage or may be bypassed with an internal fuse wire installed in a drilled hole through the resistors.

For the low-current short-circuit test, active resistors are pre-failed by overvoltage.

The frequency of the short-circuit current test supply should be not less than 48 Hz and not greater than 62 Hz.

Upon agreement between the manufacturer and the user reclosing cycles tests may be performed using a mutually agreed upon test procedure and test criteria.

Liquid-immersed arresters may be designed as either “fail-open” or “fail-short”. It is recognized that a fail-open design arrester will not always fail in an open-circuit mode for fault currents below its fail-open rating, and that a fail-short design arrester will not always fail in a short-circuit mode for available fault currents above its fail-short rating.

NOTE “Fail-open” does not imply that the arrester will interrupt the circuit. All arrester failures initiate short-circuit current which must be interrupted by an overcurrent protective device. After other devices clear the fault, the fail-open arrester allows re-energization of the protected equipment with, of course, no overvoltage protection.

The tests shall be run on each of three of the lowest and highest voltage ratings of a complete single arrester unit for each type and design for which a fail-open or fail-short current rating is claimed. These tests shall be considered to substantiate conformance to this standard for intermediate voltage ratings of the same type and design.

For fail-open design arresters, all specimens are tested at the lowest claimed fail-open current level. No samples are tested at the “low short-circuit current” level which may be below the fail-open current rating.

For fail-short design arresters, one sample shall be tested at each of the three current levels according to 8.7.4. The nominal short-circuit level may be different from that listed in Table 15 and shall be selected by the manufacturer. The two reduced short-circuit current levels shall be selected from Table 15. One additional sample shall be tested according to 8.7.5.

13.8.7.3 Mounting of the test samples

This subclause replaces 8.7.3.

The test samples shall be mounted in the position intended to be used when mounted in service. The arrester shall be immersed in insulating liquid in a container sufficiently large that it does not become involved in arcing activity.

For non-base mounted arresters (for example, pole-mounted arresters), the test sample should be mounted to a non-metallic pole using mounting brackets and hardware typically used for service installation. For the purpose of this test, the mounting bracket should be considered as a part of the arrester base. In cases where the foregoing is in variance with the manufacturer's instructions, the arrester should be mounted in accordance with the installation recommendations of the manufacturer. The entire lead between the base and the current sensor should be insulated for at least 1 000 V. The top end of the test sample should be fitted with the base assembly of the same design of the arrester or with the top cap.

For base-mounted arresters, the bottom end fitting of the test sample should be mounted on an insulating support that is the same height as a surrounding circular or square enclosure. The insulating support and the enclosure should be placed on top of an insulating platform, as shown in Figures 14a and 14b. For non-base-mounted arresters, the same requirements apply to the bottom of the arrester. The arcing distance between the top end cap and any other metallic object (floating or grounded), except for the base of the arrester, should be at least 1,6 times the height of the sample arrester, but not less than 0,9 m. The enclosure should be made of non-metallic material, except for small metal such as nails or screws used to fabricate the enclosure and platform, and be positioned symmetrically with respect to the axis of the test sample. The height of the enclosure should be 40 cm ± 10 cm, and its diameter (or side, in case of a square enclosure) should be equal to the greater of 1,8 m or the diameter of the test sample plus twice the test sample height. The enclosure should not be permitted to open or move during the test.

Test samples should be mounted vertically unless otherwise agreed upon between the manufacturer and the user.

NOTE The mounting of the arrester during the short-circuit test and, more specifically, the routing of the conductors must represent the most unfavourable condition in the field. The routing shown in Figure 14a is the most unfavourable during the initial phase of the test before venting occurs.

However, during the remaining arcing time, this routing forces the arc to move away from the arrester, thus reducing the risk of the arrester catching fire. Both the initial phase of the test and the risk of fire are significant, especially for arresters where the external part of the housing is made of polymeric material. For arresters without a pressure-relief device, it is therefore proposed, as an alternative, that the ground conductor should be directed to the right, as described in Figure 14b. In this way, the arc will stay close to the arrester during the entire duration of the short-circuit current, thus creating the most unfavourable conditions with regard to fire hazard.

13.8.7.4 Evaluation of test results

This subclause replaces 8.7.6.

The conformance of the test specimens with this standard shall be judged by the following:

a) from the oscillographic recordings showing test current amplitude and duration;
b) from the results of the following voltage withstand test made at any time after the short-circuit event. The specimen shall be energized at U_c in a circuit with limited, but known, available current for a period of 1 min during which time

1) substantially no current flows in the case of a fail-open design arrester, or

2) substantially full available current flows in the case of a fail-short design arrester;

c) from the physical appearance of the specimens after the test.

All tested specimens shall meet these requirements.

13.8.7.5 High current short-circuit tests

This subclause replaces 8.7.4.

One sample should be tested at a rated short-circuit current selected from Table 15. Second and third samples should be tested, one at each of the two reduced short-circuit currents corresponding to the selected rated short-circuit current. All three samples should be prepared according to 8.7.2 and mounted according to 8.7.3.

Tests should be made in a single-phase test circuit, with an open-circuit test voltage of 107 % to 77 % of the rated voltage of the test sample arrester, as outlined in 8.7.4.1. However, it is expected that tests on high-voltage arresters will have to be made at a testing station which might not have the sufficient short-circuit power capability to carry out these tests at 77 % or more of the test sample rated voltage. Accordingly, an alternative procedure for making the high-current short-circuit tests at a reduced voltage is given in 8.7.4.2. The measured total duration of test current flowing through the circuit should be equal to, or greater than, 0,2 s.

For fail-open design arresters, the impedance of the test circuit shall be adjusted to produce not more than the fail-open current rating of the arrester through the specimen. The fail-open rating which can be claimed is the highest measured r.m.s. symmetrical current which flows in any specimen during the test.

For fail-short design arresters, the impedance of the circuit shall be adjusted to produce not less than the fail-short current rating of the arrester through the specimen. The fail-short rating which can be claimed is the lowest measured r.m.s. symmetrical current which flows through any specimen during the nominal current test.

13.9 Routine tests and acceptance tests

Clause 9 applies without modification.

Annex A
(normative)

Abnormal service conditions

The following are typical abnormal service conditions which may require special consideration in the manufacture or application of surge arresters and should be called to the attention of the manufacturer.

1) Temperature in excess of +40 °C or below –40 °C.
2) Application at altitudes higher than 1 000 m.
3) Fumes or vapours which may cause deterioration of insulating surface or mounting hardware.
4) Excessive contamination by smoke, dirt, salt spray or other conducting materials.
5) Excessive exposure to moisture, humidity, dropping water or steam.
6) Live washing of arrester.
7) Explosive mixtures of dust, gases or fumes.
8) Abnormal mechanical conditions (earthquakes, vibrations, high wind velocities, high ice loads, high cantilever stresses).
9) Unusual transportation or storage.
10) Nominal frequencies below 48 Hz and above 62 Hz.
11) Heat sources near the arrester (see 5.4b)).
12) Wind speed > 34 m/s.
13) Non-vertical erection and suspended erection.
14) Earthquake (see Clause M.2)
15) Torsional loading of the arrester
16) Tensile loading of the arrester
17) Use of the arrester as a mechanical support.

Annex B
(normative)

Test to verify thermal equivalency between complete arrester and arrester section

A test according to the following or another procedure agreed on between the purchaser and manufacturer shall be carried out.

The complete arrester or the unit containing most resistors per unit length of a multi-unit arrester is placed in a still air ambient temperature of 20 °C ± 15 K. The ambient temperature shall be held at ±3 K. Thermocouples and/or some sensors, for example, utilizing optical fibre technique to measure temperature are attached to the resistors. A sufficient number of points must be checked to calculate a mean temperature or the manufacturer may choose to measure the temperature at only one point located between 1/2 to 1/3 of the arrester length from the top. The latter will give a conservative result, thus justifying the simplified method.

The resistors shall be heated to a temperature of approximately 120 °C by the application of power-frequency voltage with an amplitude above reference voltage. This temperature should correspond to a mean value if the temperature is measured on several resistors or a single value if only the 1/2 to 1/3 point is checked. The heating time is not critical if approximately the same time is used when later heating the test section. This time may be chosen from minutes to hours depending on the power capacity of the voltage source. When this predetermined temperature is reached, the voltage source shall be disconnected and the cooling time curve shall be determined over a period of not less than 2 h. In the case of several measuring points a mean temperature curve is constructed.

The test section shall thereafter be tested in the same way as the complete arrester in still air ambient temperature in the range of 20 °C ± 15 K. The ambient temperature shall be held at ±3 K. It shall be heated to the same resistor temperature rise above ambient temperature as for the complete arrester by the application of power frequency voltage. The voltage amplitude is chosen to give a heating time approximately the same as for the complete arrester. A mean temperature shall be determined by measuring the temperature of several resistors. Alternatively, the temperature may be measured on one block located between 1/2 to 1/3 of the section from the top. When the section has reached the predetermined temperature, the voltage source shall be disconnected and the cooling time curve shall be determined over a period of not less than 2 h.

The cooling curves for the complete arrester and the section shall be compared. Either the mean or the single values are used. They shall be adjusted to the same ambient temperature by adding the difference in ambient temperatures to the lower curve.

To prove thermal equivalency, the test section shall for all instants during the cooling period have a temperature equal to or higher than the complete arrester.

Annex C
(normative)

Requirements for high lightning duty arresters for voltage range 1 kV to 52 kV

This annex describes the requirements on 20 000 A arresters especially applicable for high lightning intensity areas with highest system voltage in the range 1 kV to 52 kV.

Test requirements are specified in Table C.1.

The operating duty test shall be carried out according to 6.9 and 8.5.4 and shall consist of the application to each sample of three 30/80 current impulses with a peak value of 40 kA.

The time intervals between the three current impulses shall be 50 s to 60 s.

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 25 μs to 35 μs for virtual front time;
c) from 70 μs to 90 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 complete test sequence is illustrated in Figure C.1.

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

The thermal stability test (see 9.2.2) shall be carried out according to Figure C.2.

Table C.1 – Test requirements on 20 000 A high lightning duty arresters[a]

1.	Rated voltage U_r (kV_{rms})	$3 \leq U_r \leq 60$
2.	Insulation withstand tests on the arrester housing	6.1, 8.2.6 and 8.2.8
3.	Residual voltage test	Table K.1 and 6.3
	a) Steep current impulse residual voltage test	8.3.1
	b) Lightning impulse residual voltage test	8.3.2
	c) Switching impulse residual voltage test	Not required
4.	Long-duration current impulse withstand test	8.4
5.	Operating duty test	6.9 Annex D
	a) High current impulse operating duty test	8.5.4
	b) Switching surge operating duty test	Not required
6.	Power-frequency voltage-versus-time curve	6.10
7.	Short-cicuit	6.11
8.	Arrester disconnector/fault indicator (when fitted)	6.12 and 8.6
9.	Polluted housing test	Annex F

[a] Numbers in rows 2 to 9 refer to clauses and subclauses in this standard.

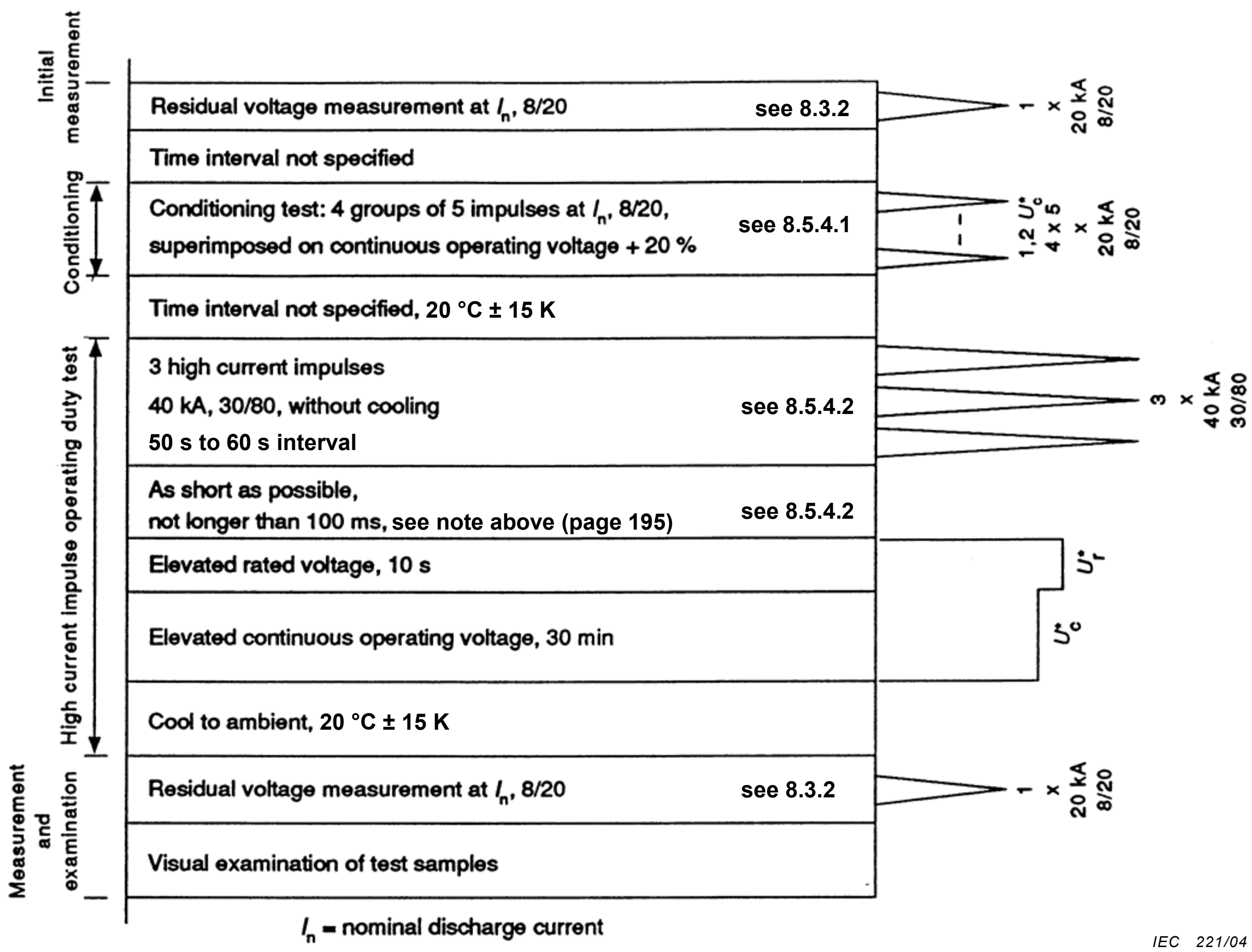


Figure C.1 – Operating duty test on 20 000 A high lightning duty arresters

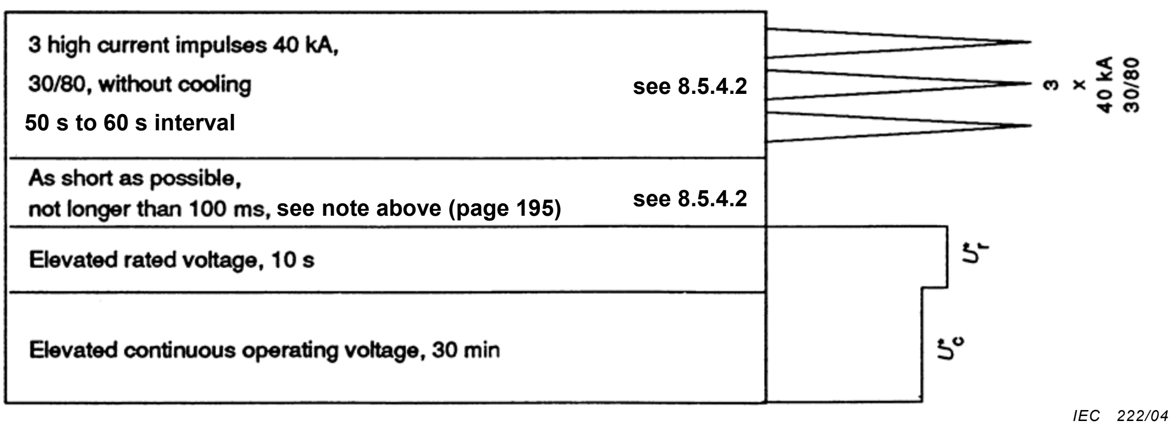


Figure C.2 – Thermal stability test on 20 000 A high lightning duty arresters (see 9.2.2)

Annex D
(normative)

Procedure to verify the power-frequency voltage-versus-time characteristics of an arrester

When the experimental verification of the power-frequency voltage-versus-time curve supplied by the manufacturer is agreed upon by the manufacturer and the purchaser, the last part of the operating duty test specified in Figures 1, 2 or C.1, depending on the category of the arrester, shall be used with modification of the level and duration of the applied power-frequency voltage prior to the U_c^* voltage application. Three points on the curve shall be considered sufficient for verification.

For the arresters categorized as 10 000 A line discharge class 1 and 5 000 A, 2 500 A and 1 500 A, the procedure starts with preheating the test sample to 60 °C ± 3 K. It is followed by one high current impulse which gives the energy prior to the power-frequency voltage application (see Figure D.1).

For high lightning duty arresters (Annex C), the procedure starts with the three successive applications of high current impulse on the sample at ambient temperature (see Figure D.2).

For 10 000 A arresters with line discharge Classes 2 and 3 and 20 000 A arresters with Classes 4 and 5, the sample is preheated to 60 °C ± 3 K and two shots of long-duration current impulses are applied to give the energy prior to the power-frequency voltage application (see Figure D.3).

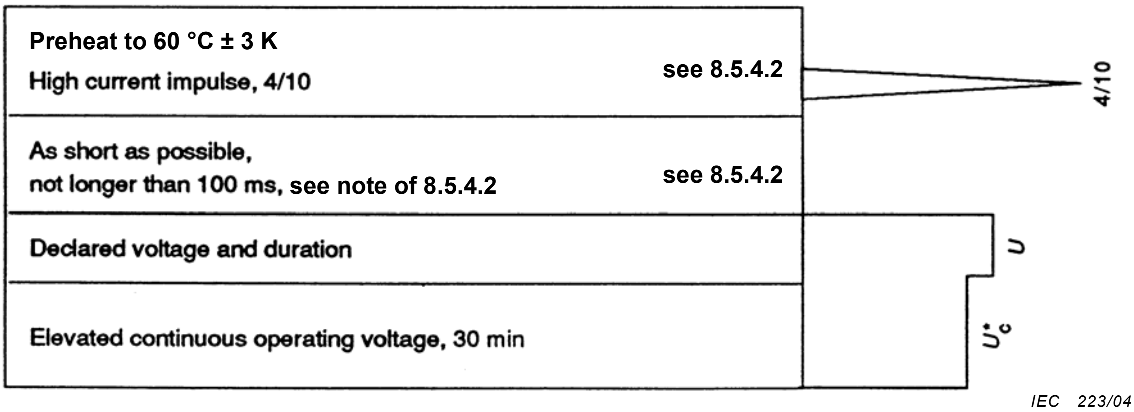


Figure D.1 –Test on 10 000 A line discharge class 1, 5 000 A, 2 500 A and 1 500 A arresters

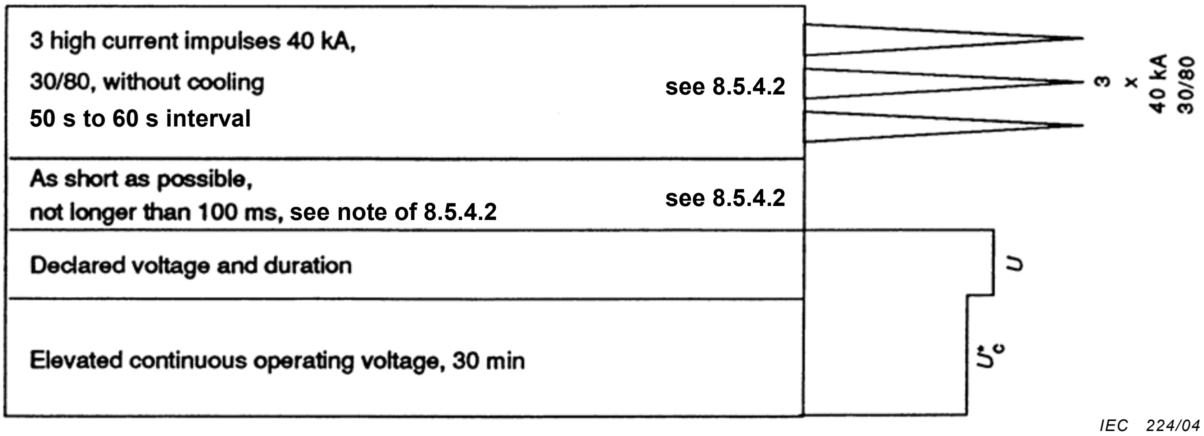


Figure D.2 – Test on 20 000 A high lightning duty arresters

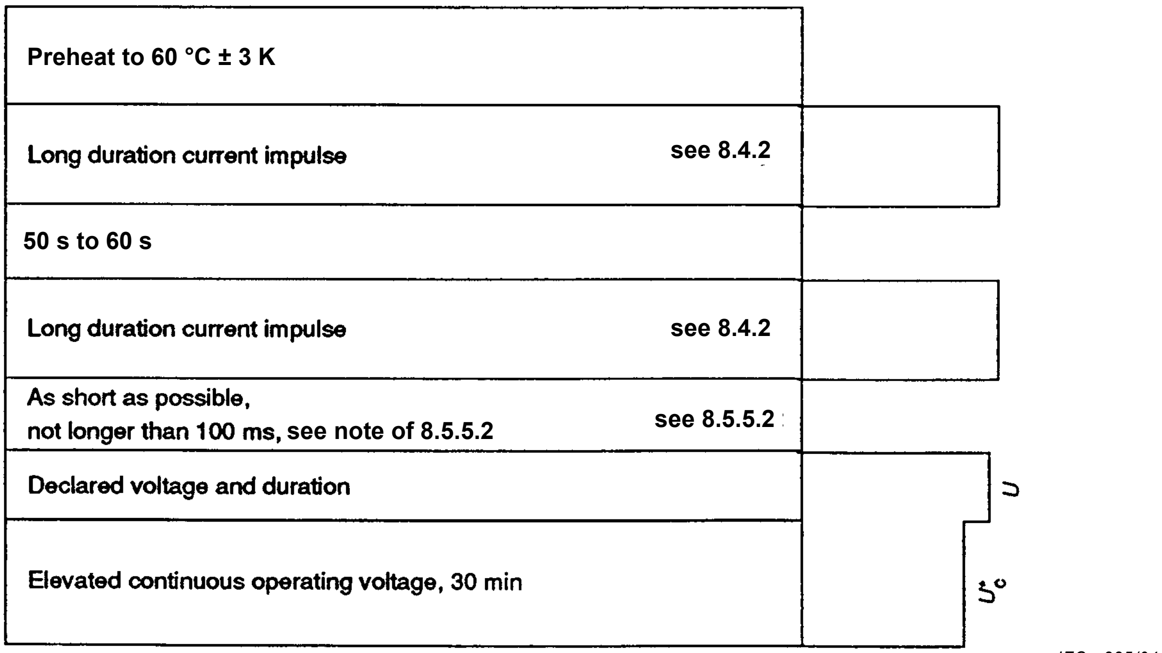


Figure D.3 – Test on 10 000 A arresters, line discharge Classes 2 and 3 and 20 000 A arresters, line discharge Classes 4 and 5

Annex E
(informative)

Guide to selection of line discharge class

The parameters for the line discharge test in Table 5 have been specified to obtain increasing energies with increasing discharge class for arresters having a given ratio of switching impulse residual voltage to rated voltage. The energy generated in the arrester during the test, however, is strongly dependent on the actual switching impulse residual voltage of the tested resistors. This energy can be determined with sufficient accuracy from the following formula:

$$W' = \frac{U_{res}}{U_r}\left[\frac{U_L}{U_r} - \frac{U_{res}}{U_r}\right] \times \frac{U_r}{Z} \times T \qquad \text{(E.1)}$$

where

U_r is the rated voltage (r.m.s. value);

U_L is the charging voltage of the generator;

W' is the specific energy equal to the energy divided by the rated voltage;

U_{res} is the residual voltage at switching impulse current (see 7.3.3);

Z is the surge impedance of the line;

T is the virtual duration of the current peak.

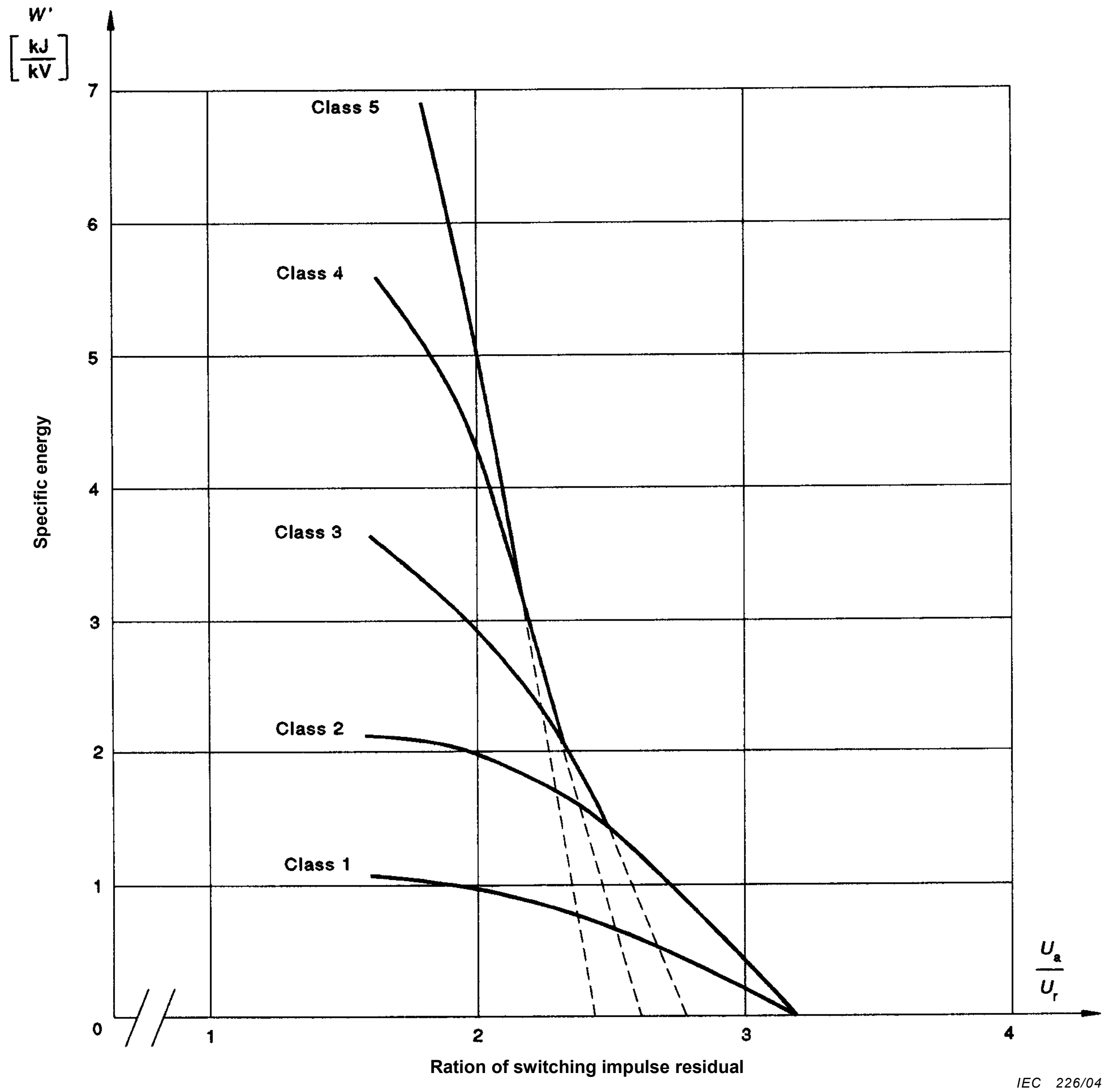
The dependence of the specific energy on the switching impulse residual voltage is shown in Figure E.1.

The selection of the line discharge class is done in the following sequence.

a) Determine the energy which is generated in the metal-oxide arrester in service, taking into account possible events caused by lightning and/or switching.

b) Determine the specific energy by dividing the energy by the r.m.s. value of the rated voltage.

c) Compare this specific energy with the specific energy generated in the test using equation (E.1) or Figure E.1 and select the next higher line discharge class.



Parameter: line discharge class.

Figure E.1 – Specific energy in kJ per kV rating dependant on the ratio of switching impulse residual voltage (U_a) to the r.m.s. value of the rated voltage U_r of the arrester

Annex F
(normative)

Artificial pollution test with respect to the thermal stress on porcelain-housed multi-unit metal-oxide surge arresters

F.1 Glossary

F.1.1 Measured quantities

q_z [C/hm] Mean external charge flowing on the surface of insulators and surge-arrester housings during pollution events in service, relevant to a pollution event lasting a time t_z. This parameter is used for the classification of the pollution severity of a site.

t_z [h] Duration of a pollution event in service.

Q_e [C] Charge flowing on the surface of the units of the surge arrester during the pollution test.

Q_i [C] Charge flowing in the internal parts of the units of the surge arrester during the pollution test.

ΔT_k [K] Temperature rise relevant to unit k.

β [K/C] Ratio between the temperature rise of the internal parts of the arrester and the relevant charge flowing internally as determined in the preliminary heating test.

τ [h] Equivalent thermal time constant of the arrester as determined in the preliminary heating test.

F.1.2 Calculated quantities

D_m [m] Average diameter of the surge-arrester housing: it is calculated according to the method reported in IEC 60815.

Q_{tot} [C] Total charge relevant to the surge arrester: it is the sum of Q_i and Q_e and is measured at the earth terminal of the surge arrester.

$\Delta T_{z\ max}$ [K] Maximum theoretical temperature rise in service calculated as a function of β, q_z, t_z, D_m and τ.

WU Weighted unbalance of the arrester calculated as a function of the electrical and geometrical characteristic of each unit of the surge arrester. This parameter is used to select the most critical design to be submitted to the pollution test.

K_{ie} Ratio between the maximum external charge and the maximum internal charge flowing in the surge-arrester units during the pollution test.

ΔT_z [K] Expected temperature rise in service calculated as a function of β, q_z, t_z, D_m, K_{ie} and τ.

T_{OD} [°C] Starting temperature to be used for the operating duty test.

F.2 General

Pollution on external insulation of a metal-oxide surge arrester should be considered with regard to three possible effects:

a) risk of external flashover;
b) partial discharges inside the surge arrester due to radial fields between the external surface and the internal active elements;
c) temperature rise of the internal active elements due to a non-linear and transient voltage grading caused by the pollution layer on the surface of the arrester housing.

This test procedure considers only the third possible effect.

Laboratory tests and service experience have shown that the heating of the internal active parts of the surge arrester under pollution conditions is related to the charge absorbed: this parameter is therefore considered essential in the evaluation of the pollution performance of surge arresters.

A classification of the pollution severity of representative sites has been set up considering the mean external charge flowing on the surface of different insulators and surge arresters.

The procedures described in this annex refer only to surge arresters with a porcelain housing; the procedures for polymeric type surge arresters may require further investigation and are presently under consideration.

This annex describes the procedure for the determination of the preheating to be applied to the test sample before the operating duty test, in order to take into account the heating effect of the pollution; this procedure is synthesized in the flow-chart of Figure F.1. In particular:

– the pollution severity of different representative sites is expressed in terms of q_z. Relevant data are given in Table F.1;
– the thermal characteristics of the surge arrester are determined according to a procedure derived from that of Annex B. This procedure allows the determination of the equivalent thermal time constant τ and the calculation of the parameter β by means of the criteria described in F.4;
– the knowledge of the thermal characteristics of the surge arrester and of the expected pollution severity of the site in which the surge arrester is going to be installed allows a preliminary calculation of the maximum temperature rise in the most conservative conditions in which all the charge relevant to the pollution event would flow internally into the surge arrester;
– if the calculation of the maximum temperature rise $\Delta T_{z\ max}$ results in values less than 40 K, the pollution tests are not required and the starting temperature of the operating duty test shall be 60 °C. If the calculation of the maximum temperature rise $\Delta T_{z\ max}$ results in values of 40 K or higher, a test according to the procedure described in this annex shall be carried out unless, by agreement between user and manufacturer (for example, based on service experience in specified environments), the pollution test can be omitted. Moreover, at the decision of the manufacturer, even if the calculation of $\Delta T_{z\ max}$ results in values higher than 40 K, the pollution test may be avoided using as a starting temperature for the operating duty test the value $(20 + \Delta T_{z\ max})$ °C;

– laboratory pollution tests, when deemed necessary, are carried out on a surge arrester representative of a certain type and design. During the pollution test, the external and internal charges Q_e and Q_i shall be measured for each surge-arrester unit. Alternatively, the total charge Q_{tot} and the temperature rise ΔT of the internal parts may be measured. A statistical analysis of the test results is necessary to take into account the stochastic behaviour of the surge arrester heating under pollution conditions. The elaboration of the test results, described in detail in the following clauses, gives the factor K_{ie} which expresses the tendency of the charge to flow internally and therefore to heat the active parts. This factor is a characteristic value for a given surge-arrester type and design;

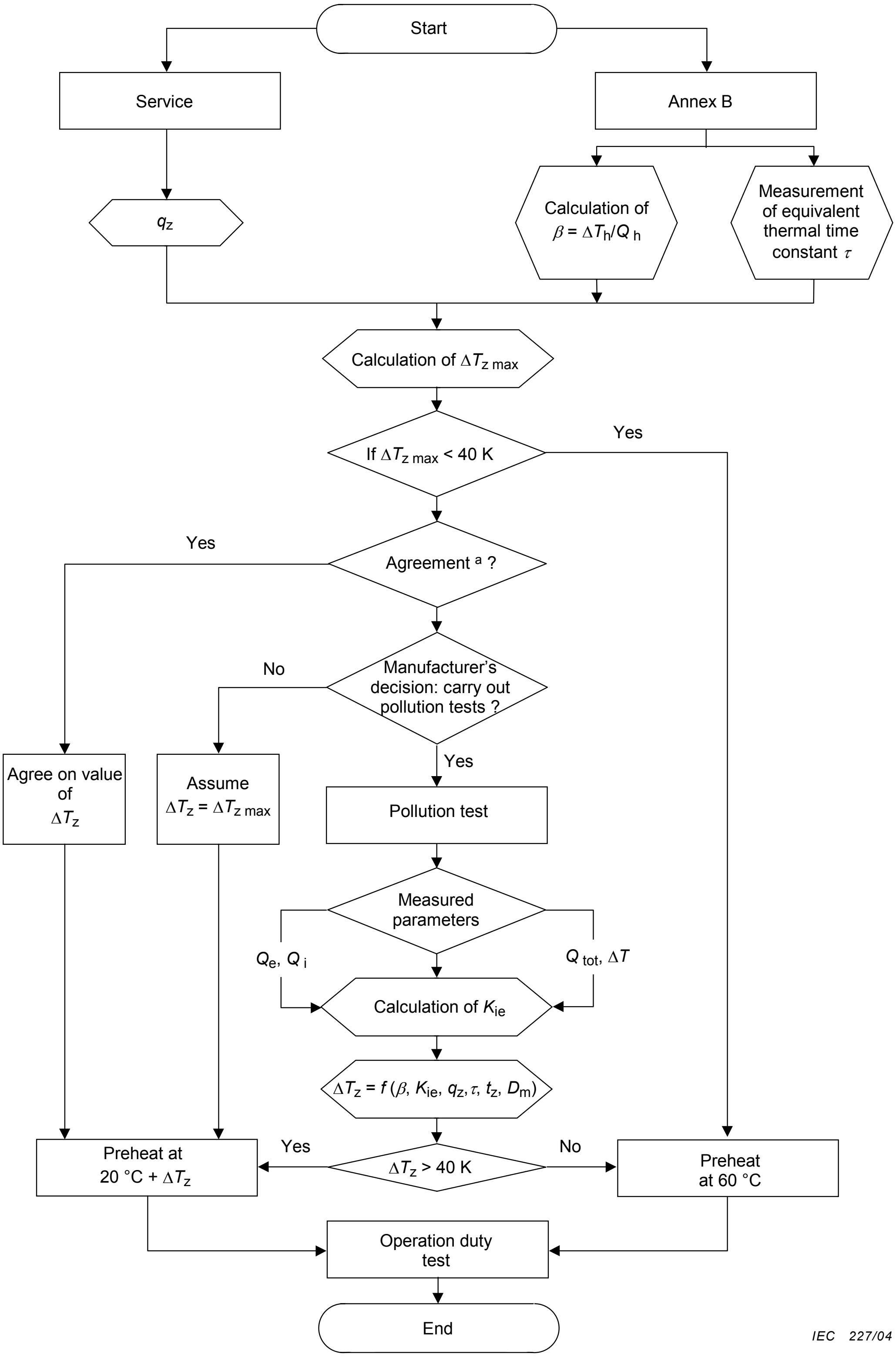
– the expected temperature rise ΔT_z in service is calculated as a function of q_z, K_{ie}, D_m, t_z, β and τ;

– the starting temperature T_{OD} of the operating duty test is calculated on the basis of the following criteria:

  – if ΔT_z is greater than 40 K, T_{OD} = 20 °C + ΔT_z;

  – if ΔT_z is lower than or equal to 40 K, T_{OD} = 60 °C;

– the operating duty test is performed according to the procedure described in 7.5 with a starting temperature equal to T_{OD}.



[a] Agreement between user and manufacturer (for example, based on service experience in specified environment).

Figure F.1 – Flow-chart showing the procedure for determining the preheating of a test sample

F.3 Classification of site severity

The classification of the pollution severity of a site is made on the basis of the expected mean external charge q_z, based on measurements carried out in sites representative of different pollution severities.

Considering that the charge flowing on the surface of an insulator is proportional to its diameter, the value of q_z is normalized to an equivalent diameter of 1 m.

The duration of pollution phenomena (t_z) are assumed as follows:

– pollution event of medium duration with high intensity: 2 h;
– pollution event of long duration: 6 h.

The value of q_z to be considered in the subsequent calculations is that one corresponding to the most severe situation (2 h or 6 h), according to equation (F.2), for the pollution level relevant to the site of installation of the surge arrester.

The values of q_z for the different pollution zones are given in Table F.1.

Table F.1 – Mean external charge for different pollution severities

Pollution level (zone[a])	Minimum specific creepage distance	q_z: mean external charge C/h·m	
	mm/kV	t_z = 2 h	t_z = 6 h
I – Light	16	0,5	0,24
II – Medium	20	3,3	2,4
III – Heavy	25	24,0	14,0
IV – Very heavy	31	55,0	36,0

[a] Pollution levels (zones) correspond to the definition of pollution levels given in Table 1 of IEC 60815.

NOTE The q_z values were obtained using a threshold value of 2 mA (see F.6.3.1).

F.4 Preliminary heating test: measurement of the thermal time constant τ and calculation of β

A procedure similar to that specified in Annex B, relevant to the complete arrester, shall be used, but with the following exceptions:

– the heating time (t_h) shall be shorter than 10 min;
– the charge Q_h applied to the surge arrester during the heating shall be measured;
– τ is the time derived from the cooling curve of the arrester between the temperatures of 60 °C and 22 + 0,63 T_a, where T_a is the ambient temperature in degrees Celsius.

The parameter β shall be calculated according to the following equation:

$$\beta = \frac{\Delta T_h}{Q_h} \qquad \text{(F.1)}$$

where

ΔT_h is the temperature rise during the heating test;

Q_h is the charge applied during the heating test.

NOTE After the heating test, it shall be verified that the heating time (t_h) is shorter than 0,1 × τ; otherwise the heating test shall be repeated with a shorter t_h.

F.5 Verification of the need to perform the pollution tests

In order to check the effective need to carry out the pollution test, a preliminary calculation of the maximum theoretical temperature rise in service ($\Delta T_{z\ max}$) shall be carried out. This calculation assumes that all the charge expected in service (q_z) flows internally. In this hypothesis, $\Delta T_{z\ max}$ can be derived as follows:

$$\Delta T_{z\ max} = \beta\, q_z\, D_m\, \tau \left(1 - e^{\left(-\frac{t_z}{\tau}\right)}\right)\left(\frac{U_r - U_{r\ min}}{U_r}\right) \qquad (F.2)$$

where

U_r is the rated voltage of the surge arrester;

$U_{r\ min}$ is the minimum rated voltage among the surge arrester units.

If the calculation of the maximum temperature rise $\Delta T_{z\ max}$ results in values less than 40 K, the pollution tests are not required and the starting temperature of the operating duty test shall be 60 °C. If the calculation of the maximum temperature rise $\Delta T_{z\ max}$ results in values of 40 K or higher, a test according to the procedure described in this annex shall be carried out unless, by agreement between user and manufacturer (for example, based on service experience in specified environments), the pollution test can be omitted. Moreover, at the decision of the manufacturer, even if the calculation of $\Delta T_{z\ max}$ results in values higher than 40 K, the pollution test may be avoided by using as starting temperature for the operating duty test the value (20 + $\Delta T_{z\ max}$) °C.

F.6 General requirements for the pollution test

F.6.1 Test sample

The test sample shall be representative of the most critical design relevant to a certain arrester type.

The characteristics of the test sample shall be selected according to the criteria given in Table F.2.

Table F.2 – Characteristic of the sample used for the pollution test

Parameter	Selection criteria (characteristic of the sample to be tested with respect to the relevant design type)
U_C/U_R	Maximum
Weighted unbalance (*WU*)[a]	Maximum
Specific creepage distance [mm/kV]	Minimum
Block cross-sectional area	Minimum
Equivalent porcelain diameter	Maximum

[a] The weighted unbalance (*WU*) shall be derived as follows:

$$WU = \max\left(\frac{U_{rk}^2\, CD}{CD_k\, U_r^2}\right) \qquad (F.3)$$

where

U_r is the rated voltage of the surge arrester;

U_{rk} is the rated voltage of the unit k;

CD is the creepage distance of the surge arrester;

CD_k is the creepage distance of the unit k;

k = 1, 2 … n;

n is the number of units of the surge arrester.

F.6.2 Testing plant

The testing plant shall fulfil the requirements of 6.2 of IEC 60507.

F.6.3 Measuring devices and measuring procedures

F.6.3.1 Measurement of the charge

A suitable device for the measurement of the charge shall be used.

For the measurement of the internal charge, only the resistive component of the current shall be considered: the effect of the capacitive current on the charge measurement shall be eliminated. Examples of methods for eliminating the effect of the capacitive current are the waveform subtraction method or the integration upon exceeding a threshold limit (for example, 2 mA (see Table F.1)).

The minimum requirements for the measuring device are given in Table F.3.

Table F.3 – Requirements for the device used for the measurement of the charge

Characteristic	Requirement
Minimum current integration range	0 mA to 500 mA
Minimum current resolution	0,2 mA
Minimum analogue bandwidth	0 Hz to 2 000 Hz
Minimum sampling frequency	1 000 Hz
Maximum updating period of the charge	1 min
Maximum residual capacitive charge in the updating period	±10 % of the total charge in the updating period
Maximum overall measurement uncertainty	±10 %

In the case of two-unit surge arresters, the internal and external charges shall be measured both on the line and earth terminals.

In the case of surge arresters composed of more than two units, the following measuring procedure shall be adopted:

– the internal and external charges shall be measured on the line and earth terminals of the surge arrester;
– only the external charge shall be measured for intermediate units;
– the internal charge is evaluated by means of the following equation:

$$Q_i = \frac{(Q_{iT} + Q_{eT}) + (Q_{iB} + Q_{eB})}{2} - Q_e \qquad \text{(F.4)}$$

where

Q_i is the internal charge of the intermediate unit;
Q_{iT} is the internal charge of the top unit;
Q_{iB} is the internal charge of the bottom unit;
Q_e is the external charge of the intermediate unit;
Q_{eT} is the external charge of the top unit;
Q_{eB} is the external charge of the bottom unit.

F.6.3.2 Measurement of the temperature

The temperature of the internal parts of the arrester may be measured instead of the internal charge.

In this case the measurement of the temperature shall be performed by means of sensors positioned in at least three evenly distributed positions along each unit. The distance between the sensors shall be $h/(n+1)$ where h is the height of the unit and n the number of sensors used.

The minimum requirements for the devices are given in Table F.4.

Table F.4 – Requirements for the device used for the measurement of the temperature

Characteristic	Requirement
Temperature measuring range	20 °C to 200 °C
Absolute measuring uncertainty	±1 K
Resolution	≤0,4 K
Maximum thermal time constant	1 min
Minimum sampling rate	1 min^{-1}
NOTE Typical temperature rises in the test are below 100 K.	

In the case of internal temperature measurement, the charge Q_{tot} shall be measured only at the earth terminal of the surge arrester.

F.6.4 Test preparation

F.6.4.1 Cleaning of the test sample

The surge-arrester housing shall be carefully cleaned so that all traces of dirt and grease are removed.

After cleaning the insulating parts of the surge arrester shall not be touched by hand.

Water, preferably heated to 50 °C, with the addition of trisodium phosphate or equivalent detergent, shall be used, after which the insulator shall be thoroughly rinsed with tap water.

The surface of the insulator is deemed sufficiently clean and free from any grease if large continuous wet areas are observed.

F.6.4.2 Installation of the sample

The arrester shall be tested completely assembled as intended to be used in service. The devices used for the measurement of the charge and of the temperature shall not have any significant influence on the behaviour of the surge arrester under test.

F.7 Test procedures

One of the two test procedures described in F.7.1 and F.7.2 may be used.

F.7.1 Slurry method

F.7.1.1 General

F.7.1.1.1 Contaminant preparation

The contaminant shall be stored in a container so that it can be thoroughly agitated just prior to application. The contaminant shall consist of a slurry of

– water;
– bentonite, 5 g per litre of water;
– an undiluted non-ionic detergent consisting of nonyl-phenol-polyethylene-glycol-ether, or other comparable long-chain non-ionic ether; 1 g per litre of water;
– sodium chloride.

The volume resistivity of the slurry shall be adjusted by the addition of sodium chloride to a range between 400 Ω.cm and 500 Ω.cm.

Volume resistivity shall be measured at a temperature of 20 °C. If, during the measurement of the volume resistivity, the temperature of the slurry is different from 20 °C, a calculation for temperature correction shall be made.

F.7.1.1.2 Ambient conditions

At the start of the test, the surge arrester shall be in thermal equilibrium with the air in the test chamber. The ambient temperature shall not be less than 5 °C nor greater than 40 °C.

F.7.1.2 Preconditioning of the surge-arrester surface

Before starting the preconditioning, the reference voltage of the surge arrester shall be determined, according to the procedure specified in 7.2.

The following steps shall be applied.

a) With the arrester de-energized, the pollutant shall be applied to the complete arrester, including the underside of the sheds. The pollution layer shall appear as a continuous film. Maximum time for application of the pollutant is 10 min.
b) Three minutes after the slurry application is completed the arrester shall be energized at a voltage U_c (see note 2 of F.7.1.3) for 10 min.
c) The arrester shall be cleaned by washing with water and thereafter left to drip dry.
d) Steps a), b) and c) shall be repeated three times.

At the end of the preconditioning process, the surge arrester shall be left to cool at ambient temperature.

In order to verify that no damage has occurred to the surge arrester during the pre-conditioning process, the reference voltage of the surge arrester shall be measured and compared with the measurement performed before the preconditioning. Acceptable limits of variation of the reference voltage shall be specified by the manufacturer.

The test shall start as soon as possible after completion of the preconditioning process.

F.7.1.3 Test procedure

The following steps shall be applied.

a) With the arrester de-energized, the pollutant shall be applied to the complete arrester, including the underside of the sheds. The pollution layer shall appear as a continuous film. Maximum time for application of the pollutant is 10 min.

b) Three minutes after the slurry application is completed the arrester shall be energized at a voltage U_c (see note 2) for 10 min; the charge measurement shall start at the moment of voltage application.

c) The arrester shall be cleaned by washing with water and thereafter left to drip dry. Before starting the next test the internal parts of the arrester shall be left to cool to maximum ±2 K from the average ambient temperature. If the temperature of the internal parts is not measured, a minimum time of 2τ shall be interposed between two subsequent tests in order to ensure that the surge arrester has cooled close to ambient temperature. Any means to cool the arresters to near ambient temperature, which are accepted by the manufacturer, are permitted. Several arresters may be tested in parallel in order to reduce the waiting time.

d) Steps a), b) and c) shall be repeated five times.

e) The expected temperature rise ΔT_z shall be calculated according to the procedure specified in Clause F.8.

f) If the value of ΔT_z is lower than 40 K, no further pollution test is required and the starting temperature T_{OD} of the operating duty test shall be 60 °C. If the value of ΔT_z is higher than, or equal to, 40 K, steps a), b) and c) shall be repeated five more times and the expected temperature rise ΔT_z shall be calculated according to the procedure specified in Clause F.8.

NOTE 1 Washing after each cycle is used to remove any influence from previous test cycles and thus improve the statistical independence between test cycles.

NOTE 2 In cases in which the continuous operating voltage out of other reasons has been selected much higher than the phase-to-earth operating voltage of the system, the test may be carried out at the phase-to-earth voltage by agreement between manufacturer and purchaser.

F.7.2 Salt fog method

F.7.2.1 General

F.7.2.1.1 Contaminant preparation

The salt solution shall be prepared in accordance with Clause 7 of IEC 60507: the salt solution shall be made of sodium chloride (NaCl) of commercial purity and tap water.

The salinity used shall be two steps below the specified withstand salinity of the surge arrester. Tolerances on the value of the salinity shall be in accordance with Clause 7 of IEC 60507. The measurement of the salinity shall be made by measuring the conductivity with a correction of temperature in line with the indications of IEC 60507.

F.7.2.1.2 Spraying system

The system for the production of the salt fog shall be in accordance with the specifications of Clause 8 in IEC 60507.

F.7.2.1.3 Preconditioning of the arrester surface

Before starting the preconditioning, the reference voltage of the surge arrester shall be determined, according to the procedure specified in 7.2.

The preconditioning process shall be carried out on one unit of the surge arrester at a time. If the preconditioning is carried out on the units assembled in the surge arrester, the other units are therefore short-circuited with an external wire, and are not energized.

The unit shall be energized at voltage U_c and submitted to the salt fog for 20 min or until flashover.

If flashover does not occur, the voltage is raised to the rated voltage of the surge arrester unit for 5 s or until flashover, and then lowered again to the U_c value for 5 min. This procedure is repeated until eight flashovers are obtained.

In order to obtain the eight flashovers without an excessively high number of voltage increase cycles, the preconditioning shall be carried out at a value of salinity preferably higher than the expected maximum withstand level of the unit.

Alternatively, by agreement between the manufacturer and the purchaser, the preconditioning may be carried out on the arrester housing without the internal elements.

After the preconditioning of each unit, the fog shall be cleared and the surge arrester shall be washed down with tap water.

At the end of the preconditioning process, the surge arrester shall be allowed to cool to ambient temperature.

In order to verify that no damage has occurred to the surge arrester during the pre-conditioning process, the reference voltage of the surge arrester shall be measured and compared with the measurement carried out before the preconditioning. Acceptable limits of variation of the reference voltage shall be specified by the manufacturer.

The salt fog test shall start as soon as possible after completion of the preconditioning process.

At the start of the test, the surge arrester shall be in thermal equilibrium with the air in the test chamber. The ambient temperature shall not be less than 5 °C nor greater than 40 °C and its difference from the temperature of the water solution shall not exceed 15 K.

F.7.2.2 Test procedure

The following steps shall be applied.

a) The surge arrester shall be uniformly rinsed with tap water. The test voltage U_c (see note 2) shall be applied while the surge arrester is still completely wet.
b) The surge arrester shall be energized at the specified test voltage and the salt-solution pump and air compressor shall be switched on. The test is deemed to have started as soon as the compressed air has reached the normal operating pressure at the nozzles. This starting time is intended also for the charge measurement system.
c) The fog production shall be stopped after 15 min and the surge arrester shall be kept energized for another 15 min.
d) The salt fog shall be evacuated and the surge arrester shall be allowed to cool to ambient temperature before starting the subsequent cycle. In order to ensure that the surge arrester has cooled close to ambient temperature a minimum time of 2τ shall be interposed between two subsequent tests. Any means to cool the arresters to near ambient temperature, which are accepted by the manufacturer, are allowed. Several arresters may be tested in parallel in order to reduce the waiting time.
e) Steps a), b), c) and d) shall be repeated five times.
f) The expected temperature rise ΔT_z shall be calculated according to the procedure specified in Clause F.8.

g) If the value of ΔT_z is lower than 40 K, no further pollution test is required and the starting temperature T_{OD} of the operating duty test shall be 60 °C. If the value of ΔT_z is higher than, or equal to, 40 K, steps a), b), c) and d) shall be repeated five more times and the expected temperature rise ΔT_z shall be calculated according to the procedure specified in Clause F.8.

NOTE 1 Washing after each cycle is used to remove any influence from previous test cycles and thus improve the statistical independence between test cycles.

NOTE 2 In cases in which the continuous operating voltage out of other reasons has been selected much higher than phase-to-earth operating voltage of the system, the test may be carried out at this phase-to-earth voltage by agreement between manufacturer and purchaser.

F.8 Evaluation of test results

F.8.1 Calculation of K_{ie}

For each repetition of the test cycle the value of K_n is calculated as follows:

$$K_n = \frac{\sum \left(\frac{Q_{ik} \, U_{rk}}{U_r} \right)}{Q_{e\,max}} \tag{F.5}$$

where

$Q_{e\,max}$ is the maximum of external charge levels;

Q_{ik} is the internal charge relevant to unit k;

U_{rk} is the rated voltage of unit k;

U_r is the rated voltage of the surge arrester;

k = 1, 2 ... n;

n is the number of units of the surge arrester.

In the case in which the temperature of the internal parts has been measured instead of the internal charge, equation (F.5) is replaced by equation (F.6):

$$K_n = \frac{\sum \left(\frac{\Delta T_k \; U_{rk}}{\beta \; U_r} \right)}{Q_{e\,max}} \tag{F.6}$$

where ΔT_k is the temperature rise relevant to unit k calculated as the arithmetical mean value between the maximum temperature measured in the different points of the unit.

NOTE If the internal temperature rise ΔT_k is directly measured during the test, $Q_{e\,max}$ can be calculated according to the following equation:

$$Q_{emax} = \max \left(Q_{tot} - \frac{\Delta T_k}{\beta} \right) \tag{F.7}$$

The average value K_{ieM} is calculated as the arithmetical mean of the values of K_n, σ is calculated as the standard deviation of the values of K_n, and the statistical ratio K_{ie} is calculated according to the following formula:

$$K_{ie} = K_{ieM} + c\,\sigma \tag{F.8}$$

where

c = 2 in the case where the calculation is carried out on the basis of the measurements relevant to 10 test cycles;

c = 2,9 in the case where the calculation is carried out on the basis of the measurements relevant to five test cycles.

F.8.2 Calculation of the expected temperature rise ΔT_z in service

The expected temperature rise ΔT_z is calculated according to the following equation:

$$\Delta T_z = \beta K_{ie}\, q_z\, D_m\, \tau \left(1 - e^{\left(-\frac{t_z}{\tau}\right)}\right) \tag{F.9}$$

F.8.3 Preparation for the operating duty test

The starting temperature T_{OD} of the operating duty test is calculated on the basis of the following criteria:

– if ΔT_z is greater than 40 K, T_{OD} = 20 °C + ΔT_z;

– if ΔT_z is lower than or equal to 40 K, T_{OD} = 60 °C.

The operating duty test is performed according to the procedure described in 8.5 with a starting temperature equal to T_{OD}.

F.9 Example

The following example refers to the application of the test procedure on a surge arrester having the following ratings:

U_r	198 kV
$U_{r\,min}$	90 kV
U_c	156 kV
test voltage	142 kV (see note)
number of units	2
U_r (bottom element)	90 kV
U_r (top element)	108 kV
D_m	198 mm

NOTE The value of the test voltage was chosen in line with note 2 of F.7.2.2.

F.9.1 Preliminary heating test

The results of the preliminary heating tests are the following:

τ 1,5 h

β 19 K/C (i.e. a charge of 5,3 °C was necessary to heat the surge arrester from 20 °C to 120 °C).

F.9.2 Verification of the need to perform the pollution test

The calculation of $\Delta T_{z\,max}$, by means of equation (F.2) gives the results reported in Table F.5.

Table F.5 – Calculated values of $\Delta T_{z\ max}$ for the selected example

Pollution zone	Duration of pollution event h	$\Delta T_{z\ max}$ K	Need to perform the pollution tests
I	2	1,1	No
	6	0,7	
II	2	7,5	No
	6	7,3	
III	2	54,4	Yes
	6	42,3	
IV	2	124,7	Yes
	6	108,8	

The application of the surge arrester in pollution zones I and II does therefore not require the pollution tests, and the starting temperature of the operating duty test shall be taken as 60 °C.

F.9.3 Salt fog tests

The results of the salt fog tests, at a salinity of 14 kg/m^3, are given in Table F.6.

Table F.6 – Results of the salt fog test for the selected example

Test No.	Q_{ebot} [a] C	Q_{etop} [c] C	Q_{itop} [d] C	Q_{ibot} [b] C	K_n
1	6,7	4,1	2,3	0	0,18
2	5,9	4,2	1,3	0	0,12
3	6,4	4,3	1,8	0	0,15
4	6,7	4,5	2,2	0	0,18
5	5,9	3,5	2,2	0	0,20
6	5,7	3,6	2	0	0,19
7	6,2	3,5	2,4	0	0,21
8	6,0	3,5	2,4	0	0,21
9	6,8	4,0	2,6	0	0,20
10	6,2	3,8	2,1	0	0,18

[a] Q_{ebot} is the surface charge measured at the earth terminal of the bottom unit.
[b] Q_{ibot} is the internal charge measured at the earth terminal of the bottom unit.
[c] Q_{etop} is the surface charge measured at the line terminal of the top unit.
[d] Q_{itop} is the internal charge measured at the line terminal of the top unit.

F.9.4 Calculation performed after five test cycles

F.9.4.1 Calculation of K_{ie}

The elaboration of the data obtained during the first five pollution test cycles gives the following results:

K_{ieM} = 0,166 (i.e. the arithmetical mean of the values K_n)

σ = 0,031 (i.e. the standard deviation of the values K_n).

The statistical ratio K_{ie} is calculated according to the following equation:

$$K_{ie} = 0,166 + 2,9 \times 0,031 = 0,256 \tag{F.10}$$

F.9.4.2 Calculation of ΔT_z and of T_{OD}

The calculation of the expected temperature rise in service ΔT_z (see F.8.2) relevant to the different pollution zones are reported in Table F.7.

Table F.7 – Calculated values of ΔT_z and of T_{OD} after 5 cycles for the selected example

Pollution zone	Duration of pollution event h	ΔT_z K	T_{OD} °C
III	2	26	60
	6	20	60
IV	2	59	79
	6	51	71

Therefore, in the case of application of the surge arrester in pollution zone III, no further pollution test is required and the starting temperature of the operating duty test shall be 60 °C while, for pollution zone IV, five more pollution test cycles shall be performed.

F.9.5 Calculation performed after 10 test cycles

F.9.5.1 Calculation of K_{ie}

The elaboration of the data obtained during the first 10 pollution test cycles gives the following results:

K_{ieM} = 0,182 (i.e. the arithmetical mean of the values K_n)

σ = 0,028 (i.e. the standard deviation of the values K_n).

The statistical ratio K_{ie} is calculated according to the formula below:

$$K_{ie} = 0,182 + 2 \times 0,028 = 0,238 \tag{F.11}$$

F.9.5.2 Calculation of ΔT_z and of T_{OD}

The calculation of the expected temperature rise in service ΔT_z (see F.8.2) and of the starting temperature for the operating duty test T_{OD} (see F.8.3) relevant to the different pollution zones (in this case calculation has to be made only for pollution zone IV) are reported in Table F.8.

Table F.8 – Calculated values of ΔT_z and of T_{OD} after 10 cycles for the selected example

Pollution zone	Duration of pollution event h	ΔT_z K	T_{OD} °C
IV	2	54	74
	6	47	67

Therefore, in the case of application of the surge arrester in pollution zone IV, the operating duty test shall be conducted starting at 74 °C.

Annex G
(informative)

Typical information given with enquiries and tenders

G.1 Information given with enquiry

G.1.1 System data

- Highest system voltage.
- Frequency.
- Maximum voltage to earth under system fault conditions (earth fault factor or system of neutral earthing).
- Maximum duration of the earth fault.
- Maximum value of temporary overvoltages and their maximum duration (earth fault, loss of load, ferro-resonance).
- Insulation level of equipment to be protected.
- Short-circuit current of the system at the arrester location.

G.1.2 Service conditions

For normal conditions, see 5.4.1.

Abnormal conditions:

a) For ambient conditions, see 5.4.2 and Annex A:
   - for the natural pollution level, see IEC 60071-2.
b) System:
   - possibility of generator overspeeding (voltage-versus-time characteristics);
   - nominal power frequency other than 48 Hz to 62 Hz;
   - load rejection and simultaneous earth faults. Formation during faults of a part of the system with an insulated neutral in a normally effectively earthed neutral system;
   - incorrect compensation of the earth fault current.

G.1.3 Arrester duty

a) Connection to system:
   - phase to earth;
   - neutral to earth;
   - phase to phase.
b) Type of equipment being protected:
   - transformers (directly connected to a line or via cables);
   - rotating machines (directly connected to a line or via transformers);
   - reactors;
   - HF-reactors;

- other equipment of substations;
- gas-insulated substations (GIS);
- capacitor banks;
- cables (type and length), etc.

c) Maximum length of high-voltage conductor between arrester and equipment to be protected (protection distance).

G.1.4 Characteristics of arrester

- Continuous operating voltage.
- Rated voltage.
- Steep current impulse residual voltage.
- Standard nominal discharge current and residual voltages.
- Switching current impulses and residual voltages.
- For 10 000 A and 20 000 A arresters, respective long-duration discharge class, see 8.4.2.
- Pressure-relief class (short-circuit current capability), see 6.11.
- Length and shape of creepage distance of arrester housing. Selected on the basis of service experience with surge arresters and/or other types of equipment in the actual area.

G.1.5 Additional equipment and fittings

- Metal-enclosed arrester.
- Type of mounting: pedestal, bracket, hanging (in what position) etc. and if insulating base is required for connection of surge counters. For bracket-mounted arresters whether bracket is to be earthed or not.
- Mounting orientation if other than vertical.
- Earth lead disconnector/fault indicator if required.
- Cross-section of connection lead.

G.1.6 Any special abnormal conditions

For example: very frequent operation.

G.2 Information given with tender

- All points from G.1.4 and G.1.5.

In addition:

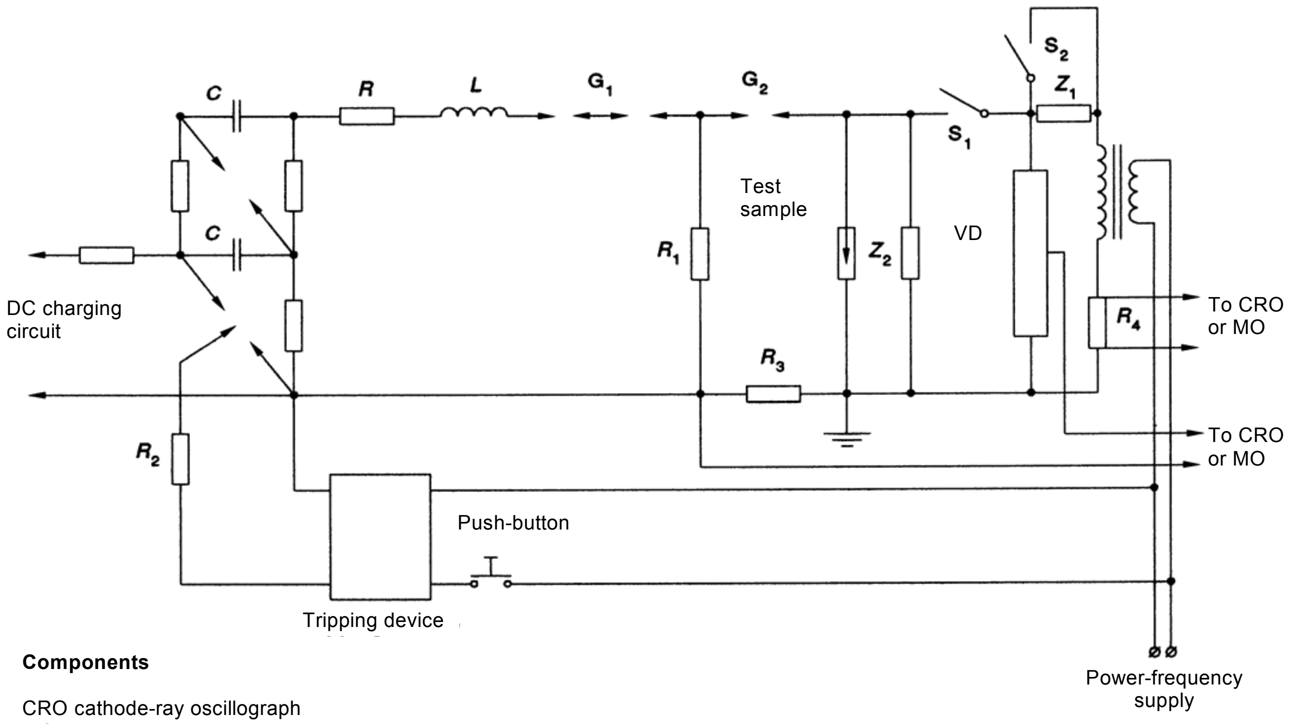
- reference current and voltage at ambient temperature;
- power-frequency voltage versus time characteristics (see Annex D);
- lightning impulse residual voltage at 0,5, 1 and 2 times the nominal discharge current. If the complete arrester acceptance test cannot be carried out at one of those currents, the residual voltage shall in addition be specified for current in the range of 0,01 to 0,25 times the nominal discharge current, see 6.3 and 8.3;
- pressure-relief function;
- clearances. Mounting specifications;
- possibilities of mounting, drilling plans, insulating base, bracket;

– type of arrester terminals and permissible conductor size;
– maximum permissible length of lead between arrester and surge counter, and between surge counter and earth;
– dimensions and weights;
– cantilever strength.

Annex H
(informative)

Typical circuit for high current impulse operating duty test
(see 8.5.4)

It is the purpose of this annex to suggest a suitable test circuit (Figure H.1) for use in the high current impulse operating duty test (see 8.5.4) and to describe the function of the various circuit components rather than to specify a standard test circuit which should be used in all tests wherever made. The requirements for the operating duty test such as the power-frequency voltage and the characteristics of the current impulse are described in 8.5.1 and 8.5.4. The exact method by which these requirements are met is not important. There are many possible variations in the choice both of the circuit and values for the various components.



Components

CRO cathode-ray oscillograph
MO magnetic oscillograph
VD voltage divider
S switch

Figure H.1 – Typical test circuit diagram for high current impulse operating duty test

The test sample is connected via a switch S_1 to the power-frequency supply, usually a transformer, although this is not essential. An impulse generator, shown as a two-stage circuit although it may be a single-stage circuit if adequate, is connected to the arrester through a resistor *R*, an inductor *L* and spark gaps G_1 and G_2. The wave-shape of the current impulse is controlled by selecting suitable values for *C*, *R* and *L*. A low-resistance non-inductive shunt R_3 and a voltage divider V.D. are shown for the measurements of impulse current and voltage respectively. A shunt R_4 is shown in the leads from the power transformer for recording the power frequency current through the arrester.

The spark gap which isolates the impulse generator from the arrester may be of various forms. In the type of gap shown, the resistor R_1, if used, may be of the order of a megohm and serves to maintain a point in the multiple spark gap at earth potential when no current is flowing. Part G_1 of the gap is not, therefore, submitted to any of the power-frequency voltage. Part G_2 of the gap is made as small as is consistent with its ability to withstand the power-frequency voltage. Z_1 and Z_2 are impedances that by the switch S_2 could be used to control the power-frequency voltages (U_r^* and U_c^* respectively) across the test sample, still fulfilling the power-frequency source requirements specified in 8.5.1.

The current from the power-frequency source may be recorded either by a magnetic oscillograph or a cathode ray oscillograph if proper precautions are taken. The power-frequency voltage may be recorded by a magnetic oscillograph or a cathode ray oscillograph through a voltage divider or a potential transformer.

The impulse generator may be tripped, as shown in Figure H.1, through a tripping device. This applies a high-voltage pulse to the centre electrode of the three electrode gap in the impulse generator. A high-resistance R_2 prevents appreciable impulse current flowing in the tripping circuit. The tripping of the impulse generator may be initiated by means of a push button.

Annex I
(informative)

Typical circuit for a distributed constant impulse generator for the long duration current impulse withstand test
(see 8.4)

It is the purpose of this annex to give the principle of a suitable test circuit for use in the long-duration current impulse withstand test and to describe the function of the various circuit components rather than to specify a standard test circuit which should be used in all tests.

The requirements of waveshape, duration, energy injected into the test sample and interval between impulses etc. are given in the test specification.

The exact method by which these requirements are met is immaterial. There are many possible variations both in the arrangement of the circuit and in the choice of values for the various components. Figure I.1 shows a simplified diagram of a distributed constant impulse generator. The surge impedance of the generator is determined by

$$Z = \sqrt{L/C}$$, when neglecting the resistance.

The number of *LC* sections of the generator will normally be about 10 to produce an acceptable waveshape. To limit the oscillations at the beginning and at the end of the peak of the wave, it may be necessary to increase the inductances at both ends of the generator as well as to introduce parallel resistors *R* to compensate for the reduced front steepness caused by the increased inductances.

The triggering gap can be a simple switch. If an auxiliary impulse generator is used to initiate the discharge of the distributed constant generator, the stored energy of the former shall not exceed 0,5 % of the stored energy of the latter.

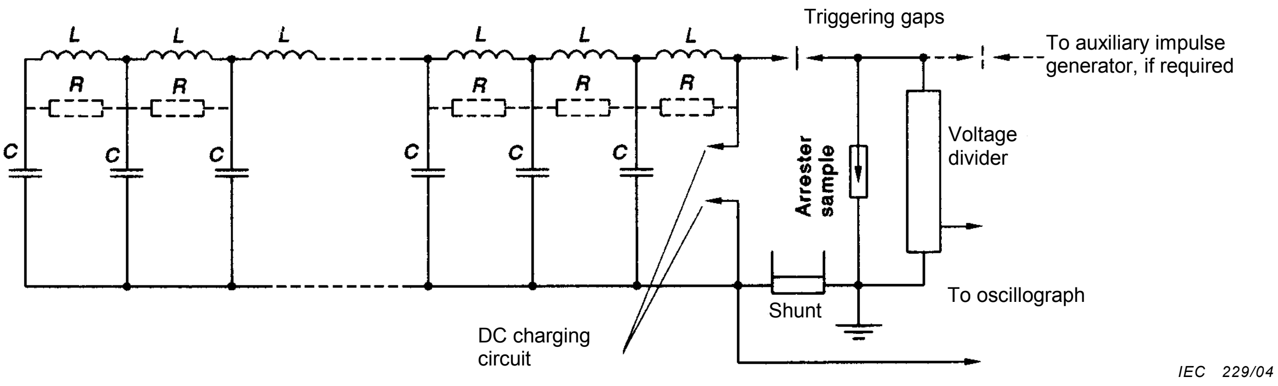


Figure I.1 – Typical distributed constant impulse generator for the long-duration impulse test

The current through, and the voltage across, the arrester sample shall be recorded.

Annex J
(informative)

Typical maximum residual voltages

Table J.1 – Residual voltages for 20 000 A and 10 000 A arresters in per unit of rated voltage

Rated voltage U_r kV r.m.s.	**20 000 A** kV (peak)/U_r			**10 000 A** kV (peak)/U_r		
	Steep[a]	**Lightning**[b]	**Switching**[c]	**Steep**[a]	**Lightning**[b]	**Switching**[c]
3 – 29				2,6 – 4,0	2,3 – 3,6	2,0 – 2,9
30 – 132	2,6 – 3,1	2,3 – 2,8	2,0 – 2,3	2,6 – 3,7	2,3 – 3,3	2,0 – 2,6
144 – 342	2,6 – 3,1	2,3 – 2,8	2,0 – 2,3	2,6 – 3,7	2,3 – 3,3	2,0 – 2,6
360 – 756	2,6 – 3,1	2,3 – 2,8	2,0 – 2,3	2,6 – 3,1	2,3 – 2,8	2,0 – 2,3

NOTE The table gives the range of maximum residual voltages normally available. Low values refer normally to arresters with high line discharge class and vice versa.

[a] For steep current impulse residual voltage test, see 8.3.1.

[b] For lightning impulse protection level, see 8.3.2.

[c] For switching impulse protection level, see 8.3.3.

Table J.2 – Residual voltages for 5 000 A, 2 500 A and 1 500 A arresters in per unit of rated voltage

Rated voltage U_r kV r.m.s.	**5 000 A** kV (peak)/U_r		**2 500 A** kV (peak)/U_r		**1 500 A** kV (peak)/U_r	
	Steep[a]	**Light-ning**[b]	**Steep**[a]	**Light-ning**[b]	**Steep**[a]	**Light-ning**[b]
0,175 – 2,9	2,7 – 4,0	2,4 – 3,6	3,7 – 5,0	3,3 – 4,5	4,5 – 6,7	4,0 – 6,0
3 – 29	2,7 – 4,0	2,4 – 3,6	4,0	3,6		
30 – 132	2,7 – 3,7	2,4 – 3,6	4,0	3,6		

NOTE The table gives the range of maximum residual voltages normally available.

[a] For steep current impulse residual voltage test, see 8.3.1.

[b] For lightning impulse protection level, see 8.3.2.

Annex K
(informative)

Ageing test procedure – Arrhenius law – Problems with higher temperatures

The Arrhenius law has provided good confidence on life expectancy of metal-oxide blocks. It is the basis for the present ageing test procedure (see 8.5.2). The upper limit for the normal ambient air temperature for metal-oxide arresters according to this standard is 40 °C. For some arresters, such as dead-front or liquid-immersed, the upper limit of the ambient temperature of the medium in which the arrester operates is higher (respectively +65 °C and +95 °C).

The accelerated rate of ageing is reasonably estimated by the acceleration factor AF_T = $2{,}5^{(\Delta T/10)}$ where ΔT is the difference between the test temperature and the upper limit of the ambient temperature associated with the product.

Table K.1 provides examples of the minimum demonstrated lifetime prediction given by a 1 000 h ageing test at 115 °C, as described in 8.5.2.

Table K.1 – Minimum demonstrated lifetime prediction

Upper limit of ambient temperature °C	**Minimum demonstrated lifetime prediction** Years
40	110
65	11
95	0,7

NOTE The minimum demonstrated lifetime prediction is obtained by multiplying the 1 000 h by the acceleration factor.

The 1 000 h test does not give enough confidence in minimum lifetime expectancy for the highest ambient temperature. To improve the situation, increasing the test temperature, test voltage or test duration could be considered.

In general, it is not acceptable to increase the test temperature above 115 °C as it may change the physics of ageing, rendering the Arrhenius law non-applicable. Increasing the test voltage is not acceptable either, as this factor is not established as an acceleration factor.

The only remaining possibility is to increase the test duration. Table K.2 shows the relationship between test duration and the equivalent time for different upper limits of the ambient temperature.

Table K.2 – Relationship between test durations at 115 °C and equivalent time at upper limit of ambient temperature

Upper limit of ambient temperature °C	Test duration at 115 °C h	Equivalent time at upper limit of ambient temperature Years
40	1 000	110
65	2 000	22
95	7 000	5

If these equivalent times at continuous use temperature are not acceptable to the user, the testing time may be increased after agreement between the manufacturer and the user. Alternatively, if it can be demonstrated that the Arrhenius law still applies, a higher temperature may be used after agreement between the manufacturer and the user.

Annex L
(informative)

Guide for the determination of the voltage distribution along metal-oxide surge arresters

L.1 General

The voltage distribution along a metal-oxide surge arrester is governed by the capacitances and the resistances of the non-linear resistors, the stray capacitances from the non-linear resistor column and metal flanges to earthed and live parts, and the boundary conditions (applied voltage, proximity and voltage applied to other objects in the vicinity). Stray capacitances result in uneven voltage distribution along the resistor column, with the maximum voltage stress typically appearing in the upper part of the arrester.

The test voltage U_{ct} for the accelerated ageing procedure (see 8.5.2) is found from the maximum voltage stress appearing along the non-linear resistor column. The voltage distribution may be determined by means of commonly available computer programs for calculation of electric fields and circuits. The results of such calculations are, however, dependent on the representations of the surge arrester and the prevailing boundary conditions. The aim of this annex is to provide basic guidance on the representation of the surge arrester geometry and its electrical characteristics, along with general information on the modelling of the boundary conditions.

Due to the complexities and variations in surge-arrester installations, simplified representations of arrester geometries and boundary conditions are often needed to facilitate computations of voltage distribution for a given arrester design. Different degrees of simplification of the arrester geometry are discussed in Clause L.2, and a simplified representation of the boundary conditions for three-phase installations is proposed in Clause L.3. For modelling of other surge arrester designs, for example, GIS arresters, no guidance is given since geometries and boundary conditions are normally well defined.

The calculation procedure may be carried out in two different ways depending on the degree of complexity in the electrical representation of the non-linear resistor column, as described in Clause L.4.

Examples of electric field calculations, representing a typical outdoor arrester installation, are presented in Clause L.5.

L.2 Modelling of the surge arrester

Since the stray capacitances are important to the voltage distribution along the non-linear resistor column, the influence of various simplifications in the surge arrester model must be considered with respect to these capacitances. A series of electric field calculations, carried out using an axi-symmetric representation of the arrester, have given the following results with respect to the degree of simplification to the arrester model.

– The non-linear resistor column, including any metal spacers, should be represented by its actual dimensions and permittivity. An "equivalent" non-linear resistor column of larger diameter, and correspondingly decreased permittivity, results in a higher maximum voltage stress. Similarly, replacing the actual non-linear resistor/spacer column with an "equivalent" column without spacers, and with a correspondingly increased permittivity, also results in a higher maximum voltage stress.

– The housing may be represented by a cylinder having an inner diameter equal to the inner diameter of the actual housing and radial thickness equal to the wall thickness of the actual housing. The permittivity should be that of the actual housing material, for example, porcelain or polymer. The sheds may be omitted since they have a negligible influence on the voltage distribution.
– The material between the insulator and the non-linear resistor column (for example, gas or any filling material) should be modelled with its actual dimensions and permittivity.
– The metal flanges may be represented by cylinders having diameters equal to the maximum outer diameter of the actual flanges and heights equal to the heights of the actual flanges.
– The grading rings may be represented by toroids of the same dimensions and physical location as the toroidal elements of the actual grading rings. Omitting the support members, which it is not possible to represent in an axi-symmetric model, may result in an over-estimation of the maximum voltage stress. The representation of the support members in axi-symmetric and three-dimensional models is discussed further in Clause L.5.
– The pedestal, if used, may be represented by a cylinder having a cross-sectional area sufficient to contain the maximum cross-section of the actual pedestal and a height equal to the actual pedestal. Reducing the height of the pedestal results in a higher maximum voltage stress in the upper part of the arrester.
– The high-voltage lead should be represented by a vertical cylindrical conductor of a diameter not greater than the diameter of the actual line lead. Omitting the high-voltage lead results in a higher maximum voltage stress in the upper part of the arrester.

L.3 Modelling of the boundary conditions

For surge arresters in typical three-phase outdoor installations, for example, in substations, the boundary conditions are determined by the distances to earthed structures and adjacent phases. In general, this is a truly three-dimensional electric field problem, where both the magnitude and the phase angle of the applied voltages need to be considered.

The calculation procedure may be simplified by reducing the original three-phase, three-dimensional (3D) configuration to an equivalent single-phase, axi-symmetric configuration, which can be treated by generally available two-dimensional (2D) calculation software. The equivalent axi-symmetric configuration is obtained by modelling the arrester in the centre of an earthed cylinder having a radius determined by the minimum phase-to-earth clearance recommended by the manufacturer. The height of the earthed cylinder should be 1,5 times the total height of the arrester plus the pedestal.

NOTE The equivalent axi-symmetric configuration is valid for a typical three-phase installation with the three arresters positioned on a straight line in parallel to an earthed structure, at a distance equal to the minimum recommended phase-to-earth clearance and with the minimum recommended phase-to-phase clearance, as shown in Figure L.1.

L.4 Calculation procedure

The calculation procedure may be performed in two different ways, as described in L.4.1 and L.4.2, depending on how the electrical properties of the non-linear resistor column are represented. The exclusively capacitive representation (see L.4.1) will always give conservative results in comparison with the combined capacitive/resistive representation (see L.4.2), which gives lower but more realistic stresses. Any other calculation procedure that leads to the same or more conservative results may also be used.

L.4.1 Capacitive representation of the non-linear resistor column

In this case, the non-linear resistor column is represented exclusively by its capacitance (permittivity), neglecting the influence of the resistive characteristic. This conservative approximation is justified as long as the calculated maximum voltage stress corresponds to a test voltage U_{ct} that is below the reference voltage of the resistors. The maximum voltage stress should be determined over an axial distance not exceeding 3 % of the total arrester length.

L.4.2 Capacitive and resistive representation of the non-linear resistor column

Here, the non-linear resistor column is represented by its capacitance in parallel to its non-linear resistive characteristic. This representation of the non-linear resistor column results in a more realistic calculated maximum voltage stress compared to the case with the more conservative capacitance-only representation.

Firstly, a capacitive electric field calculation is carried out to determine the stray capacitances to earth. Secondly, the resistive characteristic is introduced and the voltage distribution is calculated by means of electric circuit analysis. In general, an iterative calculation process is required due to the temperature dependence of the resistance. However, as a reasonably conservative approximation, the constant resistive characteristic at +20 °C should be used.

Figure L.2 shows a simplified multi-stage equivalent circuit of an arrester, which may be used with an electric circuit analysis program to determine the voltage distribution considering both capacitive and resistive effects. The arrester is modelled by the voltage-dependent resistances, the capacitances representing the non-linear resistor column and the stray capacitances to earth. Each stage of the equivalent circuit may represent one single metal-oxide non-linear resistor, as the extreme case, or a section of the non-linear resistor column. The length of each section should not exceed 3 % of the total arrester length.

With the node voltages obtained by an exclusively capacitive electric field calculation in accordance with L.4.1, the stray capacitances to earth may be derived as follows:

$$C_{e,x} = \frac{(U_{x+1} - U_x) \times C_{MO,x+1} - (U_x - U_{x-1}) \times C_{MO,x}}{U_x} \quad (x = 1, 2, ..., n - 1)$$

where

U_x is the voltage at node x;

$C_{MO,x}$ is the capacitance of section x;

$C_{e,x}$ is the stray capacitance to earth at node x;

n is the number of sections.

NOTE These calculations may result in negative values in certain cases. This is a consequence of the chosen model, with all the stray capacitances connected to earth. By using other models with different representations of stray capacitances, negative values may be avoided.

L.4.3 Determination of U_{ct}

The ratio of U_{ct} to U_c in the accelerated ageing procedure (see 8.5.2) is determined by dividing the calculated maximum voltage stress along the total length of the non-linear resistor column (energized at $U = U_c$), by the mean voltage stress along the same length.

L.5 Example calculations

Example calculations of the axial voltage distribution for a typical metal-oxide surge arrester were carried out using two different computation methods: the finite element method (FEM) and the boundary element method (BEM). The finite element method was used only for 2D computations, while the boundary element method was used for both 2D and 3D computations.

The example calculations were carried out using both the capacitance-only representation, as well as the capacitive/resistive representation. The arrester model used in the calculations is a simplified representation of a typical multi-unit arrester with porcelain housing (see Figure L.3a).

L.5.1 Modelling of the arrester and the boundary conditions

The simplifications in the modelling of the arrester were made in accordance with Clause L.2 except for the grading rings, where different approaches were applied as described below.

It was assumed that the typical arrester is equipped with one grading ring and four support members for the ring, as shown in Figure L.3a. The different representations of the grading ring and its supports, corresponding to different degrees of simplification, are shown in Figure L.3b. The first model, using one ring without supports, was used in axi-symmetric 2D and 3D computations (cases A and D, respectively). The second model was used to study the feasibility of adding a ”virtual” grading ring in axi-symmetric calculations to simulate the influence of the grading ring supports. Both 2D and 3D computations were carried out (cases B and E, respectively). The third model is a three-dimensional representation of the grading ring including the supports, used only for 3D computation (case F).

The relative permittivity of the ”equivalent” non-linear resistor columns was chosen as 800, while the relative permittivity of the porcelain housings was set equal to five. The boundary conditions were chosen in accordance with Clause L.3, i.e. the arrester is positioned in an earthed cylinder with a radius determined by the minimum clearance requirement.

L.5.2 Resistive effects of the metal-oxide non-linear resistors

The resistive effect of the metal-oxide non-linear resistors was introduced in accordance with L.4.2. The non-linear resistive characteristic used in the computations is shown in Figure L.4. The resistive effect was investigated in 2D computations with the ”virtual” grading ring included (case C) for comparison with case B, and in 3D computations with the supports included (case G) for comparison with case F.

Due to the non-linear effect introduced by the resistive characteristic, it is necessary to carry out the combined capacitive/resistive calculations at a given voltage level. For the example calculations, it was assumed that U_c = 333 kV r.m.s (471 kV peak) with a frequency of 50 Hz.

L.5.3 Results and conclusions from electric field calculations

The calculated maximum voltage stresses on the metal-oxide non-linear resistor column in each unit are summarised in Table L.1 for the different cases, A to G. The voltage stress is expressed in percent of U_c per metre length of the non-linear resistor column, assuming that the arrester is energized at U_c = 100 %, yielding a mean voltage stress of 34,7 %/m. The results in Table L.1 are average values from several computations using different FEM and BEM computation software. Deviations of 1 %/m to 2 %/m may typically be expected. The maximum stress among the three units is also expressed in terms of the ratio U_{ct}/U_c for determination of the test voltage in the accelerated ageing test (see L.4.3.) Detailed example calculation results showing the voltage stress along the arrester column are presented in Figure L.5 for case B.

In general, it can be concluded that 2D and 3D computations give similar results (case A versus D, and case B versus E). The computation time is, however, several orders of magnitude longer when using 3D computation methods.

With reference to the various simplifications in the modelling of the arrester discussed in previous subclauses, some general conclusions can be drawn from Table L.1:

– the calculated voltage stress in the top unit is significantly lower if the grading ring supports are included in the 3D computation (case A and D versus case F);
– the calculated stress is further reduced in both 2D and 3D computations if the resistive effects are considered (case B versus C, and case F versus G);
– the effect of the grading ring supports may be simulated by introducing a ”virtual” grading ring in the axi-symmetric model (case B versus F, and case C versus G). However, no general rules for proper sizing or placement of the ”virtual” ring can be given on the basis of these results.

Table L.1 – Results from example calculations

Surge arrester model	Case	Maximum voltage stress			Maximum ratio U_{ct} / U_c
		Top unit	Middle unit	Bottom unit	
		% / m	% / m	% / m	p.u.
2D computations					
One grading ring	A	50	39	26	1,44
Two grading rings	B	44	40	27	1,27
Two grading rings, resistive effects	C	41	39	29	1,18
3D computations					
One grading ring	D	50	37	27	1,44
Two grading rings	E	43	38	28	1,24
One grading ring with four supports	F	44	39	27	1,27
One grading ring with four supports, resistive effects	G	41	39	28	1,18

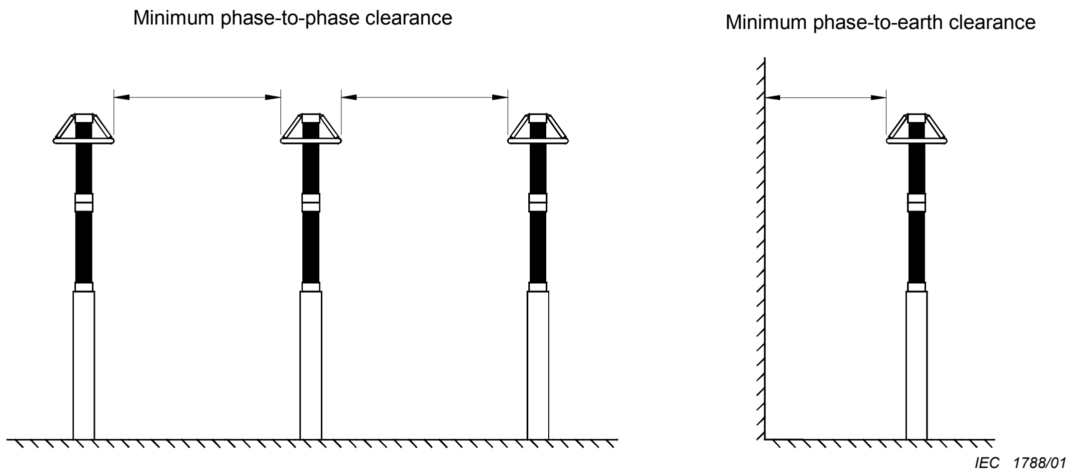
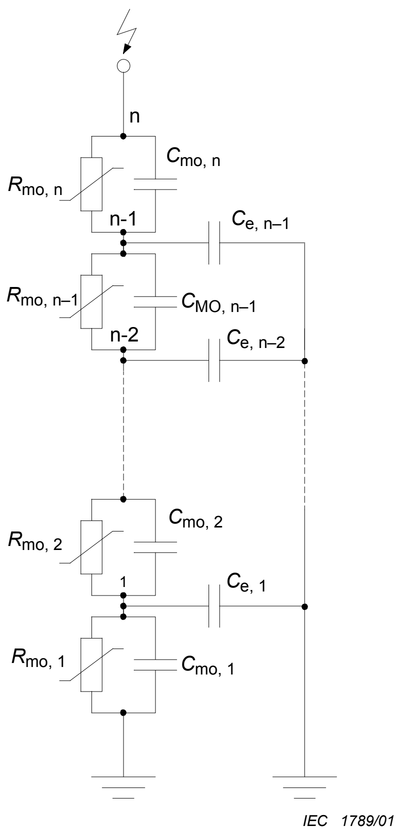


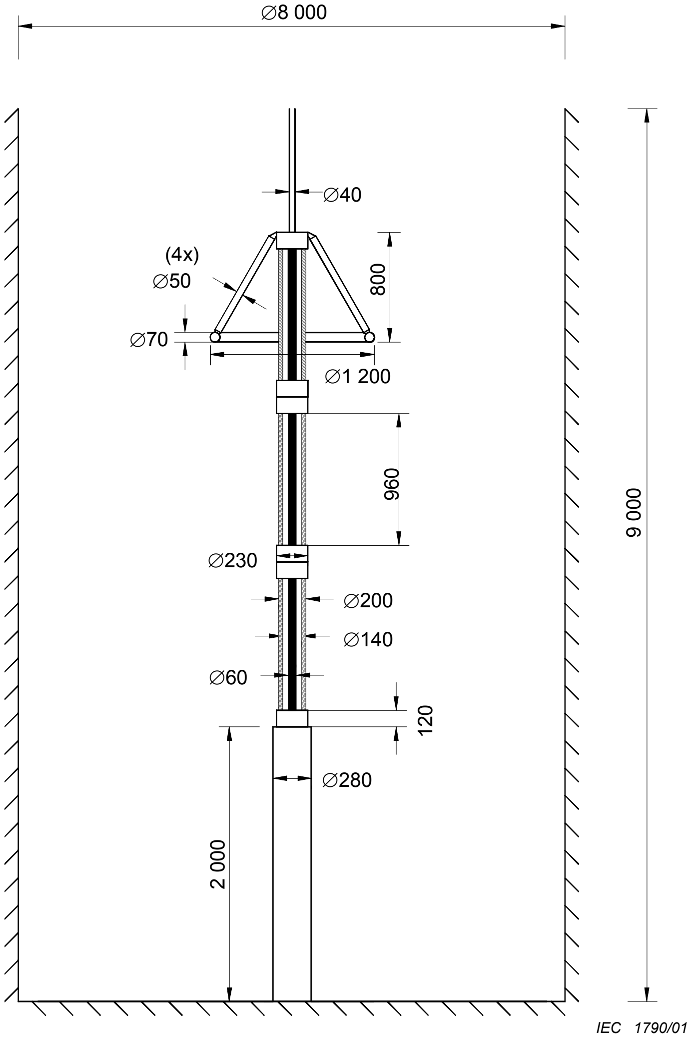
Figure L.1 – Typical three-phase arrester installation



Key

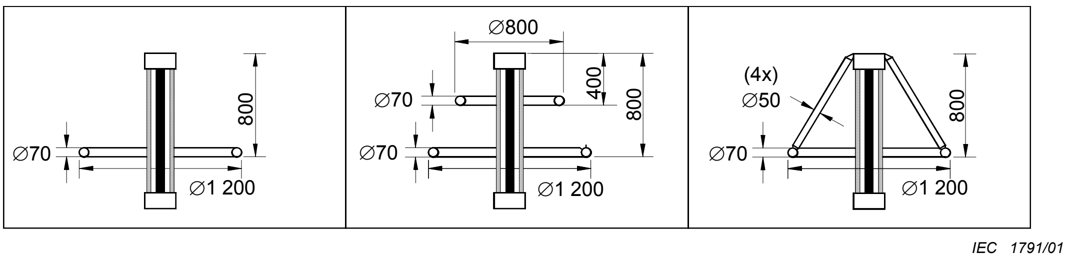
$R_{mo, x}$	Voltage-dependent resistance of section x
$C_{mo, x}$	Capacitance of section x
$C_{e, x}$	Stray capacitance to earth at node x
n	Number of sections

Figure L.2 – Simplified multi-stage equivalent circuit of an arrester



Dimensions in millimetres

Figure L.3a – Simplified model of multi-unit arrester



Case A, D Case B, C, E Case F, G

Dimensions in millimetres

Figure L.3b – Different representations of the grading ring

Figure L.3 – Geometry of arrester model

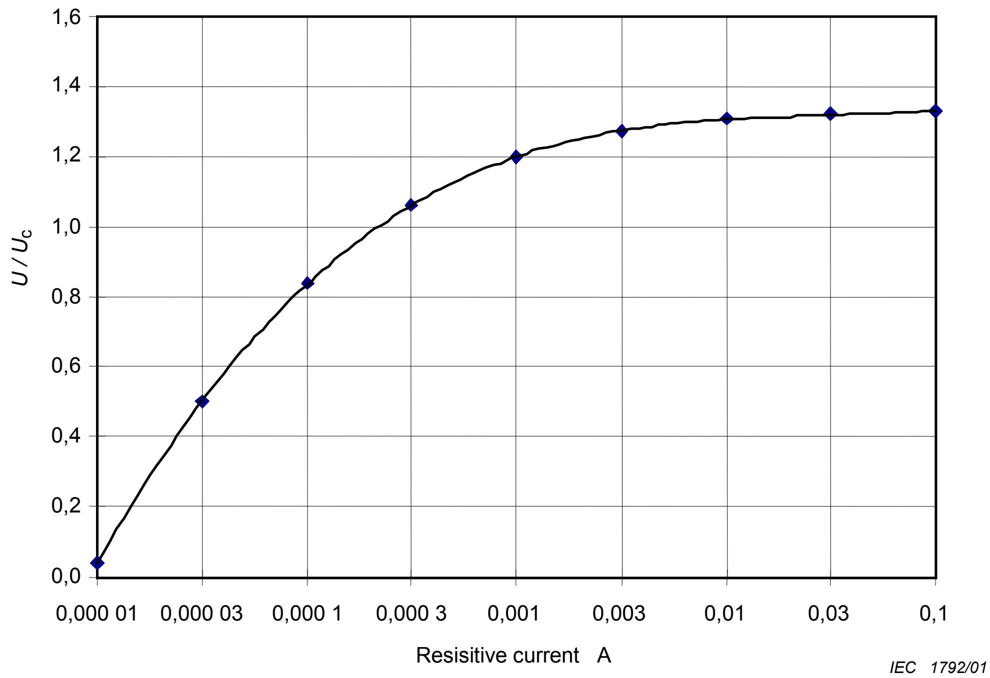


Figure L.4 – Example of voltage-current characteristic of metal-oxide resistors at +20 °C in the leakage current region

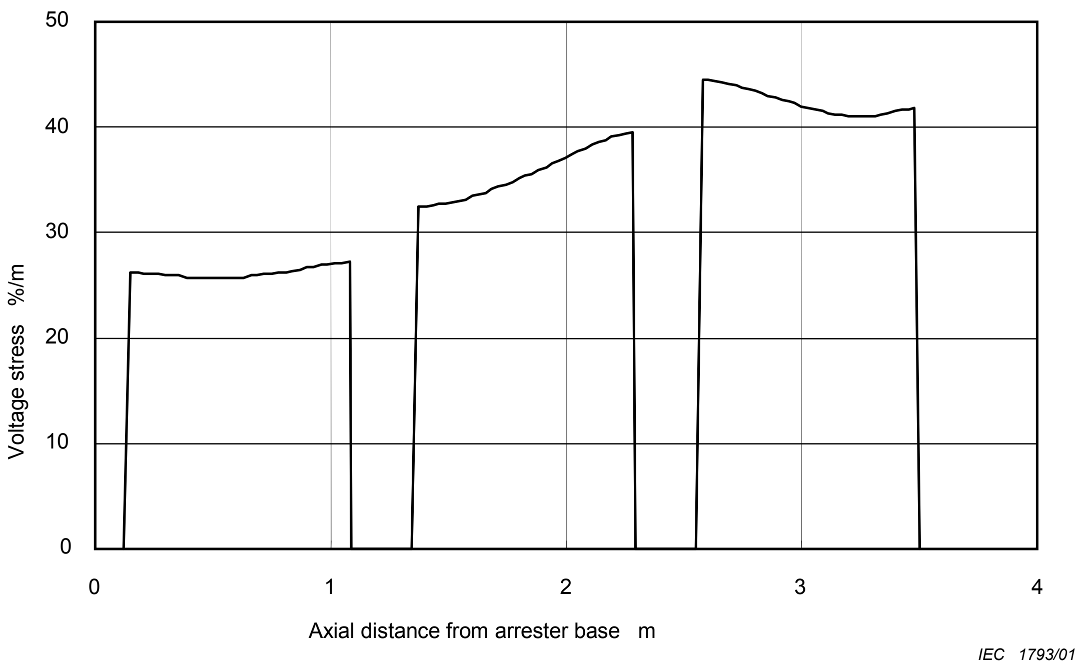


Figure L.5 – Calculated voltage stress along the resistor column in case B

Annex M
(normative)

Mechanical considerations

M.1 Test of bending moment

In the case of a multi-unit arrester, each unit shall be tested with the bending moment according to Figure M.1. The required load is calculated as given below. If the units differ only in length, but are otherwise identical from material and design, it is not necessary to test each unit.

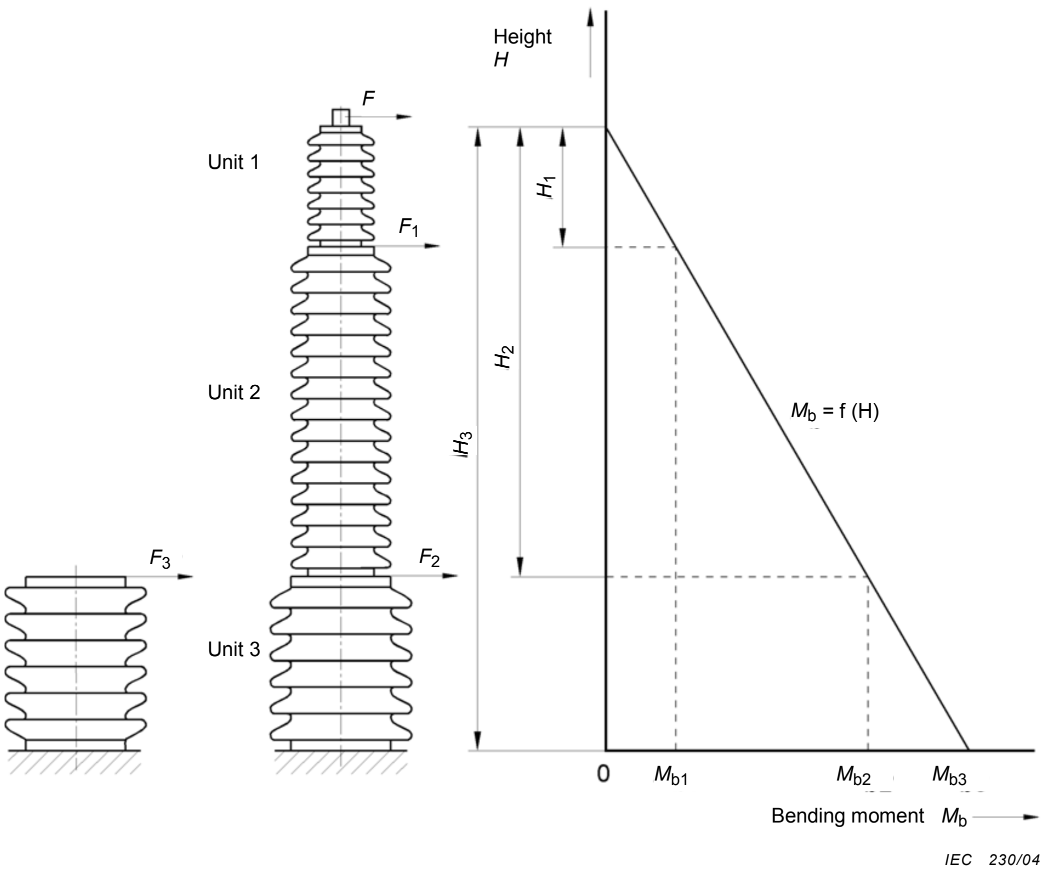


Figure M.1 – Bending moment – multi-unit surge arrester

Testing the complete arrester, the moment affecting the bottom flange is $M_{b3} = F \times H_3$.

The moment affecting the top flange of the bottom unit is $M_{b2} = F \times H_2$.

If one unit is tested separately (example for unit 3), the test force F_2 for the test of the bottom flange of unit 3 is as follows:

$$F_2 \times (H_3 - H_2) = F \times H_3 \text{ ;}$$

$$F_2 = \frac{F \times H_3}{(H_3 - H_2)}$$

The test of the top flange of unit 3 shall be performed with the unit in reversed position. Test force F_3 for the test of the top flange of unit 3 is as follows:

$$F_3 \times (H_3 - H_2) = F \times H_2$$

$$F_3 = \frac{F \times H_2}{(H_3 - H_2)}$$

M.2 Seismic test

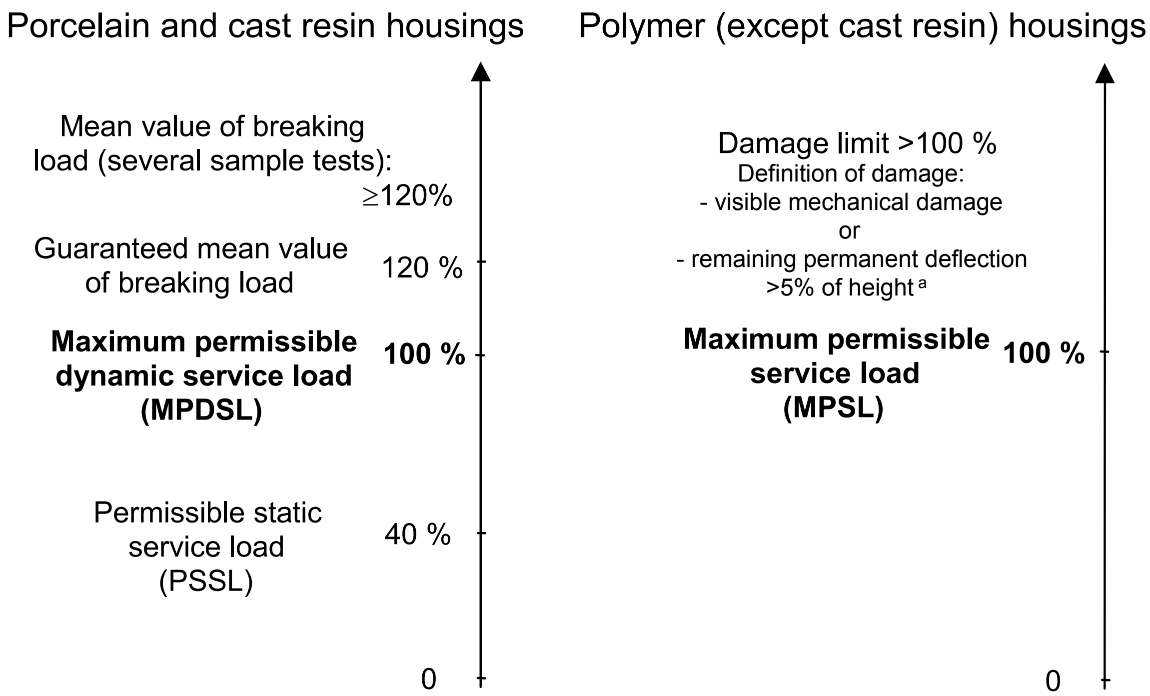
If, after agreement between the manufacturer and the user, seismic tests are performed, they shall be made in accordance with IEC 61166:

a) measurement of reference voltage;

c) internal partial discharge test;

d) leakage check.

M.3 Definition of mechanical loads



NOTE Rules for the definition of dynamic and static service loads, which strongly depend on the arrester design, are under consideration

[a] See note of 8.9.4, 10.8.9.2.3 and 10.8.9.3.3.

M.4 Definition of seal leak rate

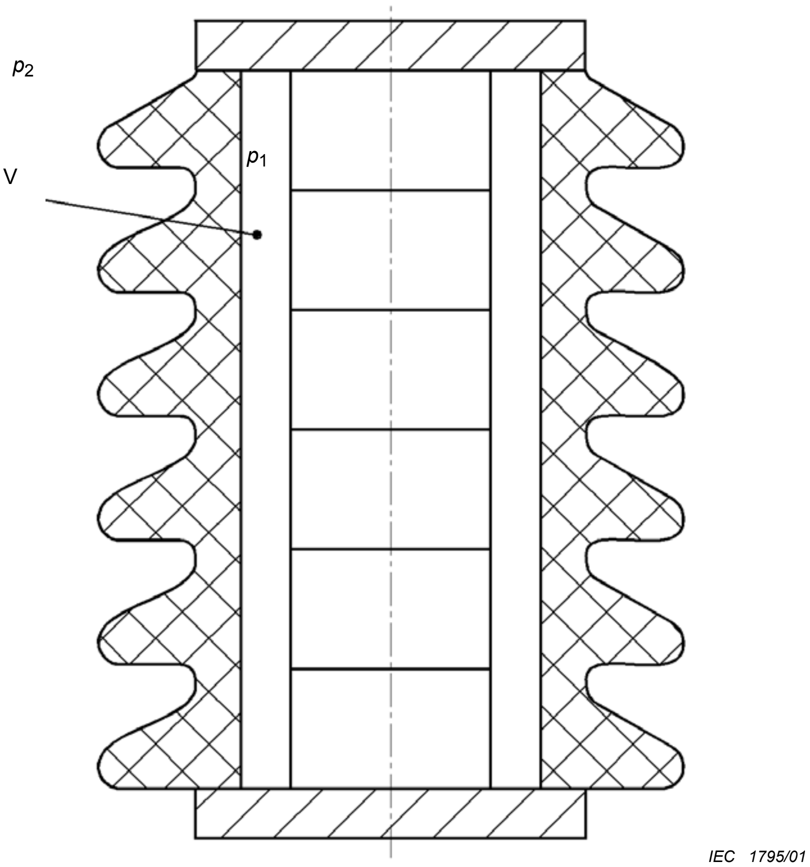


Figure M.2 – Surge arrester unit

The seal leak rate specifies the quantity of gas per unit of time which passes the seals of the housing at a pressure difference of at least 70 kPa. If the efficiency of the sealing system depends on the direction of the pressure gradient, the worst case shall be considered.

Seal leak rate $= \frac{\Delta p_1 \times V}{\Delta t}$ at $|p_1 - p_2| \geq 70$ kPa and at a temperature of +20 °C ± 15 K,

where

$\Delta p_1 = p_1(t_2) - p_1(t_1)$;

$p_1(t)$ is the internal gas pressure of the arrester housing as a function of time (Pa);

p_2 is the gas pressure exterior to the arrester (Pa);

t_1 is the start time of the considered time interval (s);

t_2 is the end time of the considered time interval (s);

$\Delta t = t_2 - t_1$;

V is the internal gas volume of the arrester (m^3).

M.5 Calculation of wind-bending-moment

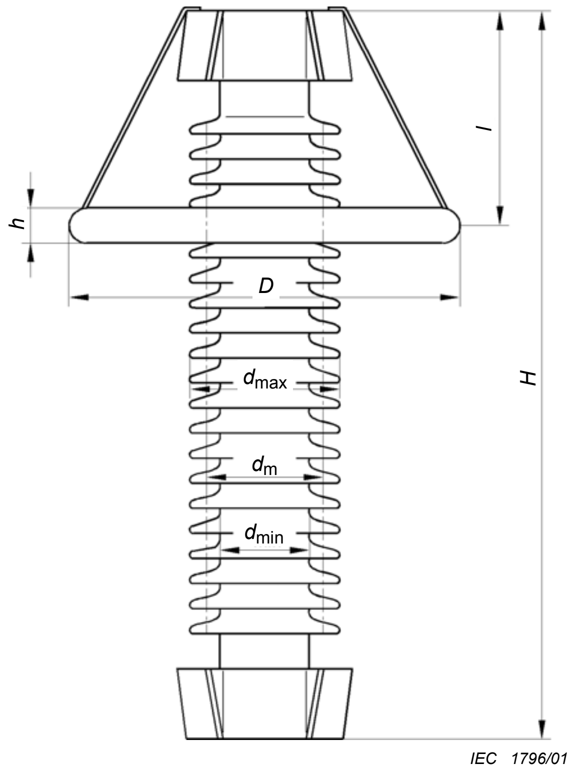


Figure M.3 – Surge-arrester dimensions

$$M_w = P \times H \times d_m \times C \times H/2 + P \times D \times h \times (H - l)$$

where

$P = (P_1/2) \times V^2$;

$d_m = (d_{max} + d_{min})/2$

M_w is the bending moment caused by the wind (Nm);

H is the height of the arrester (m);

d_m is the mean value of the insulator diameter (m);

h is the thickness of the grading ring (m);

D is the diameter of the grading ring (m);

l is the grading ring distance to the top (m);

C is the coefficient of drag for cylindrical parts; equal to 0,8;

P is the dynamic pressure of the wind (N/m^2);

P_1 is the density of air at 1,013 bar and 0 °C; equal to 1,29 kg/m^3;

V is the wind velocity (m/s).

Annex N
(normative)

Test procedure to determine the lightning impulse discharge capability

N.1 General

This test procedure applies to surge arresters used on lines with system voltages exceeding 52 kV to improve the lightning performance of such lines. In general, theses arresters are subjected to higher energy and current stresses caused by lightning than arresters installed in stations with effective lightning protection on incoming lines. In addition, the anticipated current waveform for decisive cases, with a duration of several tens of microseconds for arresters applied on shielded lines and several hundreds of microseconds for arresters on unshielded lines, considerably differs from waveforms specified in the operating duty test and in the long-duration current impulse test.

An impulse duration of 200 μsec has been considered as a suitable compromise to cover both the typical applications and the effect of multiple strokes.

Arresters intended for this application, therefore, shall be tested in accordance with the lightning impulse discharge capability test to verify the rated lightning impulse discharge capability of the arrester.

N.2 Selection of test samples

Three samples shall be tested. These samples shall include complete arresters, arrester sections or resistive elements. They shall not have been subjected to any previous tests except as necessary for evaluation purposes of this test.

The samples to be chosen for the lightning impulse discharge capability test shall have a residual voltage at nominal discharge current at the highest end of the variation range declared by the manufacturer. Furthermore, in the case of multi-column arresters, the highest value of uneven current distribution shall be considered. In order to comply with these demands the following shall be fulfilled.

a) The ratio between the rated voltage of the complete arrester to the rated voltage of the section is defined by *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 residual voltage of the test section should be equal to $k*U_r/n$, where k is the ratio between the maximum residual voltage at standard nominal discharge current of the arrester and its rated voltage. In the case where $U_{res} > k*U_r/n$ for an available test sample the factor n has to be decreased correspondingly. If $U_{res} < k*U_r/n$, the section is not allowed to be used.
c) For multi-column arresters, the distribution of the current between the columns shall be measured at the impulse current used for the current distribution test (see 9.1e)). For each test sample, the ratio of maximum current in any column to the average current, K_a, is determined and compared with the maximum ratio, K_m, specified by the manufacturer. The highest current value in any of the columns shall not be higher than that given by K_m.

N.3 Test procedure

Before commencing the tests, the lightning impulse residual voltage at nominal discharge current of each test sample shall be measured for evaluation purposes.

Each lightning impulse discharge capability 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 18 discharge operations and after the sample has cooled to near ambient temperature, the residual voltage tests, which were made before the 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.

In case of a design where the resistors cannot be removed for inspection, an additional impulse shall be applied after the sample has cooled to ambient. If the sample has withstood this 19th impulse without damage (checked by the oscillographic records), then the sample is considered to have passed the test.

NOTE With respect to possible changes in the low current range due to lightning discharges, this is considered to be sufficiently covered by present operating duty tests.

N.4 Test parameters for the lightning impulse discharge capability test

The current peak value is selected by the manufacturer to obtain a particular discharge energy and charge. The energy shall not be higher than the total energy in two line discharges of the classifying class (for line discharge class 2 to 5 arresters) or the energy due to one high current impulse, 100 kA, 4/10 μs (for line discharge class 1 arresters). If this is not the case, the operating duty test shall be repeated with increased energy to cover the claimed energy.

NOTE An increased energy in the operating duty test could be obtained by increased current (for line discharge class 2 to 5 arresters) and increased impulse duration (for line discharge class 1 arresters).

The current impulse shape shall be approximately sinusoidal. The duration of time during which the instantaneous value of the impulse current is greater than 5 % of its peak value shall be within 200 μs to 230 μs.

The peak of any opposite polarity current wave shall be less than 5 % of the peak value of the current.

The current peak value of each impulse on each test sample shall lie between 100 % to 110 % of the selected peak value.

N.5 Measurements during the lightning impulse discharge capability test

The energy, charge and peak current shall be reported for each impulse as well as the duration of time during which the instantaneous value of the impulse current is greater than 5 % of its peak value. Oscillograms of the typically applied voltage and current waveforms and dissipated energy shall be supplied on the same time base.

N.6 Rated lightning impulse discharge capability

The average peak current, charge and energy shall be calculated from the 18 discharge operations. The average energy shall be divided by the rated voltage of the sample to obtain the specific energy. For multicolumn arresters, the peak current, charge and energy for each test sample shall be multiplied by the factor K_a/K_m before the average value is determined.

The rated lightning impulse discharge capability of the arrester is the combination of the following:

a) the lowest average peak current for any of the 3 test samples;
b) an energy value selected from the list of N.7 lower than, or equal to, the lowest specific energy for any of the 3 test samples;
c) a charge value selected from the list of N.8 lower than, or equal to, the lowest average charge for any of the 3 test samples.

N.7 List of rated energy values

The following values, expressed in kJ/kV of rated voltage, are standardized as rated energy values: 1; 1,5; 2; 2,5; 3; 3,5; 4; 4,5; 5; 6; 7; 8; 9; 10; 11; 12; 13; 14; 15; 16; 17; 18; 19; 20.

N.8 List of rated charge values

The following values, expressed in coulombs, are standardized as rated charge values: 0,4; 0,6; 0,8; 1; 1,2; 1,4; 1,6; 1,8; 2; 2,4; 2,8; 3,2; 3,6; 4; 4,4; 4,8; 5,2; 5,6; 6; 6,4; 6,8; 7,2; 7,6; 8; 8,4; 8,8; 9,2; 9,6; 10.

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