BS EN 60099-9:2014

BSI Standards Publication

Surge arresters

Part 9: Metal-oxide surge arresters without gaps for HVDC converter stations

...making excellence a habit.™

National foreword

This British Standard is the UK implementation of EN 60099-9:2014. It is identical to IEC 60099-9:2014.

The UK participation in its preparation was entrusted to Technical Committee PEL/37, Surge Arresters - High Voltage.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2014

ISBN 978 0 580 73982 8

ICS 29.120.50; 29.240.10

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 September 2014.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 60099-9

September 2014

ICS 29.240.10; 29.120.50

English Version

Surge arresters - Part 9: Metal-oxide surge arresters without gaps for HVDC converter stations (IEC 60099-9:2014)

Parafoudres - Partie 9: Parafoudres à oxyde métallique sans éclateur pour postes de conversion CCHT (CEI 60099-9:2014)

Überspannungsableiter - Teil 9: Metalloxidableiter ohne Funkenstrecken für HGÜ-Stromrichterstationen (IEC 60099-9:2014)

This European Standard was approved by CENELEC on 2014-07-31. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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

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

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

CENELEC

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

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 60099-9:2014 E

Foreword

The text of document 37/417/FDIS, future edition 1 of IEC 60099-9, prepared by IEC/TC 37 "Surge arresters" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60099-9:2014.

The following dates are fixed:

– latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2015-05-01
– latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2017-07-31

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 60099-9:2014 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60071-1	NOTE	Harmonized as EN 60071-1.
IEC 60143-1	NOTE	Harmonized as EN 60143-1.
IEC 60633:1998	NOTE	Harmonized as EN 60633:1999 (not modified).
IEC 60507	NOTE	Harmonized as EN 60507.
IEC 62271-1:2007	NOTE	Harmonized as EN 62271-1:2008 (not modified).
ISO 4892-1	NOTE	Harmonized as EN ISO 4892-1.
ISO 4892-2	NOTE	Harmonized as EN ISO 4892-2.
ISO 4892-3	NOTE	Harmonized as EN ISO 4892-3.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60060-1	-	High-voltage test techniques - Part 1: General definitions and test requirements	EN 60060-1	-
IEC 60060-2	-	High-voltage test techniques - Part 2: Measuring systems	EN 60060-2	-
IEC 60068-2-11	1981	Environmental testing - Part 2: Tests - Test Ka: Salt mist	EN 60068-2-11	1999
IEC 60068-2-14	-	Environmental testing - Part 2-14: Tests - Test N: Change of temperature	EN 60068-2-14	-
IEC 60068-2-17	-	Environmental testing - Part 2: Tests - Test Q: Sealing	EN 60068-2-17	-
IEC 60071-2	1996	Insulation co-ordination - Part 2: Application guide	EN 60071-2	1997
IEC 60099-4 (mod)	2004	Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems	EN 60099-4	2004
IEC 60143-2	-	Series capacitors for power systems - Part 2: Protective equipment for series capacitor banks	EN 60143-2	-
IEC 60270	-	High-voltage test techniques - Partial discharge measurements	EN 60270	-
IEC 60721-3-2	-	Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities - Section 2: Transportation	EN 60721-3-2	-
IEC 62217	-	Polymeric HV insulators for indoor and outdoor use - General definitions, test methods and acceptance criteria	EN 62217	-

Publication	Year	Title	EN/HD	Year
IEC 62271-200	2011	High-voltage switchgear and controlgear - Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV	EN 62271-200	2012
IEC 62271-203	2011	High-voltage switchgear and controlgear - Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV	EN 62271-203	2012
IEC/TS 60071-5	2002	Insulation co-ordination - Part 5: Procedures for high-voltage direct current (HVDC) converter stations	-	-
IEC/TS 60815-2	-	Selection and dimensioning of high-voltage insulators intended for use in polluted conditions - Part 2: Ceramic and glass insulators for a.c. systems	-	-
CISPR 16-1-1	-	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-1: Radio disturbance and immunity measuring apparatus - Measuring apparatus	EN 55016-1-1	-
CISPR/TR 18-2	-	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 2: Methods of measurement and procedure for determining limits	-	-

CONTENTS

SURGE ARRESTERS –

Part 9: Metal-oxide surge arresters without gaps for HVDC converter stations

1 Scope

This part of IEC 60099 applies to non-linear metal-oxide resistor type surge arresters without spark gaps designed to limit overvoltages in HVDC converter stations of two terminal, multiterminal and back-to-back type up to and including an operating voltage of 1 100 kV. The standard applies in general to porcelain-housed and polymer-housed type arresters but also to gas-insulated metal enclosed arresters (GIS-arresters) solely used as d.c. bus and d.c. line/cable arresters. Arresters for voltage source converters are not covered. Arresters applied on the a.c. systems at the converter station and subjected to power-frequency voltage of 50 or 60 Hz principally without harmonics are tested as per IEC 60099-4. The arresters on a.c.-filters are tested according to this standard.

2 Normative references

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

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

IEC 60060-2, *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, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

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

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

IEC TS 60071-5:2002, *Insulation co-ordination – Part 5: Procedures for high-voltage direct current (HVDC) converter stations*

IEC 60099-4:2004, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC 60143-2, *Series capacitors for power systems – Part 2: Protective equipment for series capacitor banks*

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

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

IEC TS 60815-2, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 2: Ceramic and glass insulators for a.c. systems*

IEC 62217, *Polymeric HV insulators for indoor and outdoor use – General definitions, test methods and acceptance criteria*

IEC 62271-200:2011, *High-voltage switchgear and controlgear – Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

IEC 62271-203:2011, *High-voltage switchgear and controlgear – Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV*

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

CISPR/TR 18-2, *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 purpose of this document, the following terms and definitions apply.

3.1
acceptance tests
tests made on arresters or representative samples after agreement between manufacturer and user

3.2
bending moment
force perpendicular to the longitudinal axis of an arrester multiplied by the vertical distance between the mounting base (lower level of the flange) of the arrester and the point of application of the force

3.3
breaking load
force perpendicular to the longitudinal axis of a porcelain-housed arrester leading to mechanical failure of the arrester housing

3.4
continuous current of an arrester
current flowing through the arrester when energized at the continuous operating voltage

Note 1 to entry: 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 to entry: The continuous current is, for comparison purposes, expressed either by its r.m.s. or peak value.

3.5
continuous operating voltage of an HVDC-arrester
U_{cHVDC}
maximum continuous voltage characterized by the voltages CCOV, PCOV and DCOV and the frequency DFCOV where applicable and that may be applied continuously between the arrester terminals

3.6
coordination current of an arrester
for a given system under study and for each class of overvoltage, the current through the arrester for which the representative overvoltage is determined

Note 1 to entry: Standard shapes of coordination currents for steep-front, lightning and switching current impulses are given in IEC 60099-4.

Note 2 to entry: The coordination currents are determined by system studies.

3.7
crest value of continuous operating voltage
CCOV
highest continuously occurring crest value of the voltage across the arrester excluding commutation overshoots and commutation notches and calculated with a system model valid for up to approximately 5 kHz

Note 1 to entry: As an example, see Figure 10, given for valve arresters.

3.8
damage limit (mechanical)
lowest value of a force perpendicular to the longitudinal axis of a polymer-housed arrester leading to mechanical failure of the arrester housing

3.9
d.c. component of the continuous operating voltage
DCOV
highest mean or average of the continuous operating voltage, U_{cHVDC} ,across the arrester,excluding harmonics and commutation overshoots

Note 1 to entry: As an example, see Figure 11, given for bridge arrester.

3.10
d.c. system voltage
highest mean or average operating voltage to earth, excluding harmonics and commutation overshoots

3.11
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 1 to entry: It is written as T_1/T_2, both in microseconds, the sign "/" having no mathematical meaning.

3.12
discharge current of an arrester
impulse current which flows through the arrester

3.13
disruptive discharge
phenomenon associated with the failure of insulation under electric stress, which includes a collapse of voltage and the passage of current

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

Note 2 to entry: 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.

3.14
dominant frequency of continuous operating voltage
DFCOV
the frequency of the harmonic with highest rms-value in the voltage across d.c. and a.c. filter arresters

3.15
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 1 to entry: An electrical unit may have more than one mechanical unit (see Figure 4 of IEC 60099-4:2004/AMD1:2009).

3.16
equivalent continuous operating voltage of an arrester
ECOV
r.m.s. value of the sinusoidal power-frequency voltage or d.c. voltage at a metal-oxide surge arrester stressed by operating voltage of any wave shape that generates the same power losses in the metal-oxide material as the actual operating voltage

3.17
flashover
disruptive discharge over a solid surface

3.18
front of an impulse
part of an impulse which occurs prior to the peak

3.19
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 to entry: The gas pressure is normally higher than 1 bar = 10^5Pa.

Note 2 to entry: A surge arrester used in gas-insulated switchgear.

3.20
grading ring of an arrester
metal part, usually circular in shape, mounted to modify electrostatically the voltage distribution along the arrester

3.21
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

3.22
housing
external insulating part of an arrester, which provides the necessary creepage distance and protects the internal parts from the environment

Note 1 to entry: Housing may consist of several parts providing mechanical strength and protection against the environment.

3.23
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, with defining parameters being polarity, peak value, front time and time to half-value on the tail

3.24
insulating base
a short insulator (or set of insulators) on which the arrester is mounted to provide a means of connecting a current monitoring device between the base of the arrester and earth

3.25
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 MO resistor stack

3.26
internal parts
MO resistors with supporting structure and internal grading system, if equipped

3.27
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 1 to entry: The time to half-value on the tail is not critical and may have any tolerance during the residual voltage type tests (see 9.10).

3.28
lightning impulse coordination current
I_{lico}
a coordination current with a shape equal to the lightning current impulse

3.29
long-duration current impulse
rectangular current impulse which rises rapidly to maximum value, remains substantially constant for a specified period and then falls rapidly to zero, with defining parameters being polarity, peak value, virtual duration of the peak and virtual total duration

3.30
mean breaking load
MBL
the average breaking load for porcelain -housed arresters determined from tests

3.31
mechanical unit
portion of an arrester in which the MO resistors within the unit are mechanically restrained from moving in an axial direction

Note 1 to entry: An arrester may contain more than one mechanical units within an electrical unit (see Figure 13 of IEC 60099-4:2004/AMD1:2009).

Note 2 to entry: A mechanical unit may have more than one electrical unit (see Figure 13 of IEC 60099-4:2004/AMD1:2009).

3.32
metal-oxide surge arrester without gaps
arrester having non-linear MO resistors connected in series and/or in parallel without any integrated series or parallel spark gaps, incorporated in a housing with terminals for electrical and mechanical connection

Note 1 to entry: Wherever the term “arrester” or “surge arrester” is used in this document, the term refers to a metal-oxide surge arrester without gaps.

3.33
non-linear metal-oxide resistor
MO 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

3.34
non-significant continuous operating voltage
NCOV
continuous operating voltage which generates power losses in the arresters so low that no test is necessary to verify thermal stability after injection of a specified energy.

Note 1 to entry: It depends both on the applied voltage and on the design of the arrester if the continuous operating voltage (U_{cHVDC}) shall be considered as significant or non-significant.

Note 2 to entry: Arresters on neutral bus, metallic return and electrode line and arresters across DC reactor are examples of arresters with non-significant continuous operating voltage.

3.35
peak (crest) value of an impulse
maximum value of a voltage or current impulse

Note 1 to entry: Superimposed oscillations may be disregarded.

3.36
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

3.37
peak value of continuous operating voltage
PCOV
highest continuously occurring crest value of the voltage at the equipment on the d.c. side of the converter station including commutation overshoots, commutation notches and ripple calculated with a model which takes into account stray capacitances/inductances of converter transformers, valves, buswork, etc. and valid for at least 50 kHz

Note 1 to entry: As an example, see Figure 10, given for valve arresters.

3.38
polymer-housed surge arrester
arrester using polymeric and composite materials for housing.

Note 1 to entry: 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.

3.39
porcelain-housed surge arrester
arrester using porcelain as housing material, with fittings and sealing systems

3.40
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

3.41
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

3.42
protective characteristics of an arrester
combination of the following:

a) residual voltage for steep current impulse excluding and including inductive voltage contribution according to 9.10.2;

Note 1 to entry: The steep current impulse protection level of the arrester is the maximum residual voltage for the steep impulse coordination current.

b) residual voltage for lightning current impulse according to 9.10.3;

Note 2 to entry: The lightning impulse protection level of the arrester is the maximum residual voltage for the lightning impulse coordination current.

c) residual voltage for switching current impulse according to 9.10.4

Note 3 to entry: The switching impulse protection level of the arrester is the maximum residual voltage for the switching impulse coordination current.

3.43
puncture
breakdown
disruptive discharge through a solid

3.44
rated frequency of an arrester
frequency of the power system on which the arrester is designed to be used

3.45
rated voltage of an arrester
$U_{\mathbf{r}}$
r.m.s. value of power-frequency or d.c. voltage equal to the minimum reference voltage (a.c. or d.c.) multiplied by a factor specified by the manufacturer

Note 1 to entry: The rated voltage is used as a reference parameter for the specification of operating characteristics.

3.46
reference current (a.c.) of an arrester
$I_{\mathbf{refAC}}$
peak value (the higher peak value of the two polarities if the current is asymmetrical) of the resistive component of power-frequency current used to determine the reference voltage (a.c.) of the arrester

Note 1 to entry: The reference current should 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. 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.

3.47
reference current (d.c.) of an arrester
$I_{\mathbf{refDC}}$
peak value (the higher peak value of the two polarities if the current is asymmetrical) of the resistive current used to determine the reference voltage (d.c.) of the arrester

Note 1 to entry: The reference current will be typically in the range of 0,01 mA to 0,5 mA per square centimetre of disc area for single column arresters.

3.48
reference voltage (a.c.) of an arrester
$U_{\mathbf{refAC}}$
peak value of power-frequency voltage divided by √2 which is applied to the arrester to obtain the reference current

Note 1 to entry: The reference voltage of a multi-unit arrester is the sum of the reference voltages of the individual units.

Note 2 to entry: Measurement of the reference voltage is necessary for the selection of a correct test sample in the test to verify the thermal energy rating (see 9.14).

3.49
reference voltage (d.c.) of an arrester
$U_{\mathbf{refDC}}$
DC voltage which is applied to the arrester to obtain the reference current

Note 1 to entry: The reference voltage of a multi-unit arrester is the sum of the reference voltages of the individual units.

Note 2 to entry: Measurement of the reference voltage is necessary for the selection of a correct test sample in the test to verify the thermal energy rating (see 9.14).

3.50
repetitive charge transfer rating
$Q_{\mathbf{rs}}$
maximum specified charge transfer capability of an arrester, in the form of a single event or group of surges that may be transferred through an arrester without causing mechanical failure or unacceptable electrical degradation to the MO resistor.

Note 1 to entry: The charge is calculated as the absolute value of current integrated over time. For the purpose of this standard this is the charge that is accumulated in a single event or group of surges lasting for not more than 2 s and which may be followed by a subsequent event at a time interval not shorter than 60 s.

3.51
residual voltage of an arrester
$U_{\mathbf{res}}$
peak value of voltage that appears between the terminals of an arrester during the passage of discharge current

Note 1 to entry: The term "discharge voltage" is used in some countries.

3.52
routine tests
tests made on each arrester, or on parts and materials, as required, to ensure that the product meets the design specifications

3.53
seal (gas/water tightness)
ability of an arrester to avoid ingress of matter affecting the electrical and/or mechanical behaviour into the arrester

3.54
section of an arrester
prorated section
complete, suitably assembled part of an arrester necessary to represent the behaviour of a complete arrester with respect to a particular test

Note 1 to entry: A section of an arrester is not necessarily a unit of an arrester. For certain tests, a MO resistor alone constitutes a section.

3.55
shed
insulating part projecting from the housing, intended to increase the creepage distance

3.56
specified long-term load
SLL
force perpendicular to the longitudinal axis of an arrester, allowed to be continuously applied during service without causing any mechanical damage to the arrester

3.57
specified short-term load
SSL
greatest force perpendicular to the longitudinal axis of an arrester, allowed to be applied during service for short periods and for relatively rare events (for example, short-circuit current loads and extreme wind gusts) without causing any mechanical damage to the arrester

Note 1 to entry: SSL does not relate to mechanical strength requirements for seismic loads (see C.2).

3.58
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 1 to entry: The time to half-value on the tail is not critical and may have any tolerance during the residual voltage type tests (see 9.10).

3.59
steep impulse coordination current
I_{stico}
a coordination current with a shape equal to the steep current impulse

3.60
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

3.61
switching impulse coordination current
I_{swico}
a coordination current with a shape equal to the switching current impulse

3.62
tail of an impulse
part of an impulse which occurs after the peak

3.63
terminal line force
force perpendicular to the longitudinal axis of the arrester measured at the centre line of the arrester

3.64
thermal energy rating
W_{th}
maximum specified energy, given in kJ/kV of U_r, that may be injected into an arrester or arrester section in a thermal energy test within 3 minutes time duration without causing a thermal runaway.

Note 1 to entry: This rating is verified in the thermal energy test.

3.65
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 MO resistor elements culminating in failure

3.66
thermal stability of an arrester
state of an arrester if, after an operating duty causing temperature rise, the temperature of the MO resistors decreases with time when the arrester is energized at specified continuous operating voltage and at specified ambient conditions

3.67

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

3.68
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 1 to entry: 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.

3.69
unipolar sine half-wave current impulse
a unipolar current impulse consisting of one half-cycle of an approximately sinusoidal current

3.70
unit of an arrester
arrester unit
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 1 to entry: A unit of an arrester is not necessarily a section of an arrester.

3.71
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

3.72
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 1 to entry: 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.

3.73
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 to entry: For current impulses the reference points shall be 10 % and 90 % of the peak value.

Note 2 to entry: This definition applies only when scales of both ordinate and abscissa are linear.

Note 3 to entry: 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.

3.74
virtual steepness of the front of an impulse
quotient of the peak value and the virtual front time of an impulse

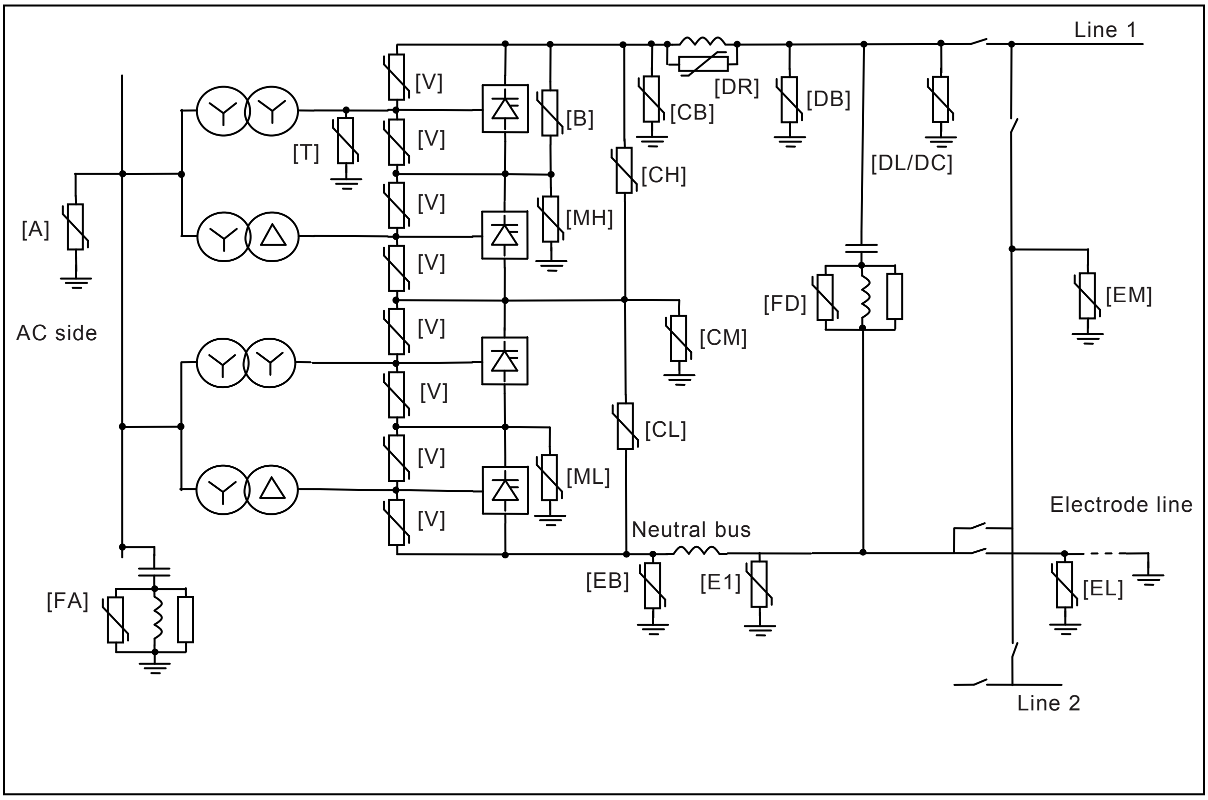
3.75
virtual time to half-value on the tail of an impulse
T_2
time interval between the virtual origin and the instant when the voltage or current has decreased to half its peak value, expressed in microseconds

3.76
virtual duration of a rectangular impulse
time during which the amplitude of the impulse is greater than 10 % of its peak value

Note 1 to entry: 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.

4 Typical HVDC converter station schemes, arrester types, locations and operating voltage

Figures 1 to 3 show the single line diagrams of typical HVDC converter stations equipped with one or two 12-pulse converter bridges in series. The main differences between the schemes consist in the presence, or not, of commutated capacitors or controlled series capacitors on the a.c. side of the HVDC converter station. Possible arrester locations are shown in Figures 1 to 3. Some of these arresters may be redundant and could be excluded depending on the specific design. In Figures 4 and 5 typical shapes of the operating voltages are shown. For the curves in Figure 4 a low-frequency model has been used to calculate the voltage curves which result in the “classic” shapes. For the curves in Figure 5 a more accurate high-frequency modelling has been used. In general the more accurate modelling gives higher voltage peaks which should be taken into account in the design and testing of the arresters. The low-frequency curves are given for a better understanding. In general the low-frequency modelling here is valid for up to approximately 5 kHz and the high-frequency modelling from 50 kHz to 1 MHz. For valve arresters normally the operating voltage is calculated with the arresters connected since the commutation overshoots may be affected by the arrester. If the voltage instead is calculated without the arresters this in general results in a more conservative result, i.e. higher voltage peaks. However, if the arrester is allowed to limit the commutation overshoots during service the continuous power losses in the arrester must be determined taking into account this limitation.

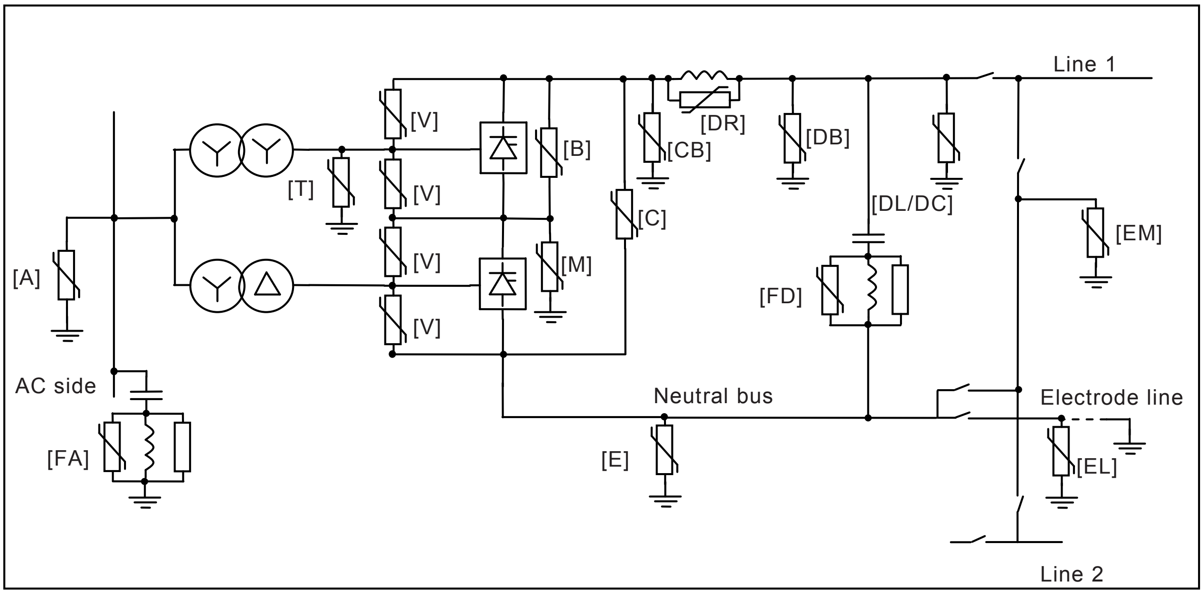


Key

A:	a.c. arresters	DL/DC:	d.c. line/cable arrester	FD:	d.c. filter arrester
B:	bridge arrester	DR:	smoothing reactor arrester	MH:	mid-point bridge arrester (high-voltage bridge)
CB:	converter unit d.c. bus arrester	EB:	converter neutral arrester (valve side of smoothing reactor)	ML:	mid-point bridge arrester (low-voltage bridge)
CH:	HV converter unit arrester (high voltage bridge)	EL:	electrode line arrester	T:	transformer valve winding arrester
CL:	LV converter unit arrester (low voltage bridge)	EM:	metallic return arrester	V:	valve arrester
CM:	arrester between converters	E1:	d.c. neutral bus arrester (line side of smoothing reactor)		
DB:	d.c. bus arrester	FA:	a.c. filter arrester		

NOTE The d.c. and a.c. filters may be much more complex than shown in the figure. Not all arresters are used for every project. The figure does not show exact location of the arresters e.g. the a.c. arresters are usually located close to the transformers.

Figure 1 – Single line diagram of typical converter station with two 12-pulse converter bridges per pole

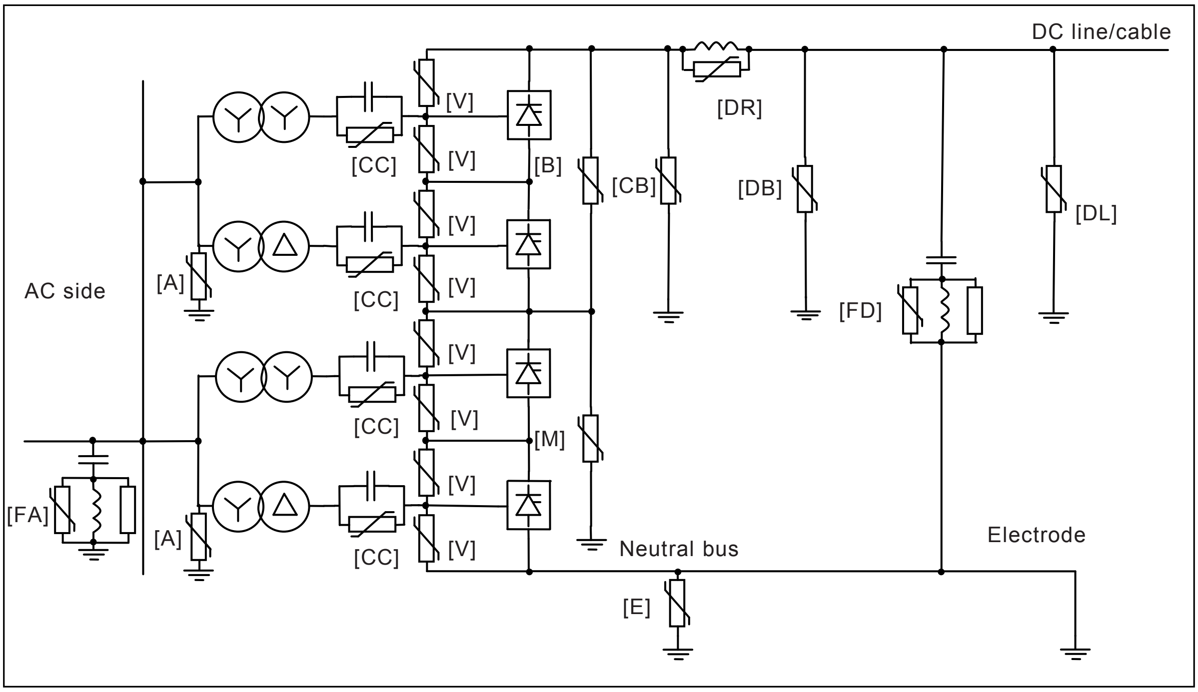


Key

A:	a.c. arresters	DL/DC:	d.c. line/cable arrester	FA:	a.c. filter arrester
B:	bridge arrester (6-pulse)	DR:	smoothing reactor arrester	FD:	d.c. filter arrester
C:	converter unit arrester	E:	d.c. neutral bus arrester	M:	mid-point d.c. bus arrester
CB:	converter unit d.c. bus arrester	EL:	electrode line arrester	T:	transformer valve winding arrester
DB:	d.c. bus arrester	EM:	metallic return arrester	V:	valve arrester

NOTE The d.c. and a.c. filters may be much more complex than shown in the figure. Not all arresters are used for every project.

Figure 2 – Single line diagram of typical converter station with one 12-pulse converter bridge per pole



IEC 1986/14

Key

A:	a.c. arresters	DB:	d.c. bus arrester	FA:	a.c. filter arrester
B:	bridge arrester (6-pulse)	DL/DC:	d.c. line/cable arrester	FD:	d.c. filter arrester
CB:	converter unit d.c. bus arrester	DR:	smoothing reactor arrester	M:	mid-point d.c. bus arrester
CC:	capacitor arrester	E:	d.c. neutral bus arrester	V:	valve arrester

NOTE The d.c. and a.c. filters may be much more complex than shown in the figure. Not all arresters are used for every project.

Figure 3 – Single line diagram of typical capacitor commutated converter (CCC) pole with two 12-pulse converters in series

Other circuit configurations are shown in Figures D.1 and D.2 in Annex D.

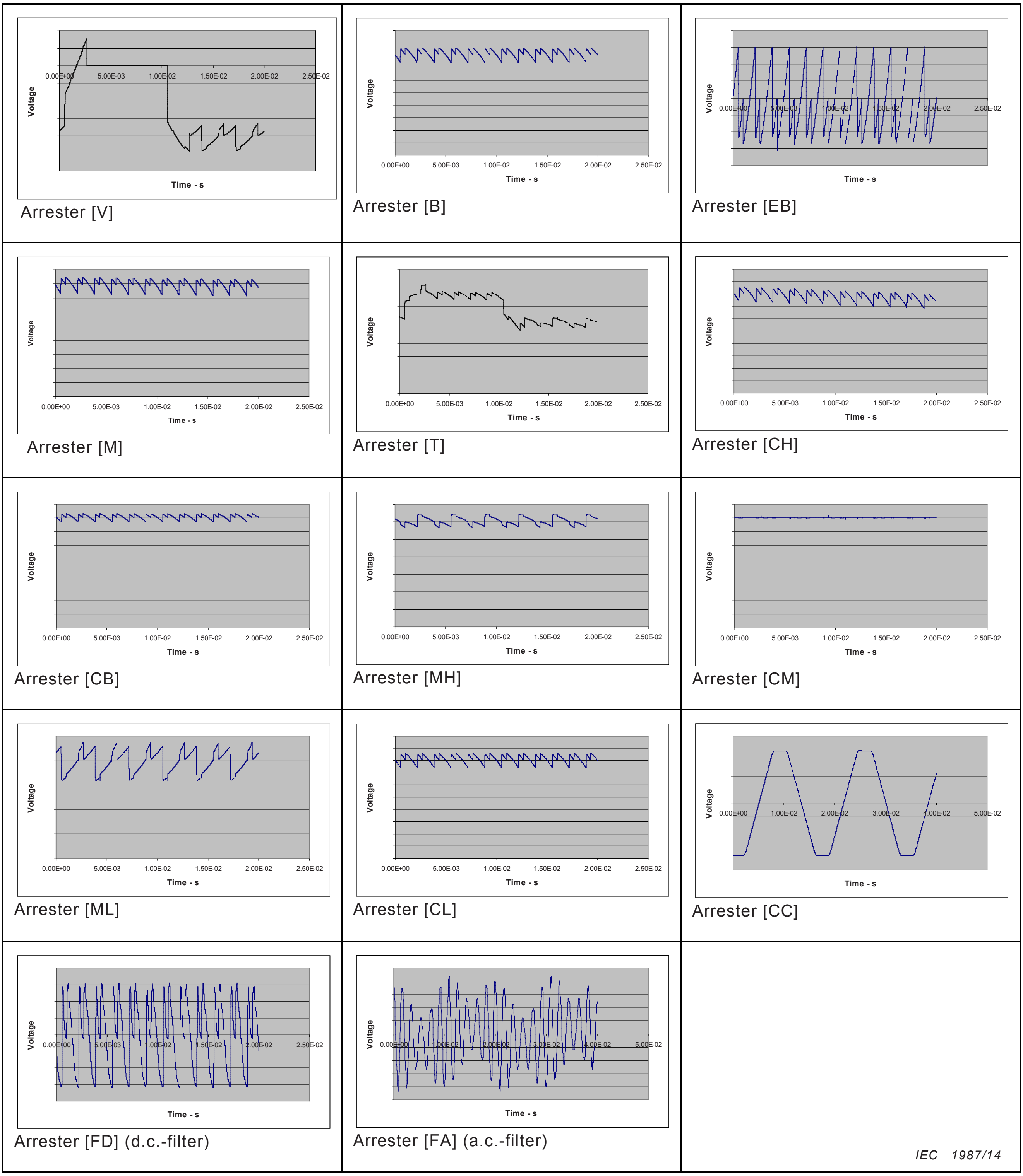


Figure 4 – Typical continuous operating voltages for different arresters – low-frequency modelling (location as per Figures 1 to 3, fundamental frequency 50 Hz)

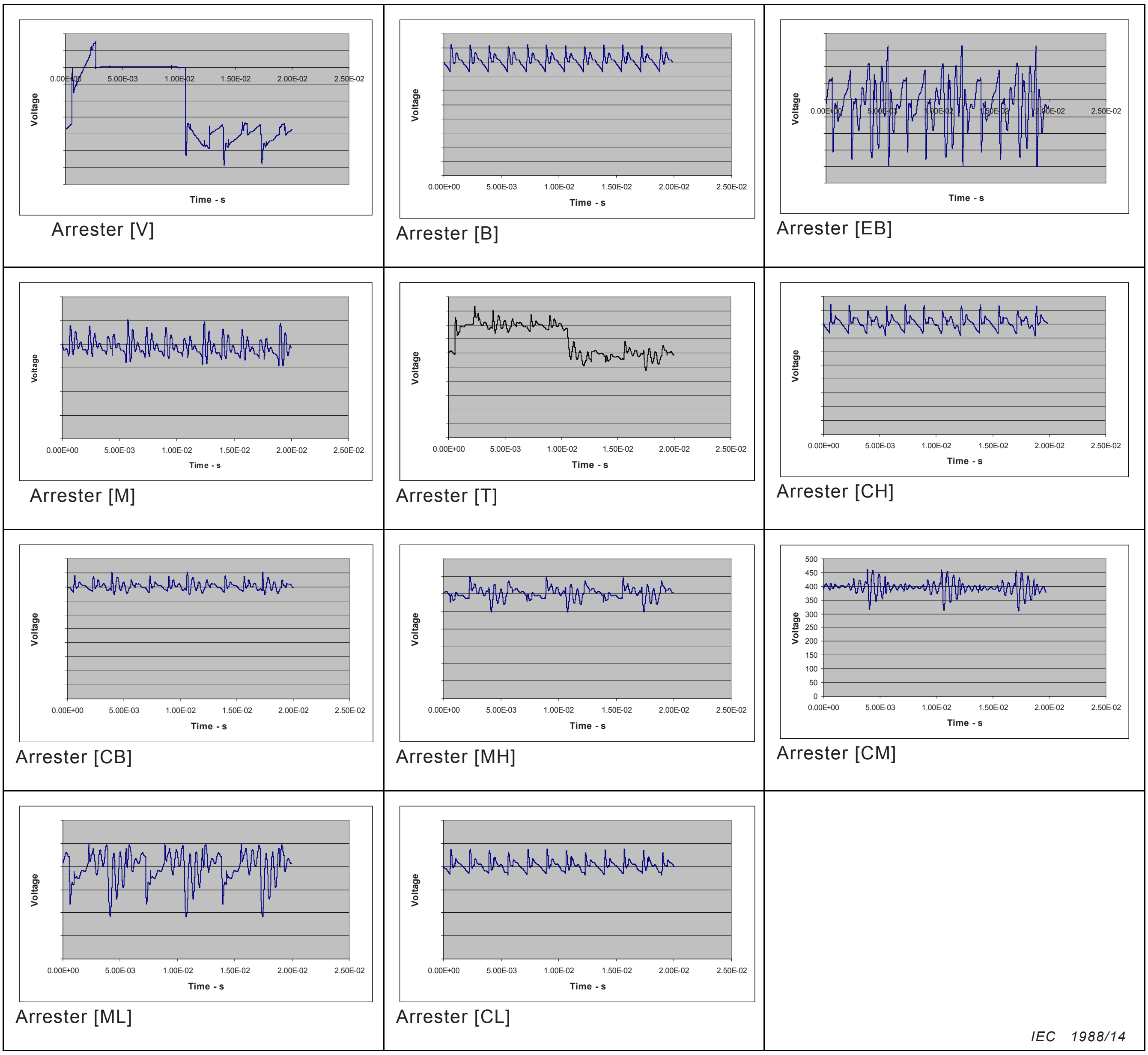


Figure 5 – Typical continuous operating voltages for different arresters – high-frequency modelling (location as per Figures 1 to 3, fundamental frequency 50 Hz)

5 Identification and classification

5.1 Arrester identification

Metal-oxide surge arresters for HVDC applications shall be identified by the following minimum information which shall appear on a nameplate permanently attached to the arrester:

– continuous operating voltage where applicable defined by
  - CCOV
  - PCOV
  - DCOV
  - ECOV;
– rated voltage;

– rated short-circuit withstand current in kiloamperes (kA). For arresters for which no short-circuit rating is claimed, the sign “0“ shall be indicated;
– residual voltage at specified coordination current (where applicable) given in x kV at y kA;
– 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;
– for GIS arresters the rated gas pressure for insulation at 20 °C.

5.2 Arrester classification

Surge arresters, covered by this standard, are classified by their location and main protection purpose (e.g. valve arrester, d.c. bus arrester, neutral bus arrester, etc.).

6 Service conditions

6.1 Normal service conditions

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

a) for outdoor installation ambient temperature within the range –40 °C to +40 °C;
b) solar radiation of maximum 1,1 kW/m^2;
c) for indoor installation in valve halls ambient temperature within the range +5 °C to +60 °C. The temperature in the valve halls may be controlled to a lower value than 60 °C which in such case could be considered in determining the start temperature in the thermal recovery test (see 9.14.3.2 and Annex B);
d) altitude not exceeding 1 000 m;
e) wind speed ≤ 34 m/s;
f) vertical erection;
g) voltage applied continuously between the terminals of the arrester not exceeding its continuous operating voltage.

6.2 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 user. Possible abnormal service conditions are:

a) temperature in excess of +40 °C for outdoor installation and in excess of +60 °C for indoor installations or below –40 °C;
b) applications at altitude higher than 1 000 m;
c) fumes or vapours which may cause deterioration of insulating surface or mounting hardware;
d) excessive contamination by smoke, dirt, salt spray or other conducting materials;
e) excessive exposure to moisture, humidity, dropping water or steam;
f) live washing of arrester;
g) explosive mixtures of dust, gases or fumes;
h) abnormal mechanical conditions (earthquake (see Annex C.2), vibrations, wind velocity > 34 m/s, high ice loads, high cantilever stresses);
i) unusual transportation or storage;

j) heat sources near the arrester;
k) non-vertical erection and suspended erection;
l) torsional loading of the arrester;
m) tensile loading of the arrester;
n) use of the arrester as mechanical support;
o) high magnetic fields due to close vicinity to reactors.

7 Requirements

7.1 Insulation withstand of the arrester housing

The arrester shall be designed such that the housings are able to adequately withstand voltages during conduction of lightning and switching impulse currents and during anticipated maximum power frequency and d.c. overvoltages. The external insulation withstand capability of the housings of porcelain and polymer-housed arresters shall be demonstrated by tests according to 9.2 and the insulation withstand capability of GIS arresters shall be tested in accordance with 11.7.4.2,while the internal insulation withstand capability shall be demonstrated by tests according to 9.15 or 9.14.3.1.

7.2 Reference voltage

The reference voltage (U_{refAC} or U_{refDC}.) (see 3.48 and 3.49) of each arrester shall be measured by the manufacturer at the reference current (I_{refAC} or I_{refDC}.) selected by the manufacturer (see 3.46 and 3.47). The minimum reference voltage of the arrester at the reference current for routine tests shall be specified and published in the manufacturer's data.

7.3 Residual voltage

The purpose of the measurement of residual voltages is to obtain the maximum residual voltages for a given design for all specified currents and wave shapes. 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 wave shape 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 wave shape.

Manufacturers' literature shall contain, for each arrester listed, the following residual voltage information:

- Maximum lightning impulse residual voltage at the lightning impulse coordination current of the arrester (see 9.10.3)
- Maximum switching impulse residual voltage at the switching impulse coordination current of the arrester (see 9.10.4)
- Maximum steep current impulse residual voltage, excluding inductive voltage contribution, for an impulse current having peak value equal to the steep impulse coordination current of the arrester (see 9.10.2)
- Maximum steep current impulse residual voltage, including inductive voltage contribution, for an impulse current having peak value equal to the steep impulse coordination current of the arrester. This residual voltage shall be equal to

  Maximum steep current impulse residual voltage (see 9.10.2), excluding inductive voltage contribution + Magnitude of inductive voltage drop (U_{L})

  where U_{L} *is calculated as follows*:

$U_L = L \times di/dt = L' \times h \times I_{stico}/T_f$

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 and indoor arresters except valve arrester;

L' = 0,6 for valve arresters if located in close vicinity (within a few meters) from the thyristor valves;

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_{stico} is the steep impulse coordination current (kA).

NOTE The contribution of inductive voltage drop is significant only for steep current impulses. It effectively increases the protective level of the arrester above the MO resistor-only steep current impulse residual voltage determined from 9.10.2. The maximum steep current impulse residual voltage including inductive voltage contribution is provided for users who wish to perform insulation coordination studies.

7.4 Internal partial discharge

Under normal and dry operating conditions, internal partial discharges shall be below a level that might cause damage to internal parts. This shall be demonstrated by tests according to 9.4.

7.5 Seal leak rate

For arresters having an enclosed gas volume and a separate sealing system, seal leak rates shall be specified as defined in 9.8 and item d) of 10.1.

7.6 Current distribution in a multi-column arrester and between matched arresters

The manufacturer shall specify the highest allowed difference between currents in columns of a multi-column arrester, see item e) of 10.1, and between currents in arresters of a set of matched arresters, see item f) of 10.1.

7.7 Long term stability under continuous operating voltage

MO resistors shall be subjected to an accelerated ageing test to provide assurance that they will exhibit stable conditions over the anticipated lifetime of the arrester (see 9.11).

7.8 Repetitive charge transfer withstand

Arresters shall withstand repetitive charge transfers as checked during type tests (see 9.12).

The repetitive charge transfer withstand is demonstrated on individual MO resistors in the test to verify the repetitive charge transfer rating (see 9.12.2).

Due to the large number of MO resistors involved in HVDC projects and to ensure the validity, charge transfer capability shall be verified by tests on project basis but which have not to be performed more than once a year or by sample tests on every manufactured batch of MO resistors used for such projects.

NOTE There may be special applications where single event charge transfers cause energy dissipations higher than the rated thermal energy rating.

7.9 Thermal energy capability

Arresters, except those with non-significant continuous operating voltage (3.34), shall have a thermal energy rating as checked by type tests (9.14).

7.10 Short-circuit performance

The manufacturer shall declare a short-circuit current rating for each family of arresters. Only for applications with expected short-circuit currents below 1 kA the rated value “zero” may be claimed. In this case “0” shall be indicated on the name plate (see 5.1). In any case, the arrester shall be subjected to a short-circuit test according to 9.3 to show that it 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.

For GIS-arresters the design of the metallic enclosures shall meet the requirements of 5.103 of IEC 62271-203:2011 or 5.102 of IEC 62271-200:2011. If the arrester has a separate internal enclosure with a pressure-relief device different from that of the metallic vessel, 9.3 applies. In this case, it is necessary that a test be performed only with the rated short-circuit current.

7.11 Requirements on internal grading components

Internal grading components, if used in the arrester, shall be able to withstand the combination of stresses arising in service, and the impedance of the grading components shall also show sufficient stability during the service life. This shall be demonstrated by the test to verify the thermal energy rating (see 9.14.3) being performed with internal grading components included in the test sections.

Furthermore, the components shall withstand the accelerated ageing and cyclic tests as specified in 9.16.

NOTE If the arrester has a non-significant continuous operating voltage, 9.15 applies instead of 9.14.3.

7.12 Mechanical loads

7.12.1 General

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

7.12.2 Bending moment

The arrester shall be able to withstand the manufacturer's declared values for bending loads (see 9.5).

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

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 Unlike porcelain-housed arresters, polymer-housed arresters might show mechanical deflections in service.

7.12.3 Resistance against environmental stresses

The arrester shall be able to withstand environmental stresses as defined in 9.6.

7.12.4 Insulating base

When an arrester is fitted with an insulating base, this device shall withstand the requirements of the test of the bending moment (9.5) without damage.

7.12.5 Mean value of breaking load (MBL)

For porcelain-housed arresters the MBL shall be ≥ 1,2 times the specified short-term load (SSL) (see 9.5.1.4.1). This shall be demonstrated in the bending moment test of 9.5.

7.13 Electromagnetic compatibility

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

In normal dry operating conditions, surge arresters shall not emit significant disturbances. For arresters with a continuous operating voltage above 100 kV peak this shall be demonstrated by a radio interference voltage test (RIV) according to 9.9. If the arrester is installed at high potential to ground this should be considered.

7.14 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.

8 General testing procedure

8.1 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 wave shape.

8.2 Reference voltage measurements

The reference voltage of an arrester (see 3.48 and 3.49) is measured at the reference current (see 3.46 and 3.47) 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.

As an acceptable approximation, for measurement of the reference voltage at a.c. 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.

8.3 Test samples

8.3.1 General

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.

For tests involving verification of thermal stability the sections must contain the highest number of parallel columns of MO resistors that is assembled within one arrester housing for the actual design.

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.

In general, the samples to verify the repetitive charge transfer rating (see 9.12) shall cover the highest residual voltage specified for the type of MO resistors used in the arrester. In the test to verify thermal energy rating (9.14) the test samples in general shall cover a reference voltage value at the lower end of the variation range declared by the manufacturer. In 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 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 $k \times U_r/n$ where k is the ratio between the minimum reference voltage of the arrester and its rated voltage. If $U_{ref} > k \times U_r/n$ for an available test sample, the factor n shall be reduced correspondingly. (If $U_{ref} < k \times U_r/n$ 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 for current distribution test (see item e) of 10.1). The highest current value shall not be higher than an upper limit specified by the manufacturer. Furthermore, for tests that are required to be performed on test sections with multiple columns the discharge energy shall be increased by a factor β_g/β_a where β_g is the guaranteed current sharing factor and β_a is the actual current sharing factor for the test section. If the test is performed on single columns the energy shall be increased by a factor β_g.

d) The samples in the test to verify the repetitive charge transfer rating shall be of the longest length of the type of MO resistors used in the design, and shall have a 10-kA residual voltage stress of not less than 0,97 × ($U_{10\ kA}$ per mm of MO resistor length)$_{max}$, where ($U_{10\ kA}$ per mm of MO resistor length)$_{max}$ is the highest 10-kA residual voltage stress specified by the manufacturer for any length of the type of MO resistors used in the arrester. If only samples of lower 10-kA residual voltage stress are available, the required transferred charge shall be increased for the test by the factor ($U_{10\ kA}$ per mm of MO resistor length)$_{max}$ / ($U_{10\ kA}$ per mm of MO resistor length)$_{actual}$.

e) The continuous operating voltage, including CCOV, PCOV and DCOV where applicable, applied to the tests sections to verify thermal recovery shall fulfil the following requirements:
   – The ratio CCOV, PCOV and DCOV (where applicable) to the rated voltage of the section shall be not less than the maximum ratio claimed for the arrester type.

8.3.2 Arrester section requirements

8.3.2.1 Thermally prorated section

The arrester section for thermal recovery tests shall thermally represent the arrester being modelled. Thermal equivalence shall be verified according to the procedure specified in Annex A.

The continuous operating voltage of the prorated section shall be at least 3 kVpeak.

In order to achieve thermal equivalence it may be necessary to introduce components that are usually not part of the design. It has to be assured that these measures do not affect the dielectric strength of the sample during energy or charge injection.

A thermally prorated section may also be a real arrester of the design.

In case of designs with two or more MO columns in parallel the thermally prorated section shall contain the same number of parallel columns as the actual arrester.

Upon agreement between manufacturer and user the thermally prorated section of a multi-column design arrester may contain only one single column if thermal equivalence is achieved.

For GIS arresters (according to 3.19) of multi-column design the thermally prorated section may contain only one single column if thermal equivalence is achieved.

An exact drawing of the thermally prorated section shall be published in the test report.

No further requirements apply, especially not on the design of the prorated section. Therefore, the thermally prorated section needs not to be a sliced portion of the arrester and needs not contain only the same material as in the arrester. It may have a design different to that of the modelled arrester, as long as thermal equivalence and sufficient dielectric strength for the energy and charge injection, respectively, are assured.

Due to the usually very complex internal design of GIS arresters, it may not be practical to carry out the test on test samples with many MO resistor columns in parallel. On the other hand, to achieve thermal equivalence with single-column sections is more realistic in GIS arresters than in AIS arresters because of their better cooling characteristic. Therefore, for GIS arresters according to 3.19, single-column sections are accepted if thermal equivalence as per Annex A can be proven.

8.3.2.2 Dielectrically prorated section

The arrester section for internal dielectric strength tests shall represent a sliced portion of the arrester being modelled, including the MO resistors, the housing and the supporting structure.

The continuous operating voltage of the prorated section shall be at least 3 kVpeak.

The section shall meet the following requirements: it shall be an exact copy of the real arrester with regard to diameters, materials etc. The mechanically supporting structure shall be included. Elements that are only located at distributed positions in the arrester being modelled, such as distance holders and spacers, shall be present in the model. The active part shall have the same surrounding medium as in the real arrester.

A dielectrically prorated section may also be a real arrester or arrester unit of the design.

An exact drawing of the dielectrically prorated section shall be published in the test report.

For GIS arresters the clause does not apply. The internal components of a GIS arrester shall be tested as per 60099-4.

8.3.2.3 Section for residual voltage tests

The arrester section for the residual voltage tests shall be a complete arrester unit, a stack of series connected MO resistors or an individual MO resistor in still air. For multi-column arresters the section may be made of the actual number of MO resistors or resistor columns in parallel or of only one MO resistor or resistor column, respectively.

8.3.2.4 Section for the test to verify the repetitive charge transfer rating, Q_{rs}

The arrester section for the test to verify the repetitive charge transfer rating, Q_{rs}, shall be an individual MO resistor either in still air or in the actual surrounding medium of the design. The choice is at the discretion of the manufacturer.

9 Type tests (design tests)

9.1 General

Type tests defined in this clause apply to both porcelain-housed and polymer-housed surge arresters, if not specifically mentioned otherwise. All tests and test procedures which are valid for most types of arresters for HVDC stations are given in this clause. Exceptions for specific arrester types are given in 11. For d.c. bus/line arresters GIS arresters are also considered and covered under 11.7.

NOTE Tests with d.c. voltage e.g. at 1,5 times the nominal d.c. voltage is not specified since such tests cannot be performed with the MO resistors in place and the internal design is tested elsewhere (see 9.14.3.1 and 9.15). The d.c. withstand voltage for external insulation is also relatively higher than for switching and power-frequency withstand voltages.

9.2 Insulation withstand test on the arrester housing

9.2.1 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 user.

The tests shall be performed in the conditions and with the test voltages specified below. The power-frequency voltage test may be replaced by a switching impulse voltage test. The choice is up to the manufacturer. The outside surface of insulating parts shall be carefully cleaned and the internal parts removed or replaced as further specified in 9.2.2 and 9.2.3.

If insulation withstand tests performed on other equipment include the arresters, e.g. test on the thyristor valves, no further tests are required on the arresters. Regarding the arrester housing during such tests 9.2.2 and 9.2.3 apply.

If any of the conditions relating dry arc distance to test voltage, as described in 9.2.6, 9.2.7 or 9.2.8, is fulfilled then the relevant test specified in 9.2.6, 9.2.7 or 9.2.8 need not be performed, since, under these conditions, the insulation withstand voltage of the arrester will inherently meet the minimum requirement.

9.2.2 Tests on individual unit housings

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. For the test, the MO resistors shall be removed from the housing or replaced by insulators.

9.2.3 Tests on complete arrester housing assemblies

For arresters with a CCOV $\geq$ 250 kV, tests shall be performed on completely assembled arresters, except that the MO resistors shall be replaced by resistors, capacitors or MO resistors to obtain, approximately, the same voltage grading of the arrester during high current discharges as would be given by the actual MO resistors used in the arrester. When using MO resistors they shall give a higher protection characteristic than the actual MO resistors. The characteristic of the MO resistors shall be selected to obtain at least 1 A peak during the insulation withstand test. This also means that MO resistors are an alternative for lightning and switching impulse voltage tests but not for a power-frequency voltage test. The tests shall be performed under as realistic conditions as possible with the arrester placed on a pedestal with the minimum height used.

9.2.4 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.

9.2.5 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.

9.2.6 Lightning impulse voltage test

The arresters, except capacitor arresters as per 11.12, shall be subjected to a standard lightning impulse voltage dry test according to IEC 60060-1. The test voltage shall be at least equal to:

– The lightning impulse protection level of the arrester (see 3.42) multiplied by:
  - For outdoor arresters and arresters installed indoors at a maximum of the daily (24 h) average ambient temperatures during a year $T \leq 40$ °C with $1{,}1 \times e^{1\,000/8\,150}$.
  - For arresters installed indoors at a maximum of the daily (24 h) average ambient temperatures during a year $T > 40$ °C with $1{,}1 \times e^{1\,000/8\,150} \times (273 + T)/313$ where T is the maximum average ambient temperature in °C.

NOTE The factors cover variation in atmospheric conditions and discharge currents higher than coordinating current. For altitude above 1 000 m (abnormal service condition) "1 000" in the formulas is replaced by actual altitude.

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.

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.

9.2.7 Switching impulse voltage test

– The arresters with a CCOV ≥ 250 kV 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. The test voltage shall be at least equal to:

– the switching impulse protection level of the arresters (see 3.42) multiplied by:
  - For outdoor arresters and arresters installed indoors at a maximum of the daily (24 h) average ambient temperatures during a year $T \leq 40$ °C with $1{,}1 \times e^{m \times 1\,000/8\,150}$ where m is taken from IEC 60071-2:1996, Figure 9, phase-to-earth insulation and where the value on the abscissa in Figure 9 shall be 1,1 times the switching impulse protection level of the arrester.
  - For arresters installed indoors at a maximum of the daily (24 h) average ambient temperatures during a year $T > 40$ °C with $1{,}1 \times e^{m \times 1\,000/8\,150} \times [(273+T)/313]^{m}$ where m is taken from IEC 60071-2:1996, Figure 9, phase-to-earth insulation and where the value on the abscissa in Figure 9 shall be 1,1 times the switching impulse protection level of the arrester.

NOTE 1 The factors cover variation in atmospheric conditions and discharge currents higher than coordinating current. For altitude above 1 000 m (abnormal service condition) "1 000" in the formulas is replaced by actual altitude.

When the insulation requirements of arresters calculated from the above are still higher than that decided for the protected equipments the same insulation levels should apply also for the arresters.

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.

If the dry arcing distance or the sum of the partial dry arcing distances is larger than given by the equation d = 2,2 × [$e^{(U/1069)}$-1], where d is the distance in m and U is the test voltage in kV, this test is not required.

NOTE 2 The equation is derived from formula G.3 of IEC 60071-2:1996, where U_{50} is given as k × 1 080 × ln(0,46 × d+1), k is the gap factor and d is the distance. For the purpose of this standard, the gap factor k is assumed to be equal to 1,1, and two standard deviations of 0,05 each are taken into account to achieve the withstand voltage.

9.2.8 Power-frequency voltage test

The arresters with a CCOV < 250 kV and capacitor arresters (11.12) shall be subjected to a 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.

– The test voltage, with a duration of 1 min, shall have a peak value at least equal to:
  - For outdoor arresters and arresters installed indoors at a maximum of the daily (24 h) average ambient temperatures during a year $T \leq$ 40 °C the switching impulse protection level (see 3.42) multiplied with 1,06 or the lightning impulse protection level (see 3.42) multiplied with 0,88.
  - For arresters installed indoors at a maximum of the daily (24 h) average ambient temperatures during a year $T >$ 40 °C the switching impulse protection level (see 3.42) multiplied with 1,06 × [(273 + T)/313] or the lightning impulse protection level (see 3.42) multiplied with 0,88 × [(273 + T)/313].

NOTE 1 The factors 1,06 and 0,88 cover variation in atmospheric conditions and discharge currents higher than coordinating current. The factor 0.88 is obtained from a coordination factor of 1,15, a test conversion factor of 0,68 from lightning to power-frequency withstand voltage and an altitude factor of 1,13. The factor 1,06 is obtained from a coordination factor of 1,1, a test conversion factor of 0,85 from switching to power-frequency withstand voltage and an altitude factor of 1,13.

The housing for capacitor arresters (11.12) shall withstand a power-frequency voltage in wet conditions for arresters for outdoor use and in dry conditions for arresters housings for indoor use for a duration of 1 min and with a peak value equal to the switching impulse protection level (see 3.42) multiplied by:

- For outdoor arresters and arresters installed indoors at a maximum of the daily (24 h) average ambient temperatures during a year $T \leq$ 40 °C with 1,2.
- For arresters installed indoors at a maximum of the daily (24 h) average ambient temperatures during a year $T >$ 40 °C with 1,2 × [(273 + T)/313].

If the dry arcing distance or the sum of the partial dry arcing distances is larger than given by the equation d = [1,82×$e^{(U/859)}$ – 1]^{0,833}, where d is the distance in m and U is the peak value of the power-frequency test voltage in kV, this test is not required.

NOTE 2 The equation is derived from formula G.1 of IEC 60071-2:1996, where the peak value of U_{50} is given as 750 × √2 × ln(1 + 0,55 × $d^{1,2}$), d being the distance. Following the recommendations given in IEC 60071-2, for the purpose of this standard the gap factor k is assumed to be equal to 1, the withstand voltage is assumed to be 90 % of U_{50} and a 10 % reduction in U_{50} is assumed for wet conditions compared to dry.

NOTE 3 The factor 1,2 is taken from IEC 60143-1.

9.3 Short-circuit tests

All arresters 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 up to 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 arrester shall be tested in accordance with the procedures and evaluation criteria given in IEC 60099-4 depending on the type of design the arrester belong to as per the classification in 60099-4.

The test currents shall be 100 %, 50 % and 25 % of the highest considered short-circuit current. In addition a test with 600 A shall be performed. The currents shall be applied for the actual duration except for the test with 600 Arms which shall be applied for 1 s. The ratio first current peak to r.m.s. value shall be as per IEC 60099-4 except that for “Design A” arresters as per IEC 60099-4 actual ratio is allowed to be used.

NOTE 1 If the arrester has a rated short-circuit current verified as per IEC 60099-4 no further tests are necessary if

– The actual short-circuit current is less than or equal to the rated short-circuit current and

– The actual duration of the short-circuit current does not exceed 0,2 s.

NOTE 2 If the actual maximum short-circuit current is ≤ 6 kArms the test at 50 and 25 % of maximum current need not to be performed.

9.4 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 1 Shielding against external partial discharges should have negligible effects on the voltage distribution.

A power-frequency voltage shall be used for the test and be as follows:

– For valve arresters the test voltage (r.m.s. value) shall be 0,9/√2 times PCOV.

– For d.c. bus arresters, d.c. line/cable arresters, for arresters at neutral bus located on line/cable side of smoothing reactor (if any), for arresters at neutral bus without smoothing reactor on the bus, for arresters on electrode line and metallic return and DC reactor arresters the test voltage shall be (r.m.s. value) 1,05/√2 times PCOV. As an alternative, on the choice of the manufacturer, the test on the d.c. bus arrester and d.c. line/cable arresters may be performed with a d.c. voltage 1,05 times the d.c. system voltage.

– For arresters at neutral bus located on the converter side of smoothing reactor (if any) the test voltage shall be (r.m.s. value) 1,0/√2 times PCOV.

– For converter unit and converter unit d.c. bus arresters the test voltage shall be (r.m.s. value) 0,95/√2 times PCOV. For mid-point d.c. bus arrester, mid-point bridge arresters, HV and LV converter unit arresters and arrester between converters the test voltage shall be (r.m.s. value) 0,9/√2 times PCOV.

– For transformer valve winding arrester the test voltage (r.m.s. value) shall be 0,9/√2 times PCOV.

– For arresters at d.c. and a.c. filters the test voltage shall be (r.m.s. value) 1,05/√2 times the PCOV.

– For capacitor arresters (11.12) the test voltage shall be (r.m.s. value) 1,05/√2 times the PCOV

The power-frequency voltage shall be increased to 1,05 times the test voltage of the sample, held for 2 s to 10 s, and then decreased to the test 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.

If the test is performed as routine test on arrester units or complete arresters the type test need not to be performed

9.5 Test of the bending moment

9.5.1 Test on porcelain-housed arresters

9.5.1.1 General

The complete test procedure is shown by the flow chart in Annex C.

9.5.1.2 Overview

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 shall be performed on complete arrester units without internal overpressure. For single-unit arrester designs, the test shall be performed on the longest unit of the design. Where an arrester contains more than one unit or where the arrester has different specified bending moments in both ends, the test shall be performed on the longest unit of each different specified bending moment, with loads determined according to C.1.

The test shall be performed in two parts that may be done in any order:

– a bending moment test to determine the mean value of breaking load (MBL);
– a static bending moment test with the test load equal to the specified short-term load (SSL), i.e. the 100 % value of C.3.

9.5.1.3 Sample preparation

One end of the sample shall be firmly fixed to a rigid mounting surface of the test equipment, and a load shall be applied to the other (free) end of the sample to produce the required bending moment at the fixed end. The direction of the load shall pass through and be perpendicular to the longitudinal axis of the arrester. If the arrester is not axi-symmetrical with respect to its bending strength, the manufacturer shall provide information regarding this non-symmetric strength, and the load shall be applied in an angular direction that subjects the weakest part of the arrester to the maximum bending moment.

9.5.1.4 Test procedure

9.5.1.4.1 Test procedure to determine mean value of breaking load (MBL)

Three samples shall be tested. If the test to verify the SSL (see 9.5.1.4.2) is performed first, then samples from that test may be used for determination of MBL. The test samples need not contain the internal parts. On each sample, the bending load shall be increased smoothly until breaking occurs within 30 s to 90 s. “Breaking” includes fracture of the housing and damages that may occur to fixing device or end fittings.

The mean breaking load, MBL, is calculated as the mean value of the breaking loads for the test samples.

NOTE The housing of an arrester may splinter under load and may present a handling hazard.

9.5.1.4.2 Test procedure to verify the specified short-term load (SSL)

Three samples shall be tested. 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 10.1) and an internal partial discharge test (see item c) of 10.1). If these tests have been performed as routine tests, they need not be repeated at this time.

On each sample, the bending load shall be increased smoothly to SSL, tolerance $^{+5}_{-0}$%, 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. The residual deflection shall be measured in the interval 1 min to 10 min after the release of the load.

NOTE The housing of an arrester may splinter under load and may present a handling hazard.

9.5.1.5 Test evaluation

The arrester shall have passed the test if

- the mean value of breaking load, MBL, is ≥ 1,2 × SSL;
- for the SSL test
  - there is no visible mechanical damage;
  - the remaining permanent deflection is ≤ 3 mm or ≤ 10 % of maximum deflection during the test, whichever is greater;
  - the test samples pass the leakage test in accordance with item d) of 10.1;
- the internal partial discharge level of the test samples does not exceed the value specified in item c) of 10.1.

9.5.2 Test on polymer-housed arresters

9.5.2.1 General

This test applies to polymer housed arresters (with and without enclosed gas volume)

Arresters that have no declared cantilever strength shall be submitted to the terminal torque preconditioning according to 9.5.2.4.2.2, the thermal preconditioning according to 9.5.2.4.2.4 and the water immersion test according to 9.5.2.4.3 if the arresters are located outdoors.

The complete test procedure is shown by the flow chart in Annex C.

9.5.2.2 Overview

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 shall be performed on complete arrester units with the highest rated voltage of the unit. For single-unit arrester designs, the test shall be performed on the longest unit with the highest rated voltage of that unit of the design. Where an arrester contains more than one unit or where the arrester has different specified bending moments in both ends, the test shall be performed on the longest unit of each different specified bending moment, with loads determined according to C.1. However, if the length of the longest unit is greater than 800 mm, a shorter length unit may be used, provided the following requirements are met:

- the length is at least as long as the greater of
  - 800 mm
  - three times the outside diameter of the housing (excluding the sheds) at the point it enters the end fittings;
- the unit is one of the normal assortment of units used in the design, and is not specially made for the test;
- the unit has the highest rated voltage of that unit of the design.

A test in three steps shall be performed one after the other on three samples as follows:

– on all three test samples a cyclic test comprising 1 000 cycles with the test load equal to the specified long-term load (SLL);

– on two of the samples a static bending moment test with the test load equal to the specified short-term load (SSL), i.e. the 100 % value of C.3 and on the 3rd sample a mechanical preconditioning test as per 9.5.2.4.2;

– on all three samples a water immersion test as per 9.5.2.4.3.

Tolerance on specified loads shall be $^{+5}_{-0}$%.

9.5.2.3 Sample preparation

The test samples shall contain the internal parts.

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

– electrical tests made in the following sequence:
  - watt losses measured at ECOV and at an ambient temperature of 20 °C ± 15 K;
  - internal partial discharge test according to item c) of 10.1;
  - residual voltage test at not less than (0,01 to 1) times the coordinating current; the current wave shape shall be in the range of T_1/T_2 = (4 to 10)/(10 to 25) μs;

– leakage tests in accordance with item d) of 10.1 for arresters with enclosed gas volume and separate sealing system.

If the partial discharge test according to item c) of 10.1 and the leakage test according to item d) of 10.1 have been performed as routine tests they need not be repeated at this time.

One end of the sample shall be firmly fixed to a rigid mounting surface of the test equipment, and a load shall be applied to the other (free) end of the sample to produce the required bending moment at the fixed end. The direction of the load shall pass through and be perpendicular to the longitudinal axis of the arrester. If the arrester is not axi-symmetrical with respect to its bending strength, the manufacturer shall provide information regarding this non-symmetric strength, and the load shall be applied in an angular direction that subjects the weakest part of the arrester to the maximum bending moment.

9.5.2.4 Test procedure

9.5.2.4.1 General

The test shall be performed on three samples. The test is performed in three steps.

Step 1:

– Subject all three samples to 1 000 cycles of bending moment, each cycle comprising loading from zero to specified long-term load (SLL) in one direction, followed by loading to SLL in the opposite direction, then returning to zero load. The cyclic motion shall be approximately sinusoidal in form, with a frequency in the range 0,01 Hz to 0,5 Hz.

Due to the control of the testing machine it may take some cycles to obtain the SLL. The maximum number of these cycles shall be specified by the manufacturer. These cycles shall not be included in the prescribed 1 000 cycles.

The maximum deflection during the test and any residual deflection shall be recorded. The residual deflection shall be measured in the interval 1 min to 10 min after the release of the load.

Step 2.1:

Subject two of the samples from step 1 to a bending moment test. The bending load shall be increased smoothly to specified short-term load (SSL) 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.

The maximum deflection during the test and residual deflection shall be recorded. The residual deflection shall be measured within 1 min to 10 min after the release of the load.

Step 2.2:

Subject the third sample from Step 1 to mechanical/thermal preconditioning according to 9.5.2.4.2.

Step 3:

Subject all three samples to the water immersion test according to 9.5.2.4.3.

9.5.2.4.2 Mechanical/thermal preconditioning

9.5.2.4.2.1 General

This preconditioning constitutes part of the test procedure of 9.5.2.4 and shall be performed on one of the test samples as defined in 9.5.2.4.

9.5.2.4.2.2 Terminal torque preconditioning

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

9.5.2.4.2.3 Thermo-mechanical preconditioning

This portion of the test applies only to arresters for which a cantilever strength is declared.

The test does not apply to arresters installed indoors in ambient conditions as per 6.1.

The sample is submitted to the specified long-term load (SLL) in four directions and in thermal variations as described in Figures 6 and 7.

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

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 test shall be conducted in air. The temperature shall be measured in the surrounding air inside the test chamber.

The applied static mechanical load shall be equal to SLL defined by the manufacturer. Its direction changes every 24 h at any temperature in the transition from hot to cold, or from cold to hot, as defined in Figure 6.

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

Any residual deflection measured from the initial no-load position shall be reported. The residual deflection shall be measured within 1 min to 10 min after the release of the load.

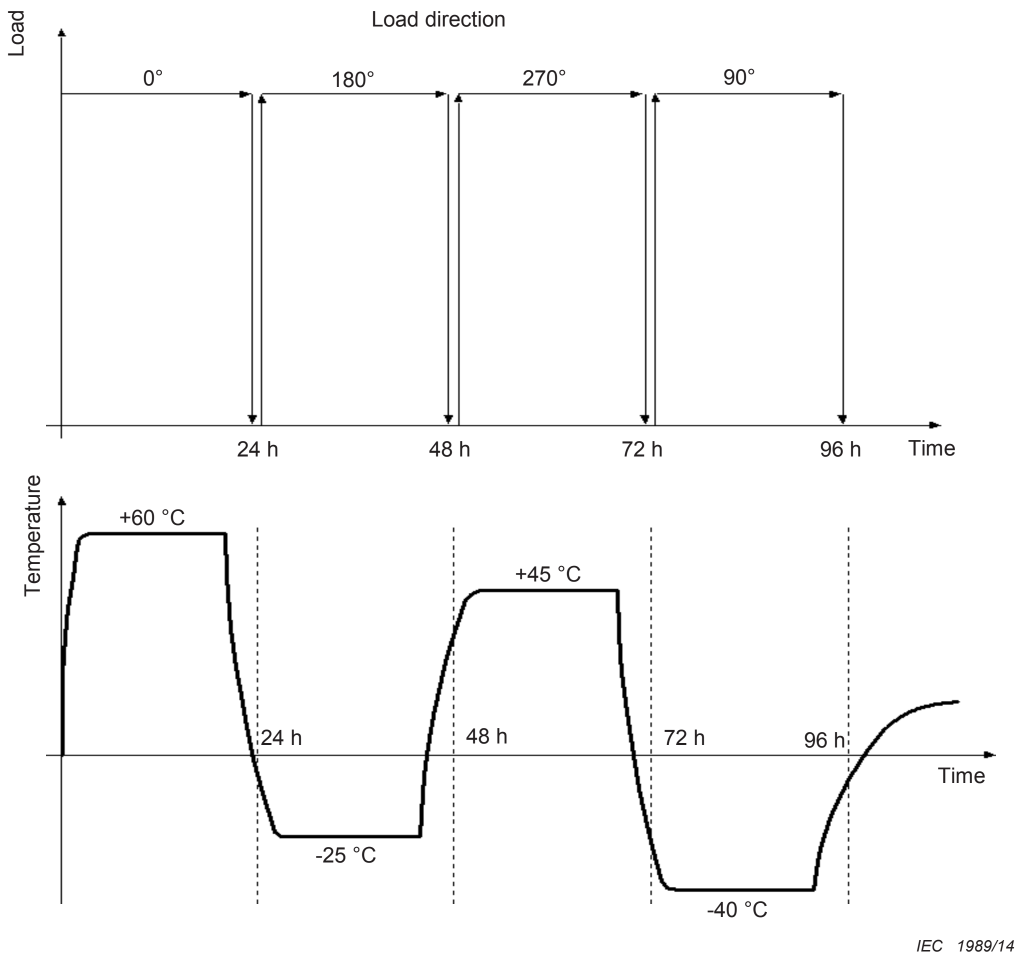


Figure 6 – Thermomechanical test

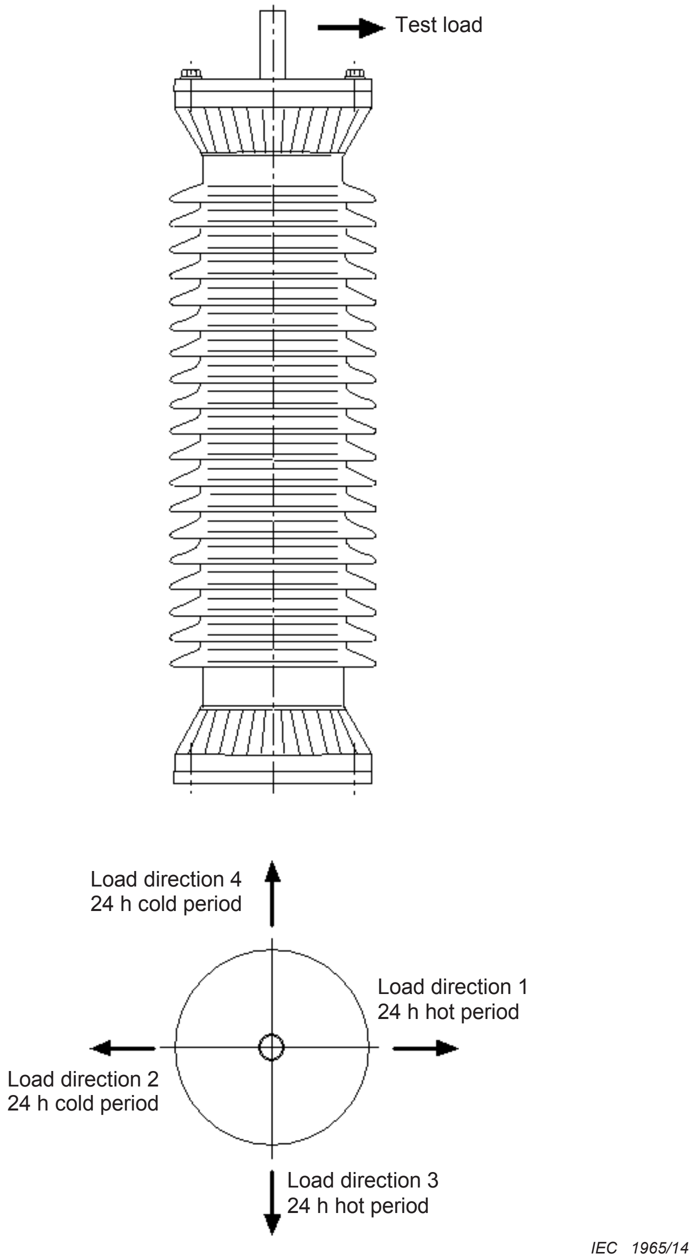


Figure 7 – Example of the test arrangement for the thermomechanical test and direction of the cantilever load

9.5.2.4.2.4 Thermal preconditioning

This portion of the test applies only to arresters for which no cantilever strength is declared.

The test does not apply to arresters installed indoors in ambient conditions as per 6.1.

The sample is submitted to the thermal variations as described in Figure 6 without any load applied.

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 test shall be conducted in air.

9.5.2.4.3 Water immersion test

This test does not apply to arresters installed indoors e.g. in valve halls.

The test samples shall be kept immersed in a vessel, in boiling deionised 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 in the water at this temperature until verification tests can be performed. The arrester shall be removed from the water and cooled to ambient temperature for not longer than three thermal time constants of the sample (as derived from the cooling curves of Annex A). The 50 °C holding temperature is necessary only if it is necessary to delay the verification tests after the end of the water immersion test as shown in Figure 8. Evaluation tests shall be made within the time specified in 9.5.2.5. After removing the sample from the water it may be washed with tap water.

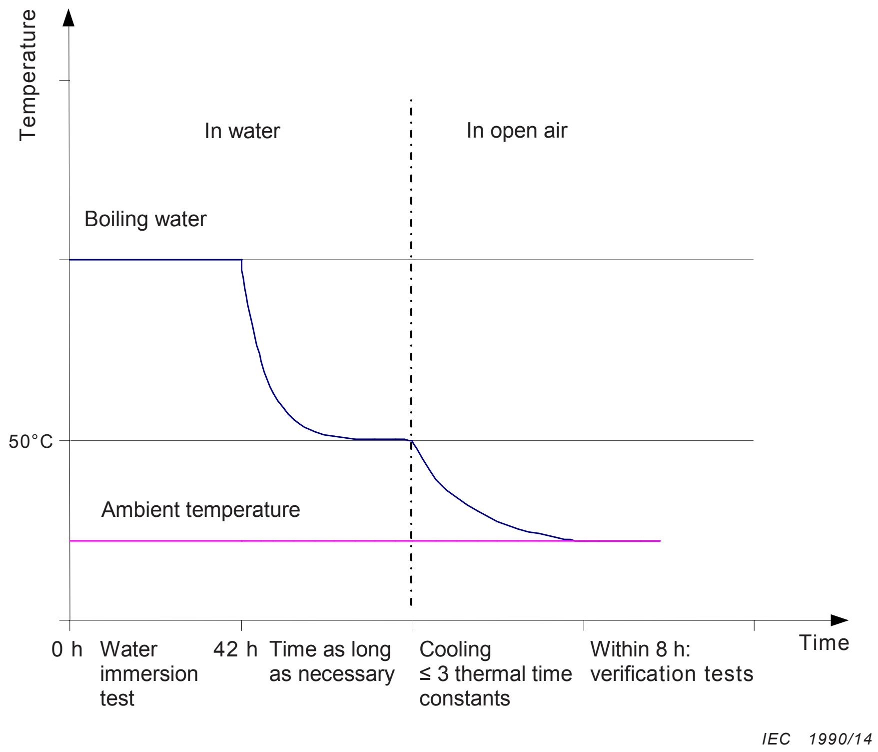


Figure 8 – Water immersion

9.5.2.5 Test evaluation

Tests according to 9.5.2.3 shall be repeated on each test sample.

The arrester shall have passed the test if the following is demonstrated:

After step 2:

– there is no visible damage;

– the slope of the force-deflection curve remains positive up to the SSL value except for dips not exceeding 5 % of SSL magnitude. The sampling rate of digital measuring equipment shall be at least 10 s^{-1}. The cut-off frequency of the measuring equipment shall be not less than 5 Hz.

Maximum deflection during step 1 and 2 and any remaining permanent deflection after the test shall be reported.

After step 3:

within 8 h after cooling as defined in Figure 8:

– the increase in watt losses, measured at ECOV and at an ambient temperature that does not deviate by more than 3 K from the initial measurements, is not more than the greater of 20 mW/kV of ECOV (measured at ECOV) or 20 %;
– the internal partial discharge measured at a voltage according to 9.4 does not exceed 10 pC;

at any time after the above watt losses and partial discharge measurements:

– for arresters with enclosed gas volume and separate sealing system, the samples pass the leakage test in accordance item d) of 10.1;
– the residual voltage measured on the complete sample at the same current value and wave shape as the initial measurement is not more than 5 % different from the initial measurement;
– the difference in voltage between two successive impulses at 10 kA discharge current does not exceed 2 %, and the oscillograms of voltage and current do not reveal any partial or full breakdown of the test sample. The current wave shape shall be in the range of T_1/T_2 = (4 to 10)/(10 to 25) μs, and the impulses shall be administered 50 to 60 s apart.

NOTE In case of extra long arresters where the blocks can be dismantled this part of the evaluation test can be performed on individual blocks or stacks of blocks. If the blocks cannot be dismantled a possible procedure would be to drill a hole in the arrester insulation to make contact with the internal stack at a metal spacer and in this way be able to test shorter arrester sections.

– the change in reference voltage measured before and after the two residual voltage tests does not exceed 2 %.

9.6 Environmental tests

9.6.1 General

These tests apply to porcelain-housed arresters. They do not apply to arresters installed indoors in e.g. valve or DC halls under controlled ambient conditions.

9.6.2 Overview

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.

The test shall be performed on complete arrester units of any length.

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

Arresters whose units differ only in terms of their lengths, and which are otherwise based on the same design and material, and have the same sealing system in each unit, are considered to be the same type of arrester.

9.6.3 Sample preparation

Prior to the tests, the test sample shall be subjected to the leakage check of d) of 10.1.

9.6.4 Test procedure

9.6.4.1 General

The tests specified below shall be performed on one sample in the sequence given.

9.6.4.2 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.

9.6.4.3 Salt mist test

The test shall be performed according to Clause 4 and Subclause 7.6, as applicable, of IEC 60068-2-11:1981:

– salt solution concentration: 5 % ± 1 % by weight;

– test duration: 96 h.

9.6.5 Test evaluation

The arrester shall have passed the tests if the sample passes the leakage check in accordance with item d) of 10.1.

9.7 Weather ageing test

9.7.1 General

This test applies to polymer-housed arresters installed outdoors.

9.7.2 Test specimens

This test has a duration of 1 000 h under salt fog conditions. The test 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.

9.7.3 Test procedure

The test is a time-limited continuous test under salt fog at constant voltage equal to the continuous operating voltage of the arrester. The applied voltage shall be a d.c. voltage for arresters located on the d.c. side of the converter and an a.c. voltage of 50 or 60 Hz for arresters on the a.c. side. For arresters subjected to a d.c. voltage the test voltage shall not be less than the DCOV for the arrester.

Filter arresters on either the d.c. side or the a.c. side of the converter subjected to an a.c. voltage with higher frequency than 50 to 60 Hz shall be tested with a.c. voltage of 50 to 60 Hz with an amplitude at least equal to the ECOV.

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 %. Not sufficient information is available on the necessary d.c. source but as an information when testing with d.c. voltage the test circuit when loaded with a current of 250 mA on the high-voltage side, should 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 $l/h/m^3 \pm 0,1\ l/h/m^3$
– 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. The number of overcurrent trip-outs shall be noted and taken into account in the evaluation of the duration of the test.

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

9.7.4 Evaluation of the test

The test is regarded as passed, if no tracking occurs (see IEC 62217), if erosion does not occur through the entire thickness of any shed or other part 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 at the same ambient temperature within ± 3 K 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 as measured according to the procedure of 9.4.

For arresters with enclosed gas volume and separate sealing system a successful leakage test in accordance with item d) of 10.1 shall be performed

9.8 Seal leak rate test

9.8.1 General

This test applies to arresters having an enclosed gas volume and a separate sealing system. It does not apply to GIS arresters.

9.8.2 Overview

This test demonstrates the gas/water tightness of the complete system.

If a routine test for seal leak rate (see item d) of 10.1) is performed with acceptance criteria at least as stringent as specified in this clause, then a type test is not required. Otherwise, a type 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.

9.8.3 Sample preparation

The test sample shall be new and clean.

9.8.4 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.

9.8.5 Test evaluation

The maximum seal leak rate (see Annex C.4) shall be lower than

$$1 \times 10^{-6} \text{ Pa} \times \text{m}^3/\text{s}$$

9.9 Radio interference voltage (RIV) test

These tests apply to open-air surge arresters having a CCOV above 100 kV. The test shall be performed on the longest arrester, with the highest continuous operating 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 nonlinearity of the potential distribution along a complete arrester.

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

If it by calculations can be shown that for a specific arrester the electrical field at critical locations is less than or equal to the electrical field on an arrester which has been successfully tested at higher or equal voltage no test is required.

The test voltage for the different arresters shall be as follows:

– For valve arresters the maximum radio interference level of the arrester energized at a power-frequency voltage (r.m.s. value) of $0{,}9/\sqrt{2}$ times the maximum peak value of continuous operating voltage including high-frequency transients shall not exceed 2 500 μV.
– For d.c. bus arresters and d.c. line/cable arresters the maximum radio interference level of the arrester energized at a power-frequency voltage (r.m.s. value) of $1{,}05/\sqrt{2}$ times the d.c. system voltage shall not exceed 2 500 μV. As an alternative, on the choice of the manufacturer, the test may be performed with a d.c. voltage 1,05 times the d.c. system voltage. Both polarities shall be tested.

- For arresters at neutral bus located on line/cable side of smoothing reactor (if any) and for arresters at neutral bus without smoothing reactor on the bus the maximum radio interference level of the arrester energized at a power-frequency voltage (r.m.s. value) of $1{,}05/\sqrt{2}$ times the maximum peak continuous operating voltage including high-frequency transients shall not exceed 2 500 μV.
- for arresters at neutral bus located on the converter side of smoothing reactor (if any) the maximum radio interference level of the arrester energized at a power-frequency voltage (r.m.s. value) of $1{,}0/\sqrt{2}$ times the maximum peak continuous operating voltage including high-frequency transients shall not exceed 2 500 μV.
- For converter unit and converter unit d.c. bus arresters the maximum radio interference level of the arrester energized at a power-frequency voltage (r.m.s. value) of $0{,}95/\sqrt{2}$ times the maximum peak continuous operating voltage including high-frequency transients shall not exceed 2 500 μV.
- For mid-point d.c. bus arrester, mid-point bridge arresters, HV and LV converter unit arresters and arrester between converters the maximum radio interference level of the arrester energized at a power-frequency voltage (r.m.s. value) of $0{,}9/\sqrt{2}$ times the maximum peak continuous operating voltage including high-frequency transients shall not exceed 2 500 μV.
- For transformer valve winding arrester the maximum radio interference level of the arrester energized at a power-frequency voltage (r.m.s. value) of $0{,}9/\sqrt{2}$ times the maximum peak continuous operating voltage including high-frequency transients shall not exceed 2 500 μV.
- For arresters at d.c. and a.c. filters the maximum radio interference level of the arrester energized at a power-frequency voltage (r.m.s. value) of $1{,}05/\sqrt{2}$ times the maximum peak continuous operating voltage shall not exceed 2 500 μV.
- For capacitor arresters (11.12) the maximum radio interference level of the arrester energized at a power-frequency voltage (r.m.s. value) of $1{,}05/\sqrt{2}$ times the maximum peak continuous operating voltage shall not exceed 2 500 μV.

If the arrester is installed at high potential to ground this should be considered.

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 18-2 and CISPR 16-1-1 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 nor less than 30 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/TR 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 voltage is increased to 1,05 times the test voltage given above and then lowered to the test voltage where it shall be maintained for 5 min. The voltage shall then be decreased by steps to 0,5 times the test voltage, raised again by steps to the test voltage for 5 min and finally decreased by steps to 0,5 times the test voltage. 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 times the test voltage.

The surge arrester shall have passed the test if the radio interference level at the test voltage 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).

The verification may also be performed in combination with tests on other equipments which the arresters are located very close to, e.g. the verification for valve arresters may be made when testing the thyristor valves.

9.10 Residual voltage test

9.10.1 General

The purpose of the residual voltage type test is to obtain the data necessary to derive the maximum residual voltages as explained in 7.3. It includes the calculation of the ratio between voltages at specified impulse currents and the voltage level checked in routine tests. The latter voltage shall be the residual voltage at a suitable lightning impulse current in the range 0,01 to 100 times the lightning impulse coordination 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.

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.

9.10.2 Steep current impulse residual voltage test

One steep current impulse (see 3.58) with a peak value equal to the steep impulse coordination 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 non-ferrous 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 MO resistor samples, no inductive correction to the MO resistor measurements is required.
– If the peak voltage on the metal block is between 2 % and 20 % of the peak voltage on the MO resistor sample, then the impulse shape of the metal block voltage shall be subtracted from the impulse shape of each of the MO resistor voltages and the peak values of the resulting impulse shapes shall be recorded as the corrected MO resistor voltages.
– If the peak voltage on the metal block is greater than 20 % of the peak voltage on the MO resistor samples, then the test circuit and the voltage measuring circuit shall be improved and the test shall be repeated.

NOTE 1 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 highest of the three measured residual voltages, corrected if necessary as indicated above, and multiplied by the scale factor (see 7.3) is defined as the maximum steep current impulse residual voltage, excluding inductive voltage contribution, of the arrester.

The maximum steep current impulse residual voltage, including inductive voltage contribution, of the arrester is calculated as per 7.3.

NOTE 2 Connecting leads to connect the arrester to the power system will introduce additional inductive voltage drop for steep current impulse currents.

9.10.3 Lightning impulse residual voltage test

One lightning current impulse (see 3.27) 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 lightning impulse coordination 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 7.3. 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 lightning impulse coordination current is defined as the lightning impulse protection level of the arrester.

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

9.10.4 Switching impulse residual voltage test

One switching current impulse (see 3.60) with a peak value equal to the switching impulse coordination current (see 3.61) of the arrester ±5 % shall be applied to each of the three samples. Virtual front time shall be within 30 μs to 100 μs while the half-value time (which is not critical) may have any tolerance. The residual voltages are determined in accordance with 7.3. The highest of these three voltages is defined as the switching impulse protection level of the arrester.

9.11 Test to verify long term stability under continuous operating voltage

9.11.1 General

This test is designed to determine if the MO resistors show stable or decreasing power losses when energized at continuous operating voltage. Each type of MO resistor used in the design shall be tested. Those arresters, which are subjected to a voltage with a d.c. component and for which polarity reversals may occur frequently (within days or months) or at least within a period of time not longer than 3 years, shall be tested according to 9.11.2. Arresters which will never be subjected to a polarity reversal shall be tested in accordance with 9.11.3. If polarity reversals are foreseen after more than 3 years the manufacturer should be consulted.

NOTE 1 The expected increase in power losses immediately after a polarity reversal is actually not an ageing phenomena but instead due to material polarization which is a function of the duration of applied voltage.

NOTE 2 The time period of 3 years is calculated for a maximum ambient temperature of 60 °C and assuming an acceleration factor AF_T = $2{,}5^{5{,}5}$.

Three MO resistor samples shall be stressed at a voltage equal to or higher than the corrected maximum continuous operating voltage of the sample (U_{ct}) for 1 000 h, during which the temperature shall be controlled to keep the surface temperature of the MO resistor at 115 °C ± 4 K.

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

If the actual voltage waveform is not possible to apply the test voltage shall fulfil the following requirements:

– The d.c. component shall be not less than the DCOV (3.9) in the actual wave shape;
– The peak voltage shall not be less than the PCOV (3.37);
– The voltage peak except the PCOV shall not be less than the CCOV (3.7);
– For a.c. and d.c. filter arresters the frequency of the test voltage shall not be less than the DFCOV (3.14).

During the tests, the peak and r.m.s. value of the voltage shall not deviate from the specified values by more than ±1 %.

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

During this accelerated ageing, the MO resistor shall be in the surrounding medium used in the arrester. In this case, the procedure shall be carried out on single MO 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 3 The medium surrounding the MO 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.

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 test may be carried out in open air.

9.11.2 Test procedure for arresters subjected to voltage reversal

9.11.2.1 General

Either one of the following test methods shall be applied:

a) The MO resistors shall be subjected to the test voltage with polarity reversals as shown in Figure 9. The MO resistor power losses shall be measured at a voltage of U_{ct} 0,5 h to 1 h after the voltage application, just before each polarity reversal, 0,5 h after each polarity reversal and, finally, 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. However, the final measurement shall be performed after not less than 100 h of continuous energizing. Within the temperature range allowed, all measurements shall be made at the same temperature ±1 K. The polarity reversals shall take place within 3 minutes. At the discretion of the manufacturer, instead of circuit polarity reversals the MO resistors may instead be turned upside down at the specified time in the test cycle.

   or

b) The MO resistors shall be subjected to the test voltage with a single polarity reversal after 1 000 h. The initial power losses P_0 shall be measured at a voltage of U_{ct} 0,5 h to 1 h after the voltage application. The MO resistor power losses thereafter shall be measured once in every 100 h time span and given the designation P_1 to P_9, after the first measurement giving P_0. Finally, the MO resistor power losses P_{10} 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. However, the final measurement shall be performed after not less than 100 h of continuous energizing. Within the temperature range allowed, all measurements shall be made at the same temperature ± 1 K. The polarity reversal shall take place within 4 h after the measurement of P_{10} and shall take place within 3 minutes. The MO resistors shall be energized at U_{ct} after the measurement of P_{10} until polarity reversal has been performed. 0,5 h after the polarity reversal, tolerance ±1 min, the power losses shall be measured given the designation P_{11}. At the discretion of the manufacturer, instead of circuit polarity reversals the MO resistors may instead be turned upside down.

The choice of method a) or b) is at the discretion of the manufacturer but method b) is considered to be most severe regarding change in power losses due to polarity reversal.

The applied voltage shall preferably have the same or similar wave shape as the actual voltage applied on the arrester. If not possible due to limitations in test equipments an equivalent voltage considered to give higher or equal stress must be applied. A pure d.c. test voltage is e.g. considered to be more severe than an actual d.c. voltage with superimposed transients if the amplitude of the applied pure d.c. test voltage is equal to or higher than the crest of the actual d.c. voltage including transient.

Testing time shall be increased if the arrester is installed in an ambient temperature which exceeds 60 °C (24 hours average value). The testing time shall be calculated as follows:

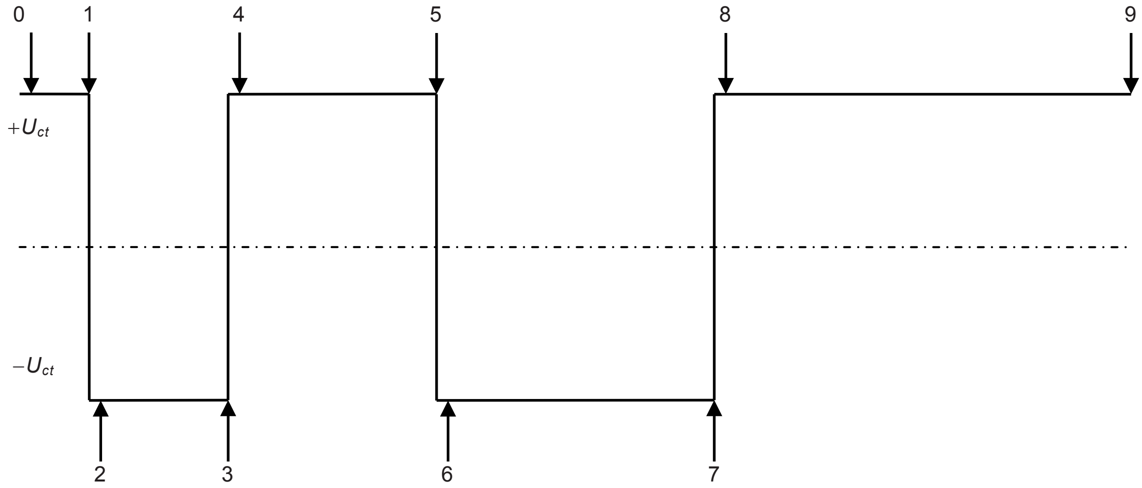
$$t = 154408/(2{,}5^{(115-T_a)/10})$$

where

t is the test duration in h

T_a is the ambient temperature

Each time period shown in Figure 9 shall be increased in relative proportion.



IEC 1991/14

Key

Point	**Time**	**Power losses measured**
0	0,5 h to 1 h	P_0
1	T_1=24 h ± 1 h	P_1
2	T_1+0,5 h ± 1 minute	P_2
3	T_2=72 h ± 2 h	P_3
4	T_2+0,5 h ± 1 minute	P_4
5	T_3=168 h ± 3 h	P_5
6	T_3+0,5 h ± 1 minute	P_6
7	T_4=360 h ± 4 h	P_7
8	T_4+0,5 h ± 1 minute	P_8
9	1 000 h $^{+100}_{0}$ h	P_9

Figure 9 – Test cycle for accelerated ageing test with polarity reversals, method a)

9.11.2.2 Test evaluation

For method a) the test is passed and the test to verify thermal energy rating (9.14) shall be performed on new MO resistors without any corrections if for all three test samples:

– P_1 to P_9 are equal to or less than 1,1 times P_0

If P_1, P_3, P_5, P_7 *and* P_9 are equal to or less than 1,1 times P_0 but any of P_2, P_4, P_6 and P_8 are greater than 1,1 times P_0 the test to verify thermal energy rating (9.14) shall be performed on test samples where the ECOV voltages are increased to correspond to the highest power losses of P_2, P_4, P_6 and P_8 for any of the test samples. On three samples comprising new MO resistors, in 9.14, the ECOV voltage is determined. At the starting temperature the power losses P_{ECOV} at ECOV are measured. Thereafter, the voltages are increased to ECOV* so that the corresponding power losses fulfill the relation:

$$\frac{P_{ECOV*}}{P_{ECOV}} = K_{ECOV}$$

where

K_{ECOV} is the highest ratio of P_2, P_4, P_6 and P_8 to P_0 for any of the three test sections in the accelerated ageing test.

Otherwise the test is considered as failed.

For method b) the test is passed and the test to verify thermal energy rating (9.14) shall be performed on new MO resistors without any corrections if for all three test samples:

– P_1 to P_{11} are equal to or less than 1,1 times P_0
– P_{10} is not greater than 1,3 times the minimum value of P_1 to P_9

If P_1 to P_{10} are equal to or less than 1,1 times P_0, P_{10} not greater than 1,3 times the minimum value of P_1 to P_9 but P_{11} greater than 1,1 times P_0 the test to verify thermal energy rating (9.14) shall be performed on test samples where the ECOV voltages are increased to correspond to the power losses P_{11} for any of the test samples. On three samples comprising new MO resistors, in 9.14, the ECOV voltage is determined. At the starting temperature the power losses P_{ECOV} at ECOV are measured. Thereafter, the voltages are increased to ECOV* so that the corresponding power losses fulfill the relation:

$$\frac{P_{ECOV*}}{P_{ECOV}} = K_{ECOV}$$

where

K_{ECOV} is the highest ratio of P_{11} to P_0 for any of the three test sections in the accelerated ageing test.

Otherwise the test is considered as failed.

9.11.3 Test procedure for arresters not subjected to voltage reversal

9.11.3.1 General

The MO resistor power losses P_0 shall be measured at a voltage of U_{ct} 0,5 h to 1 h after the voltage application. The MO resistor power losses shall be measured once in every 100 h time span and given the designation P_1 to P_9, after the first measurement giving P_0. Finally, the MO resistor power losses P_{10} 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. However, the final measurement shall be performed after not less than 100 h of continuous energizing. Within the temperature range allowed, all measurements shall be made at the same temperature ±1 K.

The applied voltage shall preferably have the same or similar wave shape as the actual voltage applied on the arrester. If not possible due to limitations in test equipments an equivalent voltage considered to give higher or equal stress must be applied. A pure d.c. test voltage is e.g. considered to be more severe than an actual d.c. voltage with superimposed transients if the amplitude of the applied pure d.c. test voltage is equal to or higher than the crest of the actual d.c. voltage including transient.

Testing time shall be increased if the arrester is installed in an ambient temperature which exceeds 60 °C (24 hours average value). The testing time shall be calculated as follows:

$$t = 154408/(2{,}5^{(115-T_a)/10})$$

where

t is the test duration in h

T_a is the ambient temperature

9.11.3.2 Test evaluation

The test shall be considered passed if for all three MO resistors:

– P_1 to P_{10} are equal to or less than 1,1 times P_0
– P_{10} is not greater than 1,3 times the minimum value of P_1 to P_9

Otherwise the test is considered as failed.

9.12 Test to verify the repetitive charge transfer rating, Q_{rs}

9.12.1 General

The purpose of this test is to verify the repetitive charge transfer rating, Q_{rs}, of an arrester.

Repetitive charge transfer capability is specified as an impulse current stress that can be withstood by the MO resistors of an arrester twenty times without mechanical or unacceptable electrical damage. One impulse current stress is considered to represent a charge transfer event in the time range of 200 μs to 2 s in real system conditions.

For some arresters e.g. a.c. and d.c. filter arresters the decisive case may in general result in current pulses of less duration than 200 μs. In such case the repetitive charge transfer test shall be performed with an impulse current of the actual or shorter duration.

The repetitive charge transfer rating is related to a certain very low failure probability and is thus not a deterministic but a statistical value. The test is performed on individual MO resistors at a charge value in the range 1,1 to 1,2 times the rated value selected from the list in 9.12.4. By this approach it is assumed that the performance of the individual MO resistors can also be assigned to a full arrester built from these MO resistors, based on the test requirements and the chosen statistical approach.

Charge has been chosen as a test basis for the purpose of better comparison between different makes of MO resistors.

For this test long-duration impulse currents or unipolar sine half-wave current impulses of similar time durations shall be applied.

Charge and energy handling capability is typically higher for lightning impulse discharges compared to long-duration current impulses. However, if the actual event is related to current impulses of shorter duration than 200 μs the test shall be carried out by impulses with this duration or shorter.

An arrester shall be assigned a Q_{rs} value from the list given in 9.12.4.

A first test sequence shall be performed on 10 samples of MO resistors selected according to 8.3.1 d). If not more than one MO resistor fails, the entire test is passed. If two MO resistors fail, a second sequence identical to the first shall be performed on an additional 10 samples. The entire test shall then be passed if there is no failure of an MO resistor during this second sequence. If more than two MO resistors fail in the first test sequence or any MO resistor fails in the second test sequence, the entire test is failed.

9.12.2 Test procedure

Ten test samples shall be tested in the first sequence. Depending on the test results, it may be necessary to test an additional ten samples in a second sequence.

The samples shall consist of individual MO resistors either in still air or in the actual surrounding medium of the design. The choice is at the discretion of the manufacturer.

The samples shall fulfil the requirements in 8.3.

The following procedure shall be followed:

- Each sample shall be subjected to a residual voltage test at 10 kA discharge current and a reference voltage test at specified reference current before and after the test.
- Each sample shall be subjected to twenty current impulses administered in ten groups of two impulses, with time between impulses within a group of 50 s to 60 s and time between groups sufficient for cooling to ambient temperature.
- The current impulses either shall be long-duration (rectangular) impulses of 2 ms to 4 ms virtual total duration or unipolar sine half-wave impulses of 2 ms to 4 ms total duration.
- The charge content of each impulse shall be as follows:
  a) for single-column arresters: at least equal to the claimed repetitive charge transfer rating (selected from the list given in 9.12.4) multiplied by 1,1;
  b) for multi-column arresters: at least equal to the claimed repetitive charge transfer rating (selected from the list given in 9.12.4) multiplied by 1,1, then divided by the number of columns, and then multiplied by the current sharing factor ,β_g (see item c) of 8.3.1).

NOTE 1 The requirement of testing at least 1,1 times the rated charge values is considered to give sufficient confidence that the performance of the individual MO resistors can also be assigned to complete arresters built from this type of MO resistors.

NOTE 2 If MO resistors tested with charge values for single-column arresters are used in a multi-column arrester and no new test is performed the repetitive charge transfer rating for the complete multi-column arrester is the next lower or equal value in the list (9.12.4) to the repetitive charge transfer rating of the MO resistors times the number of columns and divided by the current sharing factor.

9.12.3 Test evaluation

The full test shall be considered passed if either

- not more than one sample failed during the first sequence, or
- not more than two samples failed during two sequences.

Otherwise, the test is considered as failed and a lower charge level, Q_{rs}, from the list shown in 9.12.4 shall be selected, and the test shall be repeated for this lower charge level following the procedure given in 9.12.2.

NOTE 1 If only one failure occurs during the first sequence and this happens, in the worst case, at the very first impulse application, 180 impulses without failure will have been applied at the end, giving a failure probability of max. 1/181 = 0,005 6 or 0,56 % for the complete test. If two failures occur during the first sequence and this happens, again as a worst case, at the very first applications on two of the samples, 360 impulses without failure will have been applied at the end of both sequences, giving again a failure probability of max. 2/362 = 0,005 6 or 0,56 % for the complete test.

Each individual sample shall be considered to have withstood the complete series of impulses if all the following criteria are met:

- there is no indication of mechanical damage (puncture, flashover or cracking);
- any change of the reference voltage before and after the test, measured at the same temperature ± 3 K, is within ±5 %;

- any change of the residual voltage at 10 kA discharge current before and after the test is within ±5 %;
- a final application of a current impulse 8/20 μs of an amplitude of at least 20 kA is passed without mechanical damage.

NOTE 2 Burning or arcing damage to the metallization is not considered a mechanical damage if all other pass criteria are met.

9.12.4 Rated values of repetitive charge transfer rating, Q_{rs}

The repetitive charge transfer rating values shall be taken from the following list:

- from 0,1 C to 1,2 C in steps of 0,1 C
- from 1,2 C to 4,4 C in steps of 0,4 C
- from 4,4 C up to 10,0 C in steps of 0,8 C
- from 10 C to 20 C in steps of 2 C
- from 20 C upward in steps of 4 C

NOTE The following factors to calculate corresponding impulse current amplitudes from the charge values are given for guidance:

- Long-duration current, 2 ms: i_{peak} / A ≈ 500 × Q_{rs} / C
- Long-duration current, 4 ms: i_{peak} / A ≈ 250 × Q_{rs} / C
- Unipolar sine half-wave, 2 ms: i_{peak} / A ≈ 786 × Q_{rs} / C
- Unipolar sine half-wave, 4 ms: i_{peak} / A ≈ 393 × Q_{rs} / C

The resulting current amplitudes are informative and are approximate values, calculated under the assumption of an ideally rectangular impulse current shape in case of the long-duration current impulses. As an actual current shape will deviate from the ideal shape the actual amplitudes necessary to reach the rated charge values may differ from the values listed here.

9.13 Heat dissipation behaviour of test sample

9.13.1 General

In the test to verify the thermal energy rating (9.14) 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 MO resistors in the sample and in the complete arrester should in principle reach the same temperature when subjected to the same voltage stress.

A test shall be performed to demonstrate this equivalency (see 9.13.3).

9.13.2 Arrester section requirements

The requirements are specified in 8.3.2.1.

9.13.3 Procedure to verify thermal equivalency between arrester and arrester section

Thermal equivalency between the complete arrester and the arrester section shall be demonstrated following the procedure of Annex A.

9.14 Test to verify the thermal energy rating, W_{th}

9.14.1 General

The purpose of this test is to verify the arrester's ability to thermally recover after injection of the rated thermal energy, W_{th}, and following continuous operating voltage conditions. Due to the generally complex waveforms for arresters in HVDC stations the energy due to any temporary overvoltage conditions shall be included in the rated thermal energy.

The measuring equipment shall meet the requirements given in 8.1. The peak value of the applied continuous operating voltage shall not vary by more than 1 % from no-load to full-load condition. During the tests, the peak and r.m.s. value of the voltage shall not deviate from the specified values by more than ±1 %.

NOTE 1 Arresters with non-significant continuous operating voltage (3.34) need not to be tested.

NOTE 2 The rated thermal energy is taken from system studies and can be any value.

9.14.2 Arrester section requirements

The thermal recovery part of this test (9.14.3.2) shall be performed on thermally prorated sections of the real arrester as specified in 8.3.2.1. A temperature sensor shall be integrated in the sample such that the temperature of its active part can be measured.

The characterization and conditioning part (9.14.3.1) of the test may be performed at an ambient temperature of 20 °C ± 15 K on the MO resistors in still air or in the dielectrically prorated section according to 8.3.2.2.The test shall be performed on three test samples.

NOTE Although thermal stability has basically no statistical character, three test samples are specified. This compensates for statistical factors such as incorrect voltage adjustment, stray in the power loss characteristic, tolerance during energy injection etc.

The samples shall fulfil the requirements in 8.3.

The start temperature, ϑ_{start}, of the thermal recovery part of the test shall be 60 °C if the average operating temperature T_{ars} determined as per Annex B is not higher than 60 °C. Otherwise the start temperature shall be equal to T_{ars}. If the last paragraph of Annex A applies the start temperature shall be adjusted accordingly.

9.14.3 Test procedure

9.14.3.1 Characterization and conditioning

The following procedure shall be applied for characterization and conditioning:

- Each sample shall be subjected to a residual voltage test at the 10 kA discharge current and a reference voltage test at specified reference current only before the test. The reference voltage test is necessary to calculate the continuous operating voltage and the rated voltage. For multi-column arresters the distribution of the current between the columns shall be measured at the impulse current for current distribution test (see item e) of 10.1). The highest current value shall not be higher than an upper limit specified by the manufacturer. It is allowed not to measure the current distribution at impulse current but in that case β_a as per item c) of 8.3 shall be set to 1.
- For the purpose of conditioning, the samples shall be subjected to two high current impulses having at least amplitudes of 100 kA. This conditioning may be performed in the dielectrically prorated section, and the first high current impulse application may be considered the test to verify dielectric withstand of the internal components of an arrester (9.15) if all other requirements of 9.15 are also fulfilled. There shall be sufficient time between and after the impulses to allow for cooling to ambient temperature. The impulses shall be of same polarity, and their polarity shall be the same as that of the current

impulses for energy injection and charge transfer, respectively, in the thermal recovery part of the test.

- After application of the high current impulses the samples shall be stored at room temperature. If the conditioning has been performed on the dielectrically prorated section the MO resistors shall be removed from the section before storage. The samples shall not subsequently be energized by any kind of voltage or current stress before the thermal recovery test is performed.

For some applications like e.g. filter arresters the actual current may exceed 100 kA. In this case the test shall be made with actual current amplitude or if a multi-column arrester is used the current could be scaled down with respect to the number of columns and the test performed on separate columns.

NOTE Heating the samples for longer time at very high temperatures, application of alternating voltage or application of impulse currents of opposite polarity may lead to recovery from possible electrical ageing effects and is therefore not permitted.

9.14.3.2 Thermal recovery test

The following test procedure shall be applied for the thermal recovery part of the test:

- The complete test sample shall be preheated to a temperature of at least the start temperature, ϑ_{Start}. The preheating shall not take more than twenty hours.
- The temperature of the MO resistors immediately prior to the injection of energy shall be at least the start temperature, ϑ_{Start}, measured by the temperature sensor.
- The energy shall be injected within 3 minutes by one or more long-duration current impulses of approximately (2 to 4) ms virtual total duration or by unipolar sine half-wave current impulses of approximately (2 to 4) ms total duration. The current amplitude and number of the impulses is not critical, but shall be chosen such that the total discharged energy meets at least the required thermal energy rating. The injected amount of energy shall be measured (time integral of $u(t)\times i(t)$). The amplitude of the current impulses may be adjusted for each individual impulse in order to meet the required overall energy value. For multi-column arresters the energy shall be adjusted as per item c) of 8.3.
- Within 100 ms from the energy application, a voltage equal to the continuous operating voltage, U_{cHVDC}, or ECOV shall be applied for a minimum of 30 minutes to demonstrate thermal stability. The voltage shall be corrected as per 9.11.2.2 if necessary. Resistive component of current or power dissipation or temperature or any combination of them shall be monitored until the measured value is appreciably reduced (success), but for at least 30 minutes, or thermal runaway condition (failure) is evident.

9.14.3.3 Test Evaluation

The test shall be considered passed if all the following criteria are met:

- thermal recovery has been demonstrated;
- no physical damage is evident;
- any change of the residual voltage at 10 kA discharge current before and after the test is within ±5 %.

9.15 Test to verify the dielectric withstand of internal components

9.15.1 General

The purpose of this test is to verify the internal dielectric withstand capability of an arrester even under impulse currents of amplitudes higher than nominal discharge current.

If it can be demonstrated by calculations that, for a specific arrester, the electrical field at critical locations is less than or equal to the electrical field on an arrester which has been successfully tested at higher or equal voltage, no test is required. Additionally the test is required only if the conditioning part of the thermal recovery test (9.14.3.1) was not performed on a dielectrically prorated section.

The test shall be performed on one test sample.

The test sample shall be a dielectrically prorated section according to 8.3.2.2. No internal temperature sensor shall be installed.

9.15.2 Test procedure

The test sample shall be heated in an oven for a time sufficient to obtain thermal equilibrium to at least 60 °C. The test shall be performed within 10 minutes after removing the sample from the oven. The test consists of one application of a high-current impulse with amplitude 100 kA and waveform 4/10 μs.

Oscillograms of current and voltage shall be taken for the impulse application.

9.15.3 Test evaluation

The sample has passed the test if

- there is no evidence of a dielectric breakdown from the oscillograms;
- examination after the test reveals no evidence of puncture, flashover or cracking of the MO resistors or damage to the supporting elements.

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.

- After the tests, two current impulses 8/20 of an amplitude of 20 kA are applied to 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 shall not reveal any breakdown. The variation of the residual voltage between the initial measurement and the last impulse shall not be greater than 5 %.

9.16 Test of internal grading components

9.16.1 Test to verify long term stability under continuous operating voltage

If internal grading components such as capacitors or (non-linear) resistors are used in the arrester they shall be tested in an accelerated test to verify long term stability under continuous operating voltage under the same test conditions as the MO resistors (see 9.11). The test samples may be individual components or a stack of such components.

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

During the test, the test samples shall be placed in a temperature-controlled oven in the same surrounding medium as used in the arrester. The volume of the oven chamber shall be at least twice the volume of the test sample and the density of the medium in the chamber shall not be less than the density of the medium in the arrester.

NOTE The medium surrounding the grading components within the arrester might be subject to a modification during the normal life of the arrester due to internal partial discharges. Possible change of the medium surrounding the grading components in the field can significantly change their electrical properties.

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 grading components 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.

Three samples shall be tested for 1 000 h, during which the temperature shall be controlled to keep the surface of the samples at 115 °C ± 4 K. During the 1 000 h test, the samples shall be energized at a voltage corresponding to the corrected maximum operating voltage (see 9.11) for the number of MO resistors installed in parallel to the grading components in the arrester. The impedance of the grading components shall be measured at 20 °C ± 15 K before and after the 1 000 h test.

The samples shall have passed this part of the test if

- there is no evidence of a dielectric breakdown;
- examination after the test reveals no evidence of puncture, flashover or cracking of the grading components;
- a partial discharge test at the test voltage reveal partial discharges not exceeding 10 pC;
- the change in impedance of the grading components due to the 1 000 h test is not greater than ±5 %.

If the samples pass the above evaluation criteria, then MO resistors, equal in number to those used in parallel to the grading components in the arrester and fulfilling the requirements as per 8.3, shall be connected in parallel to the test sample, and two 8/20 lightning impulses of amplitude 20 kA shall be applied to the sample. The first impulse shall be 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 impulse. The impedance of the grading components shall be measured at 20 °C ± 15 K before and after the two impulses. The samples shall have passed the test if

- oscillograms of voltage and current taken during each impulse reveal no electrical breakdown
- the change in impedance of the grading components due to the two impulses is not greater than ±5 %

9.16.2 Thermal cyclic test

Three samples shall be subjected to thermal variations without voltage applied. The thermal variations consist of five 48 h cycles of heating and cooling to 60 °C and – 40 °C respectively. The hot and cold periods shall be maintained for at least 16 h. the test shall be conducted in air.

NOTE For components used in arrester located indoors the minimum temperature might be as low as 5 °C.

The samples have passed the test if

- examination after the test reveals no evidence of cracking of the grading components;
- a partial discharge test at the test voltage corresponding to the corrected maximum operating voltage (see 9.11) for the number of MO resistors installed in parallel to the grading components in the arrester reveal partial discharges not exceeding 10 pC;
- the change in impedance of the grading components due to the thermal cycles is not greater than ±5 %.

If the samples pass the above evaluation criteria, then MO resistors, equal in number to those used in parallel to the grading components in the arrester and fulfilling the requirements as per 8.3, shall be connected in parallel to the test sample, and two 8/20 lightning impulses of amplitude 20 kA shall be applied to the sample. The first impulse shall be 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 impulse. The impedance of the grading components shall be measured at 20 °C ± 15 K before and after the two impulses. The samples shall have passed the test if

- oscillograms of voltage and current taken during each impulse reveal no electrical breakdown;
- the change in impedance of the grading components due to the two impulses is not greater than ±5 %.

10 Routine tests and acceptance test

10.1 Routine tests

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

a) measurement of reference voltage (U_{ref}) (see 3.48, 3.49 and 7.2). The measured values shall be within a range specified by the manufacturer;

b) residual voltage test. The test may be performed either on complete arresters, assembled arrester units or on a sample comprising one or several MO resistors. The manufacturer shall specify a suitable lightning impulse current in the range between 0,01 and 100 times the lightning impulse coordination 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 MO resistors or the individual arrester units. The residual voltage for the complete arrester shall not be higher than the value specified by the manufacturer;

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 test voltages and test procedure according to 9.4 shall be followed;

d) for arrester units with an enclosed gas volume and a separate sealing system, a leakage check shall be made on each unit by any sensitive method adopted by the manufacturer. In order to reduce test efforts during production, higher values of seal leak rate than required for type testing (see 8.13.4) may be used in this routine test for verification of correct assembly;

e) current distribution test for multi-column arrester with all columns in the same housing. This test shall be carried out on all groups of parallel MO resistors. A group of parallel MO 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 2 times the switching impulse coordination 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 If the residual voltage of the groups of parallel MO resistors used in the design is too high compared to available test facilities, the residual voltage of the group of parallel MO resistors used in this test can be reduced by introducing intermediate electrical connections between the columns, thereby establishing several artificial groups of parallel MO resistors. Each such artificial group will then pass the current distribution test specified.

f) current distribution test for matched arresters and arresters with parallel columns in separate housings. A maximum accepted deviation in current sharing between parallel columns of MO resistors within a complete arrester or within a set of matched arresters has to be specified by the manufacturer. Further, the manufacturer shall present the routine test procedure to demonstrate that the current sharing will be within given tolerances.

g) For an arrester comprising several housings with several columns of resistors in each housing both the current sharing within the individual housings as well as between housings shall be demonstrated.

10.2 Acceptance tests

10.2.1 Standard acceptance tests

When the user 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 reference voltage, a.c. or d.c. depending on arrester type, on the complete arrester or on arrester units. The measured value shall be within a range specified by the manufacturer.
b) Lightning impulse residual voltage on the complete arrester or arrester unit (see 9.10), at the lightning impulse coordination current if possible or at a current value chosen according to 9.10. 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, for multiple unit arresters, individual units of the arrester. The test sample may be shielded against external partial discharges. The power-frequency test voltage and test procedure shall be as per 9.4. 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 user.

10.2.2 Special thermal stability test

The following test requires additional agreement between manufacturer and user prior to the commencement of arrester assembly.

This test shall be performed on three sections using MO resistors taken from current routine production and having the same dimensions and characteristics as those of the arresters under test. The test consists of repeating the test to verify the thermal energy rating as per 9.14.

MO resistor temperature or resistive component of current or power dissipation shall be monitored during the application of the continuous operating voltage, U_{cHVDC}, or ECOV to prove thermal stability. The test is passed if thermal stability occurs in all three samples (see 9.14.3.2). If one sample fails, agreement shall be reached between the manufacturer and the user regarding any further tests.

11 Test requirements on different types of arresters

11.1 General

If any test requirements differ from the general type test procedure under Clause 9, specific test procedures are given here. The designation of the different arrester types is taken from IEC/TS 60071-5 and also shown in Figures 1 to 3.

11.2 Valve arrester (V)

11.2.1 General

The arrester is connected directly across a thyristor valve.

11.2.2 Continuous operating voltage

The general shape of the voltage is given in Figure 10.

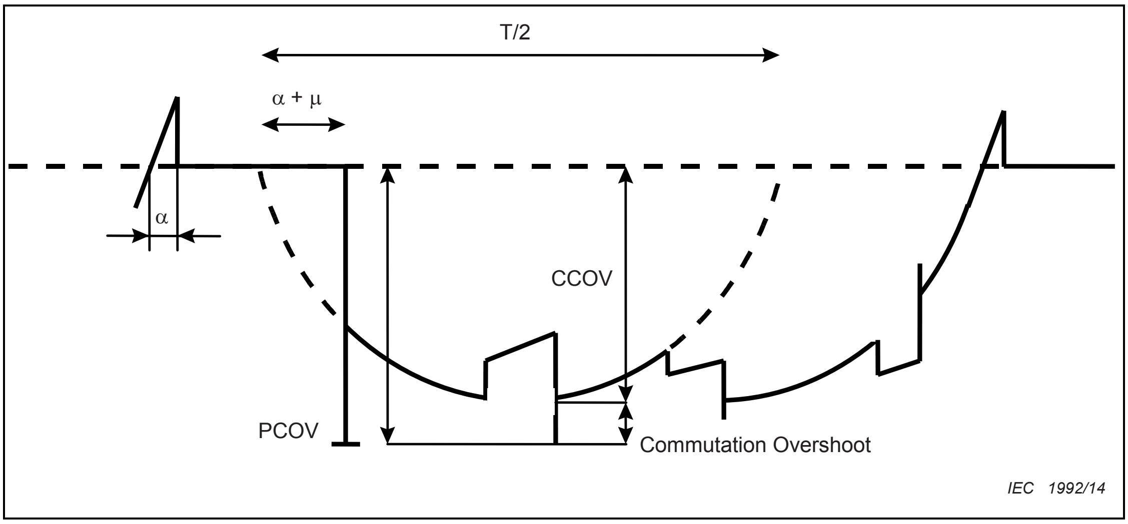


Figure 10 – Operating voltage of a valve arrester (V) (rectifier operation) and definition of PCOV and CCOV

11.2.3 Equivalent continuous operating voltage

The ECOV is determined as follows:

- On three test samples the power losses are measured at actual voltage waveform at temperatures 60 °C, 100 °C and 160 °C ± 10 K;
- At the same temperatures, within ± 5 K, a power–frequency voltage is applied and adjusted to obtain the same power losses as for the actual voltage waveform;
- The ratio power-frequency voltage to reference voltage is determined for the three temperatures and plotted in a diagram as function of temperature;
- A smooth curve is drawn through the points;
- The maximum ratio times the reference voltage obtained from the diagram at the maximum expected temperature and for any of the test samples is the ECOV and shall be applied in the test to verify thermal energy rating.

If the actual voltage waveform from high-frequency modelling is not possible to apply the voltage used shall fulfil the following requirements:

- The d.c. component shall be not less than the DCOV (3.9) in the actual wave shape
- The peak voltage shall not be less than the PCOV (3.37)
- The voltage peak except the PCOV shall not be less than the CCOV (3.7)
- The base and number of the commutation overshoots shall be not less than for the actual waveform

If the actual waveform is possible to apply only on a test sample with lower reference voltage than the samples intended to be used in the test to verify thermal energy rating, ECOV could be determined for the test sample with lower reference voltage and then the same factor in ratio of reference voltage is applied to the samples for the thermal test. All test samples shall fulfil the requirements as per 8.3 and the MO resistors shall be of the same design. Only the height is allowed to be different.

NOTE 1 For valve arresters normally the operating voltage is calculated with the arresters connected since the commutation overshoots might be affected by the arrester. If the voltage is calculated without the arresters this in general results in a more conservative result i.e. higher voltage peaks.

NOTE 2 If the expected temperature in the test to verify thermal rating is less than 160 °C, a test at a lower temperature is acceptable.

11.2.4 Type tests

In Table 1, with reference to Clause 9, relevant type tests and their applicability are listed.

Table 1 – Summary of type tests – 1

Arrester type	Valve arrester (V)	Bridge arrester and HV and LV converter unit arresters (B, CH, CL)	Converter unit arrester (C)	Mid-point d.c. bus arrester, mid-point bridge arresters and arrester between converters (M, MH, ML, CM)	Converter unit d.c. bus arrester (CB)	DC bus and d.c. line/cable arrester (DB, DL/DC)
1 Insulation withstand tests	9.2	9.2	9.2	9.2	9.2	9.2/11.7.4.2.1 [f]
2 Short-circuit tests	9.3	9.3	9.3	9.3	9.3	9.3
3 Internal partial discharge tests	9.4	9.4	9.4	9.4	9.4	9.4
4 Test of the bending moment	9.5 [b]	9.5 [b]	9.5 [b]	9.5 [b]	9.5 [b]	9.5 [b]
5 Environmental tests	9.6 [c]	9.6 [c]	9.6 [c]	9.6 [c]	9.6 [c]	9.6 [c]
6 Weather ageing test	9.7 [d]	9.7 [d]	9.7 [d]	9.7 [d]	9.7 [d]	9.7 [d]
7 Seal leak rate test	9.8 [e]	9.8 [e]	9.8 [e]	9.8 [e]	9.8 [e]	9.8 [e]
8 Radio interference voltage (RIV) test	9.9	9.9	9.9	9.9	9.9	9.9
9 Residual voltage test	9.10	9.10	9.10	9.10	9.10	9.10
10 Test to verify the long term stability under continuous operating voltage	9.11	9.11	9.11	9.11	9.11	9.11
11 Test to verify the repetitive charge transfer rating	9.12	9.12	9.12	9.12	9.12	9.12
12 Heat dissipation behaviour of test samples	9.13	9.13	9.13	9.13	9.13	9.13
13 Test to verify the thermal energy rating	9.14	9.14	9.14	9.14	9.14	9.14
14 Test to verify the dielectric withstand of internal components	9.15	9.15	9.15	9.15	9.15	9.15

Arrester type	Valve arrester (V)	Bridge arrester and HV and LV converter unit arresters (B, CH, CL)	Converter unit arrester (C)	Mid-point d.c. bus arrester, mid-point bridge arresters and arrester between converters (M, MH, ML, CM)	Converter unit d.c. bus arrester (CB)	DC bus and d.c. line/cable arrester (DB, DL/DC)
15 Test of internal grading components	9.16	9.16	9.16	9.16	9.16	9.16

Numbers in rows 1 to 15 refer to clauses and subclauses in this standard

[b] Applies except that for GIS arresters and for arresters directly suspended to the thyristor valves or suspended hanging and located indoors no test is required

[c] Applies if the arrester is of type porcelain-housed and is installed outdoors

[d] Applies if the arrester is of type polymer-housed and is installed outdoors

[e] Applies if the arrester is of a type specified in 7.5

[f] 11.7.4.2.1 applies for GIS arrester

11.2.5 Routine and acceptance tests

Clause 10 applies.

11.3 Bridge arrester and HV and LV converter unit arresters (B, CH, CL)

11.3.1 Continuous operating voltage

The voltage is a d.c. voltage with voltage ripple. Typical shape of the voltage is shown in Figures 4 and 5. In Figure 11 definitions of DCOV, CCOV and PCOV are given for a typical shape.

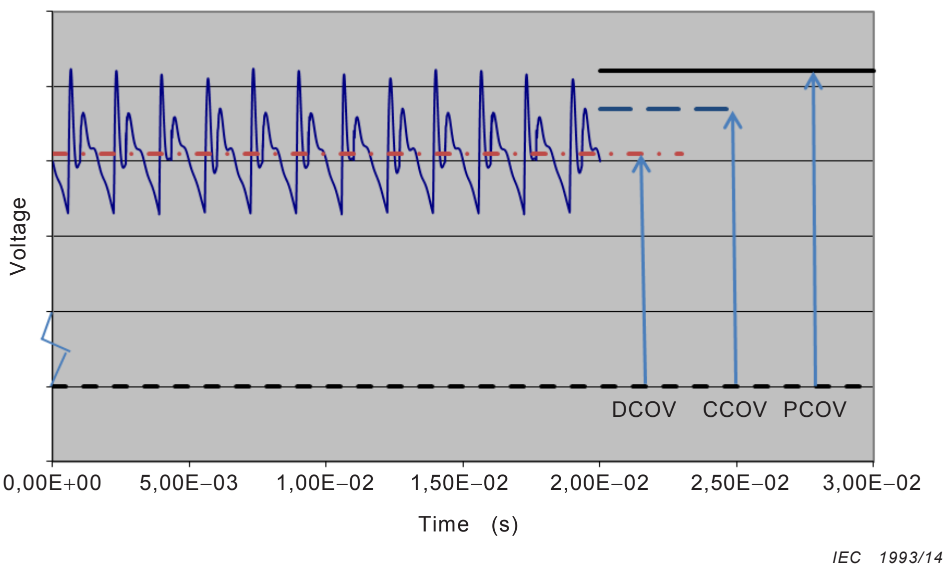


Figure 11 – Operating voltage of a bridge arrester and definition of DCOV, PCOV and CCOV

11.3.2 Equivalent continuous operating voltage

The ECOV is determined as follows:

- On three test samples the power losses are measured at actual voltage waveform at temperatures 60 °C, 100 °C and 160 °C ± 10 K;
- At the same temperatures, within ± 5 K, a power–frequency voltage is applied and adjusted to obtain the same power losses as for the actual voltage waveform;
- The ratio power-frequency voltage to reference voltage is determined for the three temperatures and plotted in a diagram as function of temperature;
- A smooth curve is drawn through the points;
- The maximum ratio times the reference voltage obtained from the diagram at the maximum expected temperature and for any of the test samples is the ECOV and shall be applied in the test to verify thermal energy rating.

If the actual voltage waveform is not possible to apply or as a conservative alternative the ECOV is set equal to a d.c. voltage with the amplitude equal to the actual voltage including voltage ripple.

If the actual waveform is possible to apply only on a test sample with lower reference voltage than the samples intended to be used in the test to verify thermal energy rating, ECOV could be determined for the test sample with lower reference voltage and then the same factor in ratio of reference voltage is applied to the samples for the thermal test. All test samples shall fulfil the requirements as per 8.3 and the MO resistors shall be of the same design. Only the height is allowed to be different.

NOTE If the expected temperature in the test to verify thermal rating is less than 160 °C, a test at a lower temperature is acceptable.

11.3.3 Type tests

In Table 1, with reference to Clause 9, relevant type tests and their applicability are listed.

11.3.4 Routine and acceptance tests

Clause 10 applies.

11.4 Converter unit arrester (C)

11.4.1 General

A converter unit arrester (shown in Figure 2) is connected between the d.c. terminals i.e. between the neutral bus and the d.c. bus on the station side of the d.c. reactor.

11.4.2 Continuous operating voltage

The voltage is a d.c. voltage with voltage ripple.

11.4.3 Equivalent continuous operating voltage

The ECOV is determined as follows:

- On three test samples the power losses are measured at actual voltage waveform at temperatures 60 °C, 100 °C and 160 °C ± 10 K;
- At the same temperatures, within ± 5 K, a power–frequency voltage is applied and adjusted to obtain the same power losses as for the actual voltage waveform;
- The ratio power-frequency voltage to reference voltage is determined for the three temperatures and plotted in a diagram as function of temperature;

- A smooth curve is drawn through the points;
- The maximum ratio times the reference voltage obtained from the diagram at the maximum expected temperature and for any of the test samples is the ECOV and shall be applied in the test to verify thermal energy rating.

If the actual voltage waveform is not possible to apply or as a conservative alternative the ECOV is set equal to a d.c. voltage with the amplitude equal to the actual voltage including voltage ripple.

If the actual waveform is possible to apply only on a test sample with lower reference voltage than the samples intended to be used in the test to verify thermal energy rating, ECOV could be determined for the test sample with lower reference voltage and then the same factor in ratio of reference voltage is applied to the samples for the thermal test. All test samples shall fulfil the requirements as per 8.3 and the MO resistors shall be of the same design. Only the height is allowed to be different.

NOTE If the expected temperature in the test to verify thermal rating is less than 160 °C, a test at a lower temperature is acceptable.

11.4.4 Type tests

In Table 1, with reference to Clause 9, relevant type tests and their applicability are listed.

11.4.5 Routine and acceptance tests

Clause 10 applies.

11.5 Mid-point d.c. bus arrester, mid-point bridge arresters and arrester between converters (M, MH, ML, CM)

11.5.1 Continuous operating voltage

The voltage is the sum of the voltage across a part of the converter and the neutral bus voltage. Typical shape of the voltage is shown in Figures 4 and 5 for the arresters.

11.5.2 Equivalent continuous operating voltage

The ECOV is determined as follows:

- On three test samples the power losses are measured at actual voltage waveform at temperatures 60 °C, 100 °C and 160 °C ± 10 K;
- At the same temperatures, within ± 5 K, a power–frequency voltage is applied and adjusted to obtain the same power losses as for the actual voltage waveform;
- The ratio power-frequency voltage to reference voltage is determined for the three temperatures and plotted in a diagram as function of temperature;
- A smooth curve is drawn through the points;
- The maximum ratio times the reference voltage obtained from the diagram at the maximum expected temperature and for any of the test samples is the ECOV and shall be applied in the test to verify thermal energy rating.

If the actual voltage waveform is not possible to apply the voltage used shall fulfil the following requirements:

- The d.c. component shall be not less than the DCOV (3.9) in the actual wave shape
- The peak voltage shall not be less than the PCOV (3.37)
- The voltage peak except the PCOV shall not be less than the CCOV (3.7)
- The base of the commutation overshoot shall be not less than for the actual waveform

As an alternative the ECOV is set equal to a d.c. voltage with the amplitude equal to the peak value of the actual voltage.

If the actual waveform is possible to apply only on a test sample with lower reference voltage than the samples intended to be used in the test to verify thermal energy rating, ECOV could be determined for the test sample with lower reference voltage and then the same factor in ratio of reference voltage is applied to the samples for the thermal test. All test samples shall fulfil the requirements as per 8.3 and the MO resistors shall be of the same design. Only the height is allowed to be different.

NOTE If the expected temperature in the test to verify thermal rating is less than 160 °C, a test at a lower temperature is acceptable.

11.5.3 Type tests

In Table 1, with reference to Clause 9, relevant type tests and their applicability are listed.

11.5.4 Routine and acceptance tests

Clause 10 applies.

11.6 Converter unit d.c. bus arrester (CB)

11.6.1 Continuous operating voltage

The voltage is a d.c. voltage with voltage ripple. Typical shape of the voltage is shown in Figures 4 and 5.

11.6.2 Equivalent continuous operating voltage

The ECOV is determined as follows:

- On three test samples the power losses are measured at actual voltage waveform at temperatures 60 °C, 100 °C and 160 °C ± 10 K;
- At the same temperatures, within ± 5 K, a power–frequency voltage is applied and adjusted to obtain the same power losses as for the actual voltage waveform;
- The ratio power-frequency voltage to reference voltage is determined for the three temperatures and plotted in a diagram as function of temperature;
- A smooth curve is drawn through the points;
- The maximum ratio times the reference voltage obtained from the diagram at the maximum expected temperature and for any of the test samples is the ECOV and shall be applied in the test to verify thermal energy rating.

If the actual voltage waveform is not possible to apply or as a conservative alternative the ECOV is set equal to a d.c. voltage with the amplitude equal to the actual voltage including voltage ripple.

If the actual waveform is possible to apply only on a test sample with lower reference voltage than the samples intended to be used in the test to verify thermal energy rating, ECOV could be determined for the test sample with lower reference voltage and then the same factor in ratio of reference voltage is applied to the samples for the thermal test. All test samples shall fulfil the requirements as per 8.3 and the MO resistors shall be of the same design. Only the height is allowed to be different.

NOTE If the expected temperature in the test to verify thermal rating is less than 160 °C, a test at a lower temperature is acceptable.

11.6.3 Type tests

In Table 1, with reference to Clause 9, relevant type tests and their applicability are listed.

11.6.4 Routine and acceptance tests

Clause 10 applies.

11.7 DC bus and d.c. line/cable arrester (DB, DL/DC)

11.7.1 General

The arrester is connected on the line/cable side of the smoothing reactor. This arrester could be porcelain- or polymer-housed or a gas-insulated metal enclosed arrester (GIS-arrester).

11.7.2 Continuous operating voltage

The voltage is an almost smooth d.c. voltage with some small voltage ripple.

11.7.3 Equivalent continuous operating voltage

The ECOV is obtained as a d.c. voltage with amplitude equal to the actual continuous operating voltage including possible voltage ripple.

11.7.4 Type tests

11.7.4.1 General

In Table 1, with reference to Clause 9, relevant type tests and their applicability are listed.

11.7.4.2 Insulation withstand tests on GIS-arresters

11.7.4.2.1 General

These tests demonstrate the ability of the insulation to withstand the required voltage stresses between the internal parts and the metal housing.

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 11.7.4.2.5).

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. The test voltages shall be at least equal to:

– 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 coordinating current. Variations in atmospheric conditions, as given for porcelain-housed and polymer-housed arresters, are not relevant for GIS-arresters. Nevertheless, the factor of 1,3 is retained to provide additional security.

– For arresters with a CCOV ≥ 250 kV, 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 coordinating current. Variations in atmospheric conditions, as given for porcelain-housed and polymer-housed arresters, are not relevant for GIS-arresters. Nevertheless, the factor 1,25 is retained to provide additional security.

– For arresters with a CCOV < 250 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.

When the insulation requirements of arresters calculated from the above are still higher than that decided for the protected equipment, the same insulation levels should apply also for the arresters.

NOTE 3 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.

11.7.4.2.2 Lightning impulse voltage test

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

The test voltage shall be as specified in 11.7.4.2.1.

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.

11.7.4.2.3 Switching impulse voltage test

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

The test voltage shall be as specified in 11.7.4.2.1.

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.

11.7.4.2.4 Power-frequency voltage test

The test voltage shall be as specified in 11.7.4.2.1.

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

11.7.4.2.5 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.

11.7.5 Routine and acceptance tests

Clause 10 applies.

11.8 Neutral bus arresters (EB, E1, E)

11.8.1 Continuous operating voltage

Normally the neutral bus voltage consists of a d.c. offset voltage and ripple. In the case of a smoothing reactor on the neutral line the ripple can be substantial for arrester EB.

11.8.2 Equivalent continuous operating voltage

The voltage is considered as non-significant continuous operating voltage as per 3.34.

11.8.3 Type tests

In Table 2, with reference to Clause 9, relevant type tests and their applicability are listed.

It is acceptable that the accelerated ageing test (9.11) is not passed due to the in general very low relative continuous operating voltage applied with respect to reference voltage but if the accelerated ageing test (9.11) is not passed the test to verify the thermal energy rating (9.14) has to be performed on MO resistors which previously have been subjected to the accelerated ageing test. The rated voltage of the test samples shall be determined before the accelerated ageing test is performed. In addition the test to verify the heat dissipation behaviour of test samples (9.13) has to be performed.

Table 2 – Summary of type tests – 2

Arrester type	Neutral bus arresters (EB, E1, E)	DC and AC filter arresters (FA, FD)	Electrode line and metallic return arresters (EL, EM)	DC reactor arrester (DR)	Capacitor arrester (CC)	Transformer valve winding arrester (T)
1 Insulation withstand tests	9.2	9.2	9.2	9.2	9.2 [f]	9.2
2 Short-circuit tests	9.3	9.3	9.3	9.3	9.3	9.3
3 Internal partial discharge tests	9.4	9.4	9.4	9.4	9.4	9.4
4 Test of the bending moment	9.5 [b]	9.5 [b]	9.5 [b]	9.5 [b]	9.5 [b]	9.5 [b]
5 Environmental tests	9.6 [c]	9.6 [c]	9.6 [c]	9.6 [c]	9.6 [c]	9.6 [c]
6 Weather ageing test	9.7 [d]	9.7 [d]	Not required	9.7 [d]	9.7 [d]	9.7 [d]
7 Seal leak rate test	9.8 [e]	9.8 [e]	9.8 [e]	9.8 [e]	9.8 [e]	9.8 [e]
8 Radio interference voltage (RIV) test	9.9	9.9	9.9	9.9	9.9	9.9
9 Residual voltage test	9.10	9.10	9.10	9.10	9.10	9.10
10 Test to verify the long term stability under continuous operating voltage	9.11	9.11	9.11	Not required	9.11	9.11

Arrester type	Neutral bus arresters (EB, E1, E)	DC and AC filter arresters (FA, FD)	Electrode line and metallic return arresters (EL, EM)	DC reactor arrester (DR)	Capacitor arrester (CC)	Transformer valve winding arrester (T)
11 Test to verify the repetitive charge transfer rating	9.12	9.12	9.12	9.12	9.12	9.12
12 Heat dissipation behaviour of test samples	Not required [f)]	9.13	Not required [f)]	Not required	9.13	9.13
13 Test to verify the thermal energy rating	Not required [f)]	9.14	Not required [f)]	Not required	9.14	9.14
14 Test to verify the dielectric withstand of internal components	9.15	9.15	9.15	9.15	9.15	9.15
15 Test of internal grading components	9.16	9.16	9.16	9.16	9.16	9.16

[a] Numbers in rows 1 to 15 refer to clauses and subclauses in this standard

[a] Applies except that for arresters directly suspended to the thyristor valves or suspended hanging and located indoors no test is required

[b] Applies if the arrester is of type porcelain-housed and is installed outdoors

[c] Applies if the arrester is of type polymer-housed and is installed outdoors

[d] Applies if the arrester is of a type specified in 7.5

[e] Applies but only a power-frequency voltage test is required

[f] Required if the accelerated ageing test (9.11) is not passed

11.8.4 Routine and acceptance tests

Clause 10 applies.

11.9 DC and AC filter arresters (FA, FD)

11.9.1 Continuous operating voltage

The operating voltage is a combination of a great number of harmonics with individual amplitudes. A conservative approach is to consider the phase angles as zero for the different harmonics. The total voltage would then be a linear sum of the amplitudes of the harmonics. Typical shape of the voltage across d.c. and a.c. filter arresters are shown in Figures 4 and 5.

11.9.2 Equivalent continuous operating voltage

The ECOV is determined as follows:

- On three test samples the power losses are measured at actual voltage waveform at temperatures 60 °C, 100 °C and 160 °C ± 10 K;
- At the same temperatures, within ± 5 K, a power–frequency voltage is applied and adjusted to obtain the same power losses as for the actual voltage waveform;
- The ratio power-frequency voltage to reference voltage is determined for the three temperatures and plotted in a diagram as function of temperature;

- A smooth curve is drawn through the points;
- The maximum ratio times the reference voltage obtained from the diagram at the maximum expected temperature and for any of the test samples is the ECOV and shall be applied in the test to verify thermal energy rating.

If the actual voltage waveform is not possible to apply the power losses on three test samples energized at the DFCOV at temperatures 60, 100 and 160 °C ± 10 K and at voltage amplitudes 0,5 to 1,0 of the actual voltage amplitude are measured. The actual waveform is then plotted in a diagram showing the % of fundamental frequency period the voltage exceeds a certain value. An example is shown in Figure 12.

If the actual waveform is possible to apply only on a test sample with lower reference voltage than the samples intended to be used in the test to verify thermal energy rating, ECOV could be determined for the test sample with lower reference voltage and then the same factor in ratio of reference voltage is applied to the samples for the thermal test. All test samples shall fulfil the requirements as per 8.3 and the MO resistors shall be of the same design. Only the height is allowed to be different.

NOTE If the expected temperature in the test to verify thermal rating is less than 160 °C, a test at a lower temperature is acceptable.

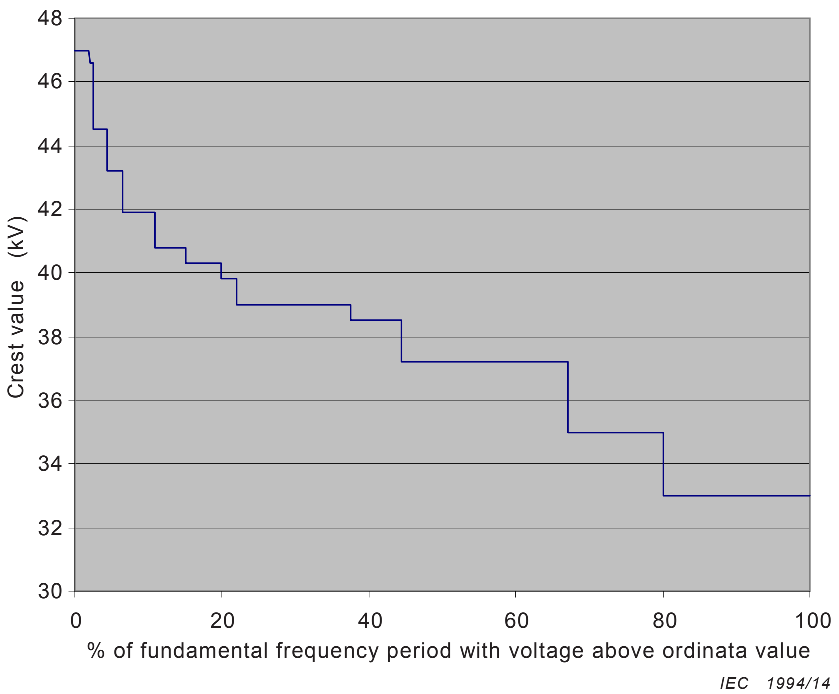


Figure 12 – Plot showing the relative duration of voltage above certain amplitudes

The ECOV is determined as follows:

- The total power consumption is determined as the integral of the measured power losses at the DFCOV as function of voltage multiplied by the duration of the voltage according to the diagram and divided by the period time. The calculation is made for all the three temperatures and three test samples;.
- At the same temperatures, within ± 5 K, a power–frequency voltage is applied and adjusted to obtain the same power losses as calculated above;
- The ratio power-frequency voltage to reference voltage is determined for the three temperatures and plotted in a diagram as function of temperature;
- A smooth curve is drawn through the points;

- The maximum ratio times the reference voltage obtained from the diagram at the maximum expected temperature and for any of the test samples is the ECOV and shall be applied in the test to verify thermal energy rating.

11.9.3 Type tests

In Table 2, with reference to Clause 9, relevant type tests and their applicability are listed.

11.9.4 Routine and acceptance tests

Clause 10 applies.

11.10 Electrode line and metallic return arresters (EL, EM)

11.10.1 Continuous operating voltage

Normally the operating voltage is insignificant.

11.10.2 Equivalent continuous operating voltage

The voltage is considered as non-significant continuous operating voltage as per 3.34.

11.10.3 Type tests

In Table 2, with reference to Clause 9, relevant type tests and their applicability are listed.

It is acceptable that the accelerated ageing test (9.11) is not passed due to the in general very low relative continuous operating voltage applied with respect to reference voltage but if the accelerated ageing test (9.11) is not passed the test to verify the thermal energy rating (9.14) has to be performed on MO resistors which previously have been subjected to the accelerated ageing test. The rated voltage of the test samples shall be determined before the accelerated ageing test is performed. In addition the test to verify the heat dissipation behaviour of test samples (9.13) has to be performed.

11.10.4 Routine and acceptance tests

Clause 10 applies.

11.11 Smoothing reactor arrester (DR)

11.11.1 General

The arrester is connected across the smoothing reactor.

11.11.2 Continuous operating voltage

The voltage consists of a voltage ripple equal to the difference between the smooth d.c. voltage on the d.c. bus and the voltage on the converter d.c. bus (Figure 1).

11.11.3 Equivalent continuous operating voltage

The voltage is considered as non-significant continuous operating voltage as per 3.34.

11.11.4 Type tests

In Table 2, with reference to Clause 9, relevant type tests and their applicability are listed.

11.11.5 Routine and acceptance tests

Clause 10 applies.

11.12 Capacitor arrester (CC)

11.12.1 General

The arrester is connected across the series capacitor in a capacitor commutated converter (CCC).

11.12.2 Continuous operating voltage

The operating voltage is a power-frequency voltage with a clipped peak as shown in Figure 4.

11.12.3 Equivalent continuous operating voltage

The ECOV is determined as follows:

- On three test samples the power losses are measured at actual voltage waveform at temperatures 60 °C, 100 °C and 160 °C ± 10 K;
- At the same temperatures, within ± 5 K, a power–frequency voltage is applied and adjusted to obtain the same power losses as for the actual voltage waveform;
- The ratio power-frequency voltage to reference voltage is determined for the three temperatures and plotted in a diagram as function of temperature;
- A smooth curve is drawn through the points;
- The maximum ratio times the reference voltage obtained from the diagram at the maximum expected temperature and for any of the test samples is the ECOV and shall be applied in the test to verify thermal energy rating.

If the actual voltage waveform is not possible to apply the ECOV is set equal to a power-frequency voltage of the same fundamental frequency (50 or 60 Hz) as for the actual waveform and with the absolute instantaneous value higher than for the actual waveform during the whole period.

If the actual waveform is possible to apply only on a test sample with lower reference voltage than the samples intended to be used in the test to verify thermal energy rating, ECOV could be determined for the test sample with lower reference voltage and then the same factor in ratio of reference voltage is applied to the samples for the thermal test. All test samples shall fulfil the requirements as per 8.3 and the MO resistors shall be of the same design. Only the height is allowed to be different.

NOTE If the expected temperature in the test to verify thermal rating is less than 160 °C, a test at a lower temperature is acceptable.

11.12.4 Type tests

In Table 2, with reference to Clause 9, relevant type tests and their applicability are listed.

11.12.5 Routine and acceptance tests

Clause 10 applies.

11.13 Transformer valve winding arrester (T)

11.13.1 General

The arrester is connected between the valve winding of the high-voltage converter transformer for 6 pulse converters and ground.

11.13.2 Continuous operating voltage

The operating voltage is a d.c. voltage with a superimposed power-frequency voltage plus voltage ripple. Typical shape of the voltage is shown in Figures 4 and 5.

11.13.3 Equivalent continuous operating voltage

The ECOV is determined as follows:

- On three test samples the power losses are measured at actual voltage waveform at temperatures 60 °C, 100 °C and 160 °C ± 10 K;
- At the same temperatures, within ± 5 K, a power–frequency voltage is applied and adjusted to obtain the same power losses as for the actual voltage waveform;
- The ratio power-frequency voltage to reference voltage is determined for the three temperatures and plotted in a diagram as function of temperature;
- A smooth curve is drawn through the points;
- The maximum ratio times the reference voltage obtained from the diagram at the maximum expected temperature and for any of the test samples is the ECOV and shall be applied in the test to verify thermal energy rating.

If the actual voltage waveform is not possible to apply or as a conservative alternative the ECOV is set equal to a d.c. voltage with the amplitude equal to the actual voltage including voltage ripple.

If the actual waveform is possible to apply only on a test sample with lower reference voltage than the samples intended to be used in the test to verify thermal energy rating, ECOV could be determined for the test sample with lower reference voltage and then the same factor in ratio of reference voltage is applied to the samples for the thermal test. All test samples shall fulfil the requirements as per 8.3 and the MO resistors shall be of the same design. Only the height is allowed to be different.

NOTE If the expected temperature in the test to verify thermal rating is less than 160 °C, a test at a lower temperature is acceptable.

11.13.4 Type tests

In Table 2, with reference to Clause 9, relevant type tests and their applicability are listed.

11.13.5 Routine and acceptance tests

Clause 10 applies.

Annex A
(normative)

Test to verify thermal equivalency between complete arrester and arrester section

For tests involving thermal recovery in which prorated arrester sections are used, it is required that the sections are thermally equivalent to the complete arrester. The following procedure shall be followed to demonstrate this equivalency. It involves tests first on the complete arrester or, in case of a multi-unit arrester, the unit containing the most MO resistors per unit length, followed by a test on the prorated section.

a) Test on the complete arrester or unit:

The complete arrester or the unit containing the most MO 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 remain within ± 3 K during the test. Thermocouples and/or some sensors, for example, utilizing optical fibre technique to measure temperature are attached to the resistors. A sufficient number of points shall 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 MO resistors shall be heated within a maximum of 1 hour to a temperature of at least 140 °C by the application of power-frequency voltage with an amplitude above reference voltage. This temperature shall be determined by the mean value if the temperature is measured on several MO resistors or the single value if only the 1/2 to 1/3 point is checked.

In case of multi-column internal design, measures may have to be taken to achieve equal temperatures of all MO resistor columns, e.g. by adding one or more linear resistors to each of the columns in each unit. These resistors shall have a mass of not more than 5 % of the mass of MO resistors in the related columns, and they shall be positioned directly on the top or bottom of the column. If this measure cannot be taken, an alternative is to use small bushings in the metal flanges and place the linear resistors outside the housing.

The temperature shall be measured on all individual MO resistor columns and the average temperature be used as column temperature. The difference between the highest and the lowest temperature among the individual columns measured at the same height shall not be greater than 20 K at an average temperature of 140 °C.

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. The temperature shall be measured at least every minute. In the case of several measuring points a mean temperature curve shall be constructed.

b) Test on the thermally prorated section:

The thermally prorated section shall be tested in still air in the same manner as the complete arrester or arrester unit was tested.

The ambient temperature shall be within ±10 K of the ambient temperature during the test on the complete arrester or arrester unit and remain within ±3 K during the test. The section shall be heated by the application of power-frequency voltage to a temperature rise above ambient that is within ±10 K of the temperature rise that occurred for the complete arrester or unit. The voltage amplitude is chosen to give a heating time approximately the same as for the complete arrester or unit.

If the prorated section contains only one column with several MO resistors in series the temperature of all MO resistors shall be measured and a mean value calculated for comparison with the complete arrester.

If, in case of designs with two or more MO resistor columns in parallel, it is not possible to achieve a difference between the highest and lowest temperature among the individual columns not greater than 20 K at the maximum heating temperature by alternating current heating one of the following methods shall be applied:

a) External linear resistors shall be used to balance the current distribution among the columns. Each column shall be connected to the alternating voltage source by a small individual bushing. Application of internal linear series resistors to achieve equal temperatures is not allowed.

   or

b) Heating shall be performed by application of long-duration current impulses at time intervals such that the same overall heating time is achieved as previously for the complete arrester or arrester unit.

A mean temperature shall be determined by measuring the temperature of several MO resistors in each column. Alternatively, the temperature may be measured on one MO resistor in each column 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.

Cooling curves displaying the relative overtemperature of the complete arrester or unit and of the section shall be plotted, the relative overtemperature, T_{rel}, being given by

$$T_{\mathrm{rel}} = (T - T_{\mathrm{A}})/(T_0 - T_{\mathrm{A}}) \qquad \text{(A.1)}$$

Where

T is the measured temperature during cooling;

T_{A} is the ambient temperature;

T_0 is the maximum heating temperature.

To prove thermal equivalency, the cooling curve of the test section shall for all instants have a relative overtemperature value equal to or higher than that of the complete arrester or unit.

If, at any time, the measured cooling curve of the section falls below the measured cooling curve of the complete arrester or unit, compensation may be made by adding a factor, *k*, to the relative overtemperature, T_{rel}, such that the cooling curve of the section is at or above the cooling curve of the complete arrester or unit over the entire cooling period. The corresponding temperature which shall be added to the start temperature for the thermal recovery tests is calculated as: k*($T_0 - T_{\mathrm{A}}$) where ($T_0 - T_{\mathrm{A}}$) is the maximum temperature difference for either the section or the complete arrester or arrester unit.

Annex B
(normative)

Determination of the start temperature in the thermal recovery test

Due to the complex voltage waveforms for most arresters in HVDC stations, except for those located on DC line/cable, tests on complete arresters to determine temperatures under continuous operating voltage is not possible except if tests are performed in an actual station. Determination of the start temperature in the thermal recovery test, therefore, has to be performed by tests on sections.

The following procedure shall be followed.

Energize a thermally prorated section (verified as per Annex A) at a voltage ECOV × $U_{\text{ref(testsection)}}/U_{\text{refmin(arrester)}}$ or, if possible, at actual $U_{\text{cHVDC}} \times U_{\text{ref(testsection)}}/U_{\text{refmin(arrester)}}$ in still air ambient temperature of 40 °C for arresters located outdoors and 60 °C for arresters located indoors until steady state temperatures are reached on the metal-oxide resistors. For multi-column designs it is essential to ensure that the different columns have approximately the same power losses. The reference voltage of the columns, measured before the start of the test, therefore, shall not deviate by more than ±1 % and the temperature increase shall not deviate by more than ±20 % between the different columns. Determine the average temperature, T_{ars}, of the metal-oxide resistors. If the result is higher than 60 °C this temperature shall be used as the preheating temperature otherwise 60 °C shall be used.

NOTE 1 If the maximum indoor temperature is lower than 60 °C the actual maximum temperature is used.

NOTE 2 The scaling of ECOV and U_{cHVDC} more accurately could be done with respect to maximum acceptable power losses at continuous operating voltage. However, it is recognized that the actual voltage waveform in general cannot be applied in routine tests. Using the reference voltages therefore is an acceptable compromise.

Annex C
(normative)

Mechanical considerations

C.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 C.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.

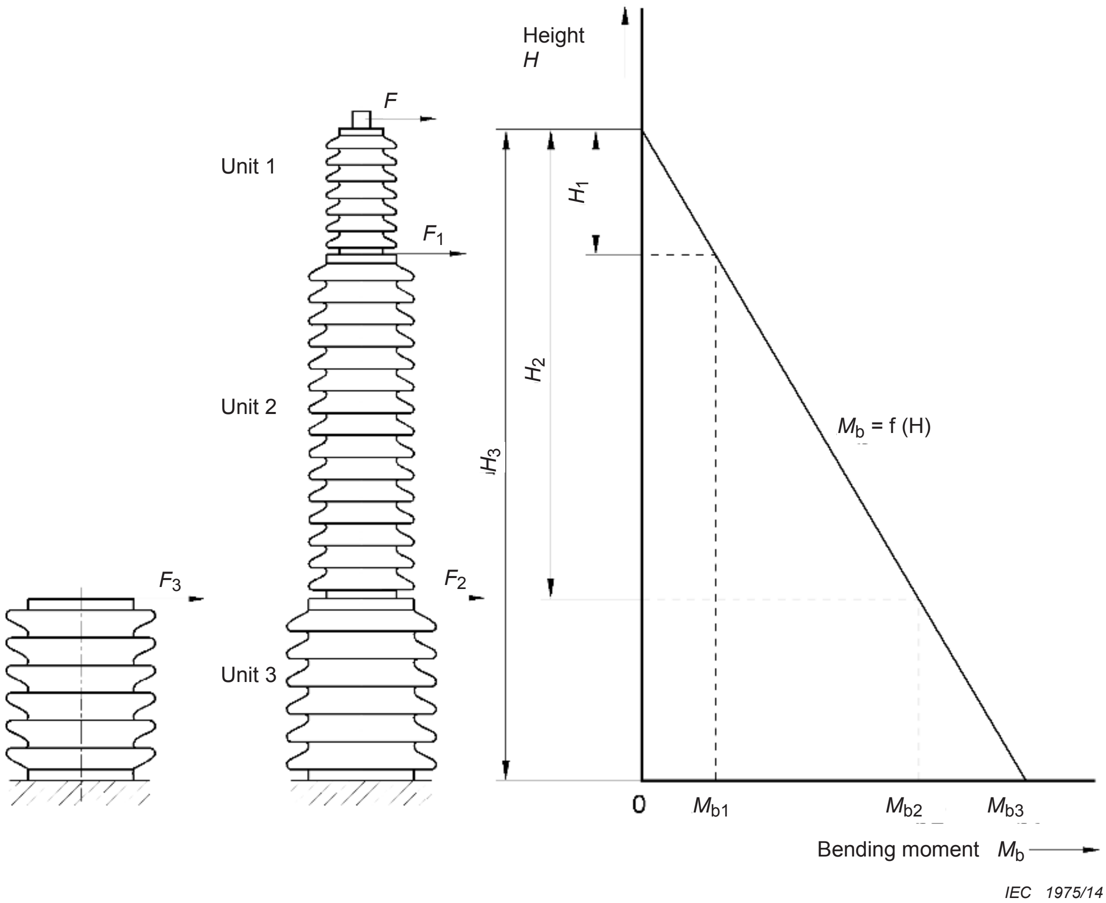


Figure C.1 – Bending moment – multi-unit surge arrester

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:

$$F_2 \times (H_3 - H_2) = F \times H_3;$$

$$F_2 = \frac{F \times H_3}{(H_3 - H_2)}$$

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:

$$F_3 \times (H_3 - H_2) = F \times H_2$$

$$F_3 = \frac{F \times H_2}{(H_3 - H_2)}$$

C.2 Seismic test

If, after agreement between the manufacturer and the user, seismic tests are performed, relevant standards are:

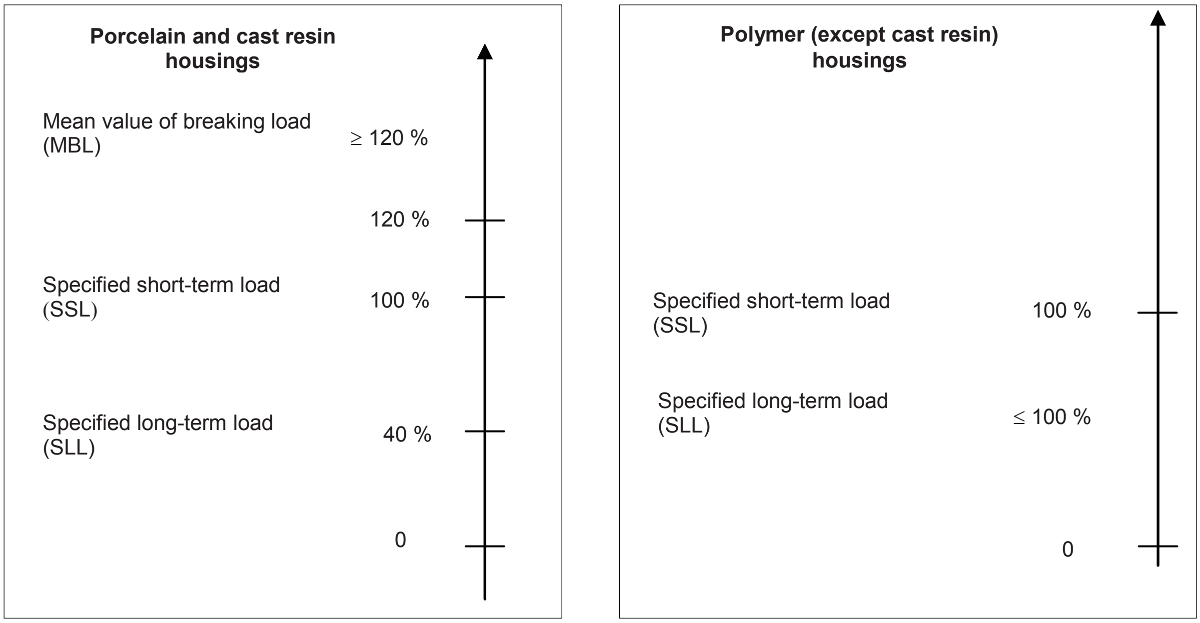
- IEC 62271-207
- IEC 62271-300
- IEC/TS 61463
- GB 50260
- JEAG 5003
- IEEE 693

In order to detect any significant changes in the arrester performance before and after the seismic test the following tests shall be performed:

- Measurement of reference voltage
- Internal partial discharge test
- Leakage check (for arrester with enclosed gas volume and a separate sealing system)

C.3 Definition of mechanical loads

Figure C.2 indicates the relationships between mechanical load ratings.



IEC 1976/14 IEC 1977/14

Figure C.2 – Definitions of mechanical loads

C.4 Definition of seal leak rate

Figure C.3 schematically represents an arrester unit.

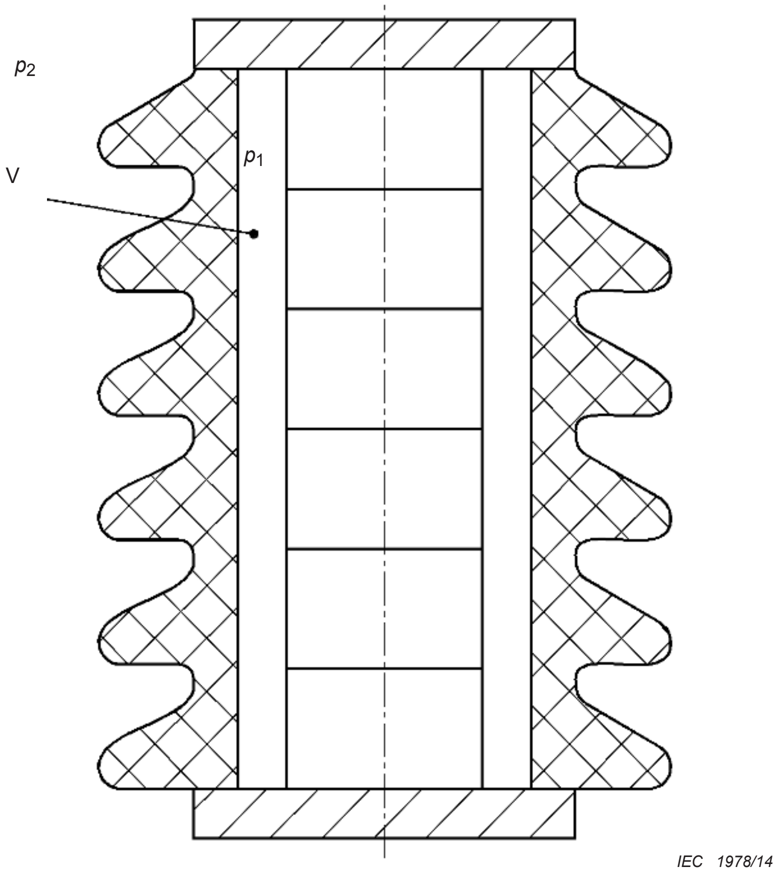


Figure C.3 – Surge arrester unit

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 $= \dfrac{\Delta p_1 \times V}{\Delta t}$ 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);

Δt $= t_2 - t_1$;

V is the internal gas volume of the arrester (m^3).

C.5 Calculation of wind-bending-moment

Figure C.4 schematically represents an assembled arrester.

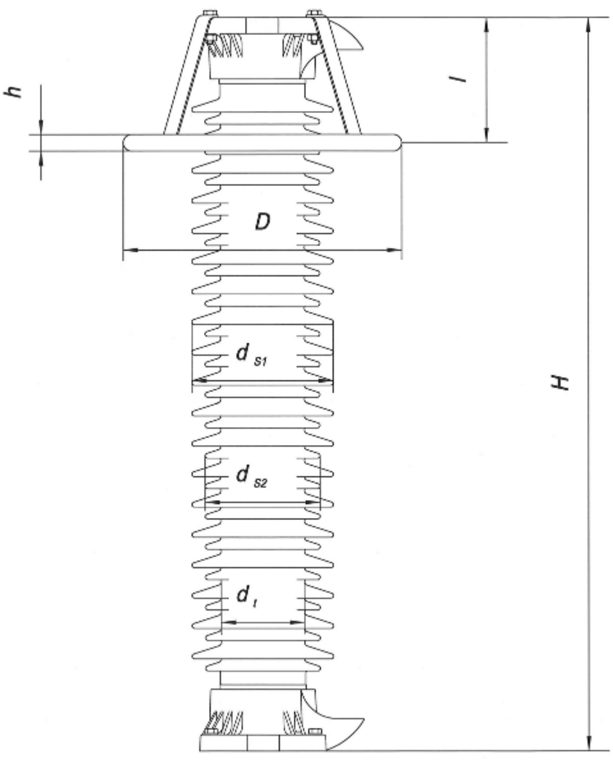


Figure C.4 – Surge-arrester dimensions

The wind-bending moment is given by

$$M_w = P \times H \times d_a \times C \times H/2 + P \times D \times h \times (H - l)$$

where

$P = (P_1/2) \times V^2$;

$d_a = (2d_t + d_{s1} + d_{s2})/4$ as per IEC 60815-2 ($d_{s1} = d_{s2}$ for non-alternating sheds)

M_w is the bending moment caused by the wind (Nm);

H is the height of the arrester (m);

d_a 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).

C.6 Procedures of tests of bending moment for porcelain and polymer-housed arresters

A flow chart of the procedures is shown in Figure C.5.

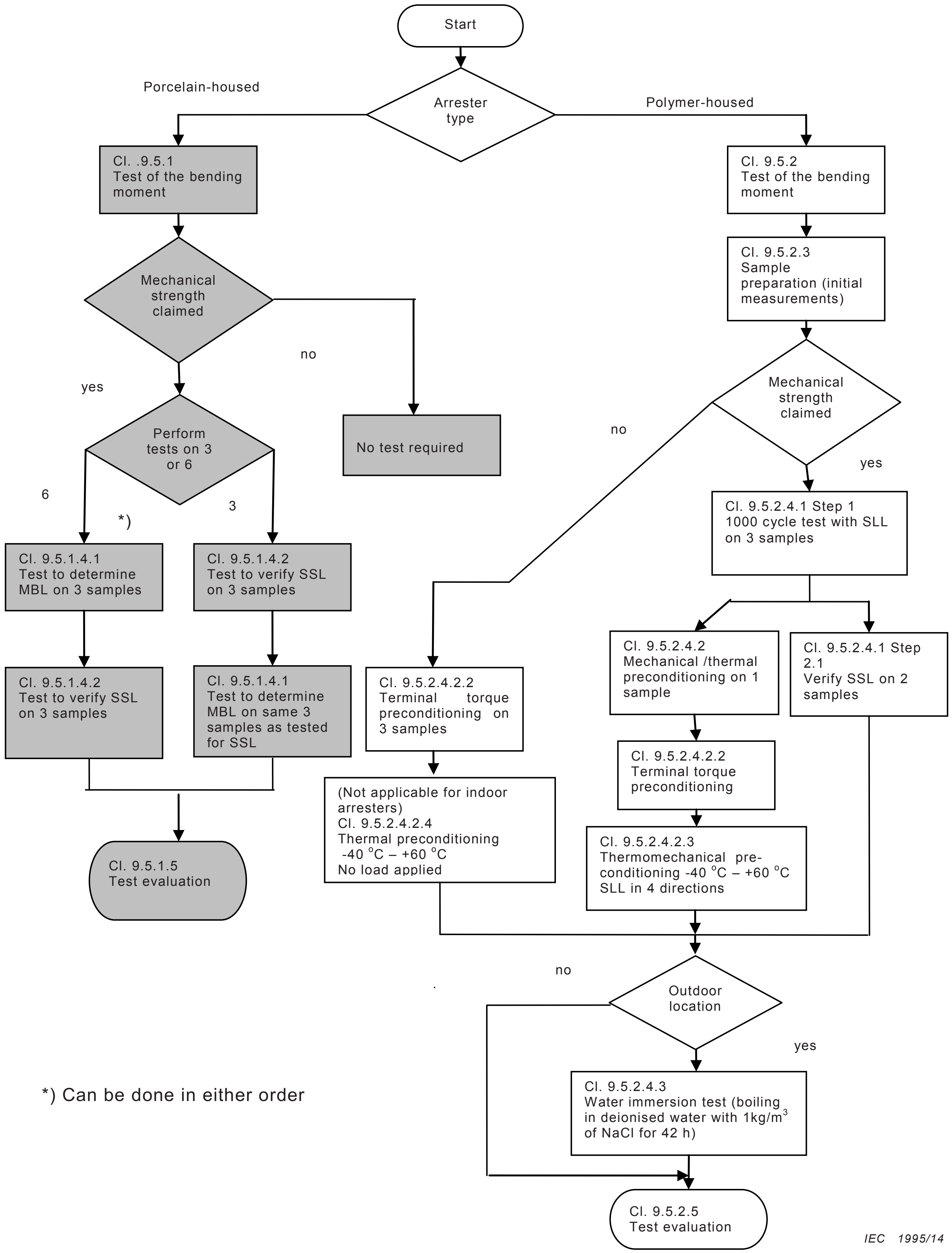
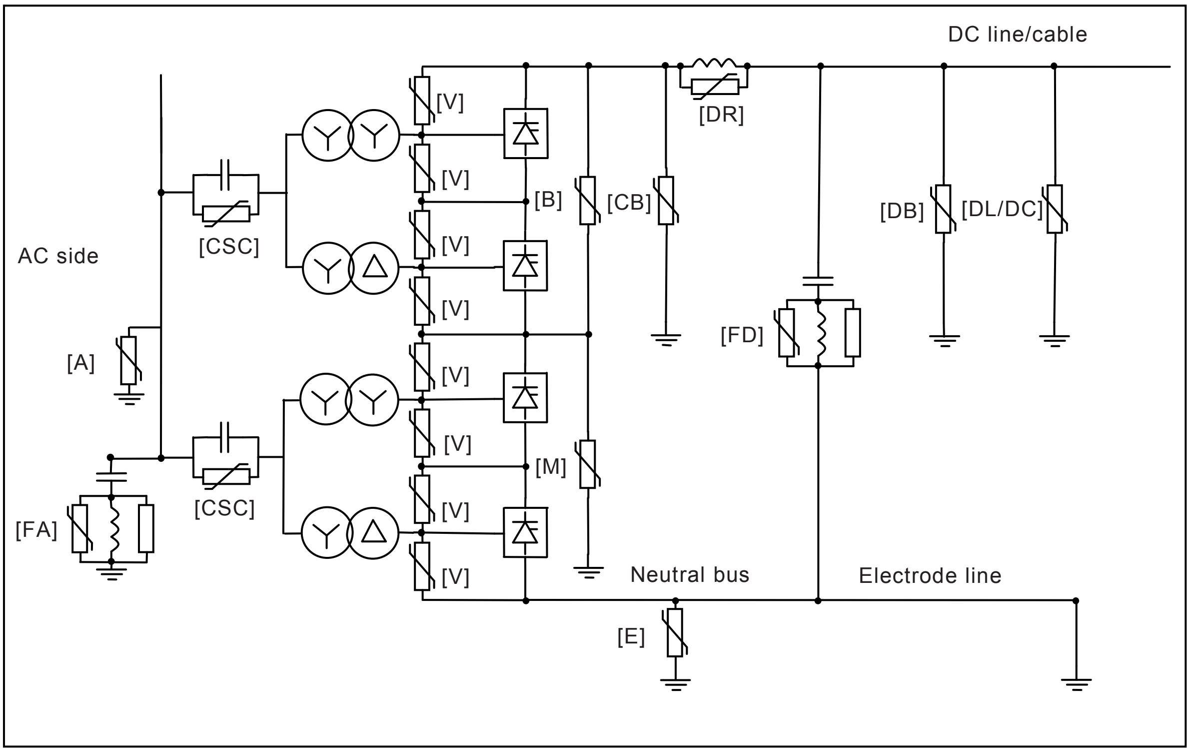


Figure C.5 – Flow chart of bending moment test procedures

Annex D
(informative)

Different circuit configurations

Figure D.1 shows a single line diagram of a CSCC converter station with two 12-pulse converters in series.



IEC 1996/14

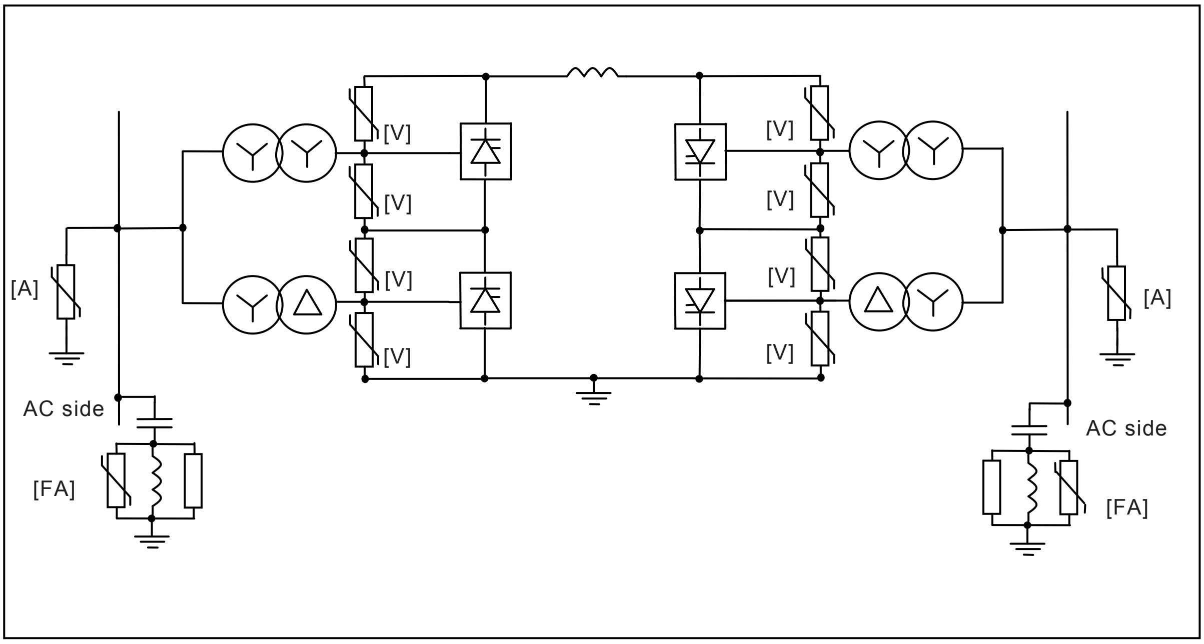
Key

A:	a.c. bus arrester	DB:	d.c. bus arrester	FA:	a.c. filter arrester
B:	bridge arrester	DL/DC:	d.c. line/cable arrester	FD:	d.c. filter arrester
CB:	converter unit d.c. bus arrester	DR:	smoothing reactor arrester	M:	mid-point d.c. bus arrester
CSC:	capacitor arrester	E:	d.c. neutral bus arrester	V:	valve arrester

NOTE The d.c. and a.c. filters may be much more complex than shown in the figure. Not all arresters are used for every project.

Figure D.1 – Single line diagram of CSCC converter station with two 12-pulse converters in series

Figure D.2 shows a single line diagram of a back-to-back converter station with two 12-pulse converters in series.



IEC 1997/14

Key

A: a.c. arresters

FA: a.c. filter arrester

V: Valve arrester

NOTE The d.c. and a.c. filters may be much more complex than shown in the figure. Not all arresters are used for every project.

Figure D.2 – Single line diagram of back-to-back converter station with two 12-pulse converters in series

Bibliography

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

IEC 60143-1, *Series capacitors for power systems – Part 1: General*

IEC 60633:1998, *Terminology for high-voltage direct current (HVDC) transmission*

IEC 60507, *Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems*

IEC TS 60815-1, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC TS 60815-3, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 3: Polymer insulators for a.c. systems*

IEC 62271-1:2007, *High-voltage switchgear and controlgear – Part 1: Common specifications*

ISO 4892-1, *Plastics – Methods of exposure to laboratory light sources – Part 1: General guidance*

ISO 4892-2, *Plastics – Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps*

ISO 4892-3, *Plastics – Methods of exposure to laboratory light sources – Part 3: Fluorescent UV lamps*

____

This page deliberately left blank

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.

...making excellence a habit.™